Downloaded from orbit.dtu.dk on: Dec 19, 2017

Technical University of Denmark

Optics and Fluid Dynamics Department annual progress report for 1998

Hanson, Steen Grüner; Johansen, Per Michael; Lading, Lars; Lynov, Jens-Peter; Skaarup, Bitten

Publication date:
1999

Document Version
Publisher's PDF, also known as Version of record

Link back to DTU Orbit

Citation (APA):
Hanson, S. G., Johansen, P. M., Lading, L., Lynov, J-P., & Skaarup, B. (1999). Optics and Fluid Dynamics Department annual progress report for 1998. (Denmark. Forskningscenter Risoe. Risoe-R; No. 1100(EN)).

DTU Library
Technical Information Center of Denmark

General rights
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Optics and Fluid Dynamics Department Annual Progress Report for 1998

Risø-R-1100(EN)

Edited by S.G. Hanson, P.M. Johansen, L. Lading, J.P. Lynov and B. Skaarup

Risø National Laboratory, Roskilde, Denmark
May 1999

Abstract Research in the Optics and Fluid Dynamics Department has been performed within the following three programme areas: (1) optical materials, (2) optical diagnostics and information processing and (3) plasma and fluid dynamics. The work is concentrated on combinations of systems, structures and materials. The *systems* work is focused on sensors, information processing and storage; the *structures* work is concentrated on pattern formation and diffractive elements; the *materials* work is centred on the understanding and utilisation of novel materials and nonlinear phenomena for optical components, including lasers, and systems. Scientific computing is an integral part of the work. Biomedical optics and polymer optics are areas of enhanced activity. The research is supported by several EU programmes, including EURATOM, by research councils and by industry. A summary of the activities in 1998 is presented.

ISBN 87-550-2511-0 (Internet)
ISSN 0106-2840
ISSN 0906-1797

Contents

1. Introduction

L. Lading
E-mail: lars.lading@risoe.dk

The year 1998 has been the most productive year since the start of the department in 1990. The number of publications is the highest, the industrial income is much higher than any previous year and the same holds for the number of licensing agreements. This upward trend reflects a much stronger degree of interaction with industry both in relation to strategic research and as regards contributing to product development. In all these areas we exceeded the milestones set forward in our plans for 1998.

Major scientific results have been demonstrated in such diverse areas as:

- fusion plasma diagnostics with spin-offs to other areas,
- models for three-dimensional speckle with applications to measurements of dynamics,
- phase conjugation with a potential for high-power high-efficiency semiconductor lasers,
- new optical materials for optical information storage,
- novel schemes for spatial cryptography, and
- new models for surface diffractive structures of importance to the miniaturisation of complex optics.

Our educational activities were as planned. We were especially pleased to participate in the first joint graduate school between the Technical University of Denmark and Risø. It should also be mentioned that strong endeavour was put forth to the establishment of a collaborative effort within biomedical optics between Risø and the Technical University of Denmark.

Economically the net result was better than the budget. However, the income from especially Danish research programmes was lower than planned. This fact was more than compensated by the increased income from industry.

Achieving each of these impressive results under the changing conditions has only become possible through the commitment, imagination, physical insight, technical skills, hard work and international collaboration of the people in the department.

2. Optical Materials

2.1 Introduction

P. M. Johansen
E-mail: per.michael.johansen@risoe.dk

The research programme on Optical Materials comprises three main areas of research: polymer optics, lasers and nonlinear optics. The last of these research areas is intimately linked with the graduate school in Nonlinear Science, which is a collaborative effort between the Technical University of Denmark, the University of Copenhagen and Risø National Laboratory.

The year 1998 was a very important year in the history of the research programme on Optical Materials. Not only have quite a number of significant scientific results been published in international literature, but we have managed to adapt to the demand for more technologically driven research. This has called for a change in the lines of thought of the highly scientifically minded people that work in the research programme.

This change has, however, become a reality by entering into formal contracts with Danish and international industry on the development of new laser diode arrays with improved spatial and temporal coherence properties, on the production of so-called smart cards for storage of information, on a refractive index sensor, and on improved systems of reproduction for the printing industry. Moreover, we have entered into very close collaboration with the Risø's Condensed Matter Physics and Chemistry Department on the development of injection moulding of microsystems, including optical components.

The scientific results achieved have brought forward new knowledge on the formation of surface relief gratings in azobenzene polymers, on the dynamics of the *cis*↔*trans* isomerisation process, and on the modelling of the microscopic features such as quantum efficiencies, absorption cross section and polarisabilities. Transparent electrodes have been deposited on polymers by means of laser ablation and the fundamental physics behind the improved quality of the laser diodes has been brought a huge step forward. The physics of two-level storage in new photorefractive materials has been elucidated and more insight into the dynamics of parametric waves in sillenites has been gained.

2.2 Polymer Optics

2.2.1 Polymer optics

L. Lindvold, P. M. Johansen, H. Pedersen, P.S. Ramanujam, J. Schou and J. Stubager
E-mail: lars.lindvold@risoe.dk

The Optics and Fluid Dynamics Department has formed an instrument centre in collaboration with the Condensed Matter Physics and Chemistry Department for polymer science and technology. The research programme on Optical Materials has contributed with the instrumention for fabrication and characterisation of polymer optics. This effort will serve to strengthen the current activities on fabrication and replication of diffractive optics, dynamic holographic recording materials, e.g., liquid crystalline polymers as well as laser microprocessing of polymer films, including laser ablation. The instrument centre for polymer optics comprises the following large instruments:

Maskaligner Karl Süss MJB 3

Micro-injection moulder Nissei

Dekak V 200 Si

An imaging ellipsometer has also been acquired for this instrument centre. Furthermore, instruments for scanning near-field optical microscopy (SNOM), atomic force microscopes (AFMs) and various set-ups for holographic recording are available along with a clean room for spin-coating of photorecording materials like photoresist plates, azodoped liquid crystalline polymers and photoablative polymer thin films.

These instruments are a part of an effort to be able to master-fabricate, replicate and characterise microstructures in polymers.

2.2.2 Surface relief and anisotropic gratings in azobenzene polymers

I. Naydenova[*]*, L. Nikolova*[*]*, T. Todorv*[*] *(Bulgarian Academy of Sciences, Sofia, Bulgaria), N. C. R. Holme (Ibsen Micro Structures A/S), S. Hvilsted (Condensed Matter Physics and Chemistry Department) and P. S. Ramanujam*
E-mail: p.s.ramanujam@risoe.dk

One of the most intriguing discoveries in polymers with azobenzene in side or main chains is the appearance of a surface relief on irradiation with laser beams in a holographic set-up. Several side-chain polymers have been examined in the current study - side-chain liquid crystalline polyesters, polyesters with a chiral substituent on the azobenzene, polyesters with a rigid main chain, methacrylate co-polymer systems with 20 to 100% azobenzene concentration, azobenzene peptide oligomers and a methacrylate polymer with disperse red. It is found that in the case of side-chain liquid crystalline polyesters the valley of the topographic grating coincides with the vertical polarisation of the recording field, while in the case of all other polymers we have investigated the peak of the topographic grating coincides with the horizontal polarisation.

In order to investigate the reason for the differing displacement between the anisotropic and topographic gratings, we have performed irradiation experiments through a transmission mask. The mask consists of a periodic amplitude grating, with a period of 30 μm with the width of the transparent region being 5 μm. The film was placed on the grating and was irradiated with polarised light. With linearly polarised light with the electric field vector perpendicular to the grating vector, atomic force microscopic investigations revealed the presence of topographic features consisting of weak maxima. On irradiation with the orthogonally linearly polarised light, strong and broad maxima were obtained. Circularly polarised light produced sharp and strong maxima.

However, similar experiments performed on amorphous side-chain polyesters, methacrylate systems and peptide oligomers showed very deep trenches on irradiation with light polarised perpendicularly to the grating lines. Irradiation performed with circularly polarised light also produced trenches, while light polarised parallel to the grating lines once again produced weak maxima. We found that in the latter case the nature of the surface relief depends on the intensity of the irradiating light. For small intensities (~ 100 mW/cm^2), broad peaks are obtained, and for high intensities (1 W/cm^2) trenches are created. Intermediate values of the intensities produce both troughs and peaks. Figure 1 shows AFM scans performed on **P6a12** and the amorphous polyester **P6aA** with azobenzene side chains after irradiation with horizontal polarization and shows that both peaks and trenches can be obtained. In some cases when the diffraction efficiency is high, the first-order diffracted waves change the polarisation modulation, resulting in the appearance of a surface relief with doubled frequency.[1]

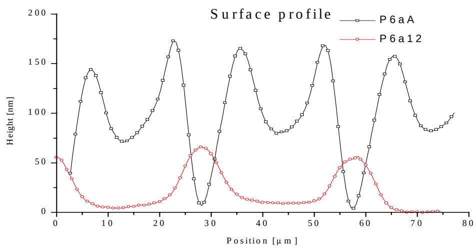


Figure 1. Surface relief in a liquid crystalline (**P6a12**) and an amorphous (**P6aA**) azobenzene polyester.

1. I. Naydenova, L. Nikolova, T. Todorov, N. C. R. Holme, P. S. Ramanujam and S. Hvilsted, J. Opt. Soc. Am. B **15**, 1257 (1998).

2.2.3 Time resolved spectroscopy of azobenzene

N. C. R. Holme (Ibsen Micro Structures A/S), T. B. Norris, M. Pedersen* (*University of Ann Arbor, Michigan, USA), R. Hildebrandt**, M. Hegelisch**, H-M. Keller**, G. Marowsky** (**Laser-Laboratorium Göttingen e.V., Göttingen, Germany), B. Fleck (Intitut für Angewandte Optik, Friedrich-Schiller-Universität, Jena, Germany), S. Hvilsted (Condensed Matter Physics and Chemistry Department) and P. S. Ramanujam*
E-mail: p.s.ramanujam@risoe.dk

Optical storage based on azobenzene has been achieved both in guest-host systems and in systems with the azobenzene attached to polymer structures. The response of azobenzene depends on the spectral and temporal dynamics in the matrix. Time resolved spectroscopic measurements have been performed on azobenzene polyesters in solutions and in solid films in order to elucidate the fundamental processes that lead to photoisomerisation. Degenerate pump-probe measurements have been performed on a series of NO_2, CN and Phenyl substituted azobenzene chromophores and diols in a THF solution at 400 nm. Pulses with a width less than 100 fs, 3 μJ energy and a repetition rate of 20 kHz have been used. Figure 2 shows the normalized changes in the absorption in the case of the CN substituted chromophore and the diol. It is seen that the isomerization is very fast.[1]

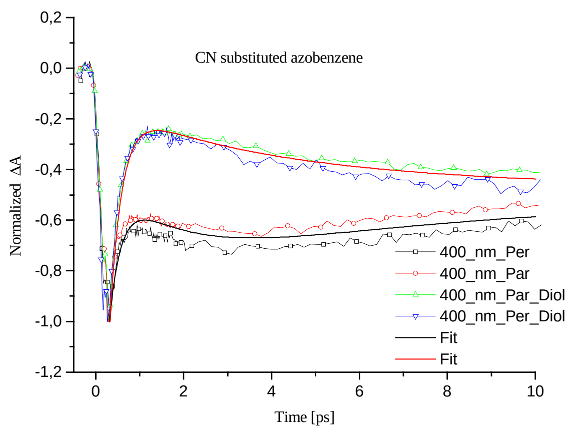


Figure 2. Experimental data (points) and theoretical fits (solid curves) to the change in normalised absorption for the case of cyanoazobenzene chromophores and in a diol.

Time-resolved measurements of photoinduced birefringence in liquid crystalline azobenzene polyester films have also been performed.[2] After excitation with a single nanosecond pulse, the induced birefringence was monitored on time scales that ranged from nanoseconds to minutes. It was found that the maximum birefringence is reached several microseconds after the excitation in a dark reaction. The induced birefringence has been found to relax with up to four different time constants. It is surmised that at high pulse energies thermal effects play a significant role in the relaxation processes. We have obtained similar results with a single 100 ps pulse as well. In both cases the induced birefringence after relaxation does not decay completely to zero.

1. N. C. R. Holme, T. B. Norris, M. Pedersen, S. Hvilsted and P. S. Ramanujam, Polym. Prepr. **39,** 334 (1998).
2. R. Hildebrandt, M. Hegelich, H-M. Keller, G. Marowsky, S. Hvilsted, N. C. R. Holme and P. S. Ramanujam, Phys. Rev. Lett 81, 5548 (1998).

2.2.4 Photoisomerisation of azobenzene polymers

T. G. Pedersen, P. M. Johansen, P. S. Ramanujam, N. C. R. Holme (Ibsen Micro Structures A/S) and S. Hvilsted (Condensed Matter Physics and Chemistry Department)
E-mails: per.michael.johansen@risoe.dk, p.s.ramanujam@risoe.dk

Eich and Wendorf[1] have revived interest in azobenzene polymers following the demonstration of reversible data storage in these materials. A theoretical framework for the temporal behaviour of photoinduced anisotropy in liquid-crystalline side-chain polymers has been constructed.[2] The intrinsic domain structure of such materials has been taken into account and the intermolecular interactions are included through a mean-field description. An example of the fit between experiment and theory is shown in Figure 3. The photoinduced *trans* ↔ *cis* isomerisation is the dominating source of chromophore reorientation and it is demonstrated how the mechanism in conjunction with the multidomain picture is capable of accounting for the long-term stability of the anisotropy. A similar mean-field model[3] has been applied to study the photoinduced surface relief in dye containing side-chain polymers. It is shown that photoinduced ordering of dye molecules subject to anisotropic intermolecular interaction leads to a mass transport even when the intensity of the incident beam is spatially uniform. Theoretical profiles are obtained using a simple variational approach, and excellent agreement with experimental surface reliefs recorded under various polarisation configurations is found.

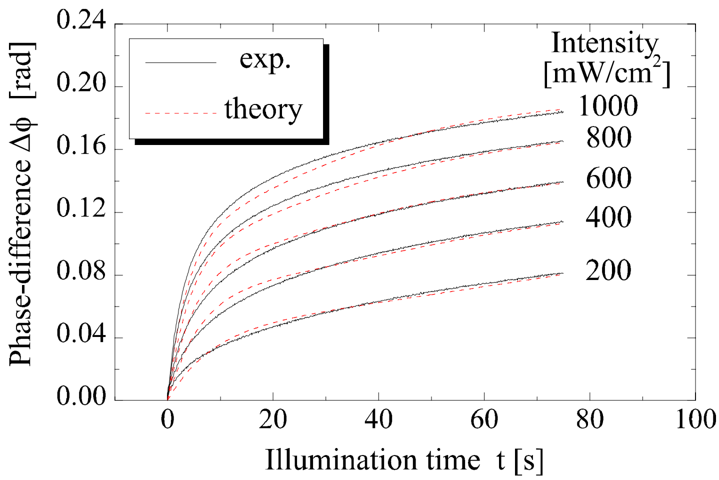


Figure 3. Comparison between the experimental phase difference (solid curves) and the theoretical prediction (dashed curves). The curves have been reproduced from Ref. 2.

Using a simple Pariser-Parr-Pople (PPP) model, it has been possible to compute the hyperpolarisabilities since the absorption spectrum of azobenzene is dominated by π-π* band. However, detailed simulations of the performance of azocompounds used in optical data storage are still lacking. Due to the involvement of non-bonding states in the photoisomerisation processes, excitation energies and oscillator strengths of both π-π* and n-π* transitions are required for the prediction of the optical storage properties. A quantum model[4] for the prediction of microscopic properties of azobenzene chromophores is presented and verified by comparison with experimental absorption spectra for *trans and cis* isomers of cyanomethoxy azobenzene. Through a measurement of the *trans-cis* quantum efficiency, and combined theoretical and experimental work, the magnitude and anisotropy of the absorption cross section, see Figure 4, and various components of the polarisability are calculated for both *trans and cis* isomers.

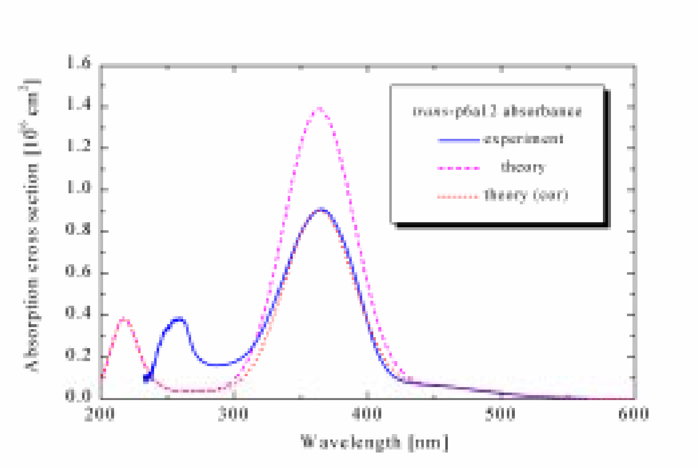


Figure 4. Comparison between the experimental (solid curve) and theoretical (dashed curve) absorption cross section for the *trans* isomer of CM azobenzene. The dotted curve shows the theoretical result obtained by suitable scaling of the calculated oscillator strength of the fundamental π-π* transition.

1. M. Eich and J. H. Wendorff, J. Opt. Soc. Am. B **6**, p. 1339 (1989).
2. T. G. Pedersen and P. M. Johansen, Optical Materials **9**, p. 212 (1998); T. G. Pedersen, P. M. Johansen, N. C. R. Holme, P. S. Ramanujam and S. Hvilsted, J. Opt. Soc. Am. B **15**, p. 1120 (1998).
3. T. G. Pedersen, P. M. Johansen, N. C. R. Holme, P. S. Ramanujam and S. Hvilsted, Phys. Rev. Lett. **80**, p. 89 (1998).
4. T. G. Pedersen, P. S. Ramanujam, P. M. Johansen and S. Hvilsted, J. Opt. Soc. Am. B **15**, p. 2721 (1998).

2.2.5 Handling of conductive transparent films on polymers and glass substrates by pulsed laser ablation

B. Thestrup, J. Schou, A. Nordskov, N. B. Larsen[*] and P. Sommer-Larsen[*] (Condensed Matter Physics and Chemistry Department)
E-mails: birgitte.thestrup@risoe.dk, j.schou@risoe.dk

Films of thicknesses from 30 nm to 500 nm of indium tin oxide (ITO) have been deposited on various substrates. ITO is a relatively hard semiconductor which is transparent for visible light and has many applications in, for example, displays, optoelectronic devices and coatings for solar cells.

We have studied the possibility of using thin films of ITO as electrodes on polymers. The films have been produced by pulsed laser deposition,[1] which can be used for fabrication of conductive films even with the polymer substrates kept at room temperature, which is in contrast to most of the other standard methods. The results obtained so far indicate that the specific resistivity is somewhat higher for films on polymers than for those on glass substrates.

The results in Figure 5 show resistivity measurements for ITO electrodes on Kapton deposited at room temperature. The resistance was determined by a standard four-point-probe technique and the film thickness was determined by atomic force microscopy or calibration with quartz crystal microbalances.

Results from literature indicate that the electrodes and the underlying polymer can be processed by UV laser irradiation as well.

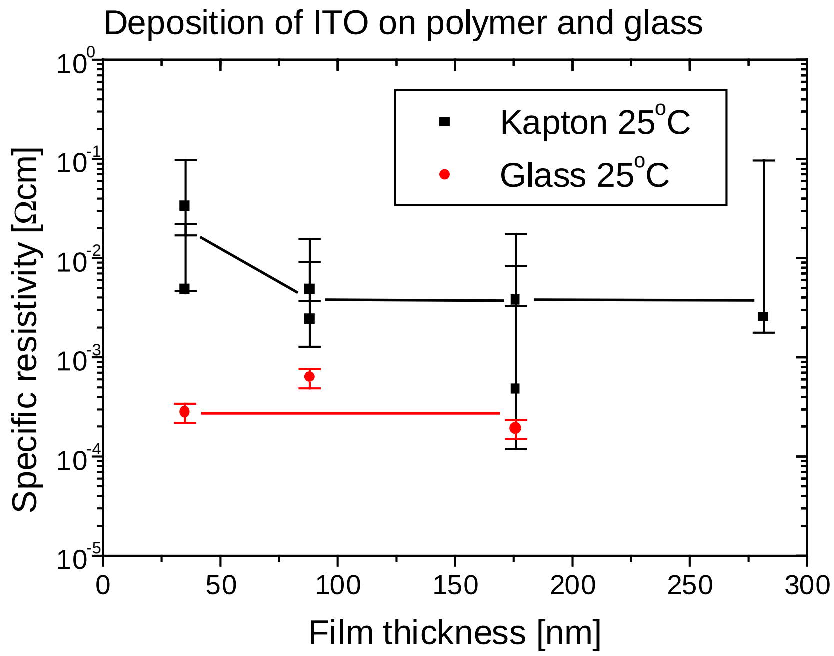


Figure 5. The specific resistivity of ITO electrodes deposited on Kapton at 25° C as a function of film thickness. Laser fluence: 2.2 J/cm^2. Laser wavelength: 355 nm. Typical deposition rate: 0.3 nm/s.

1. B. Thestrup, J. Schou, A. Nordskov and N. B. Larsen, Appl. Surf. Sci. (in press).

2.2.6 Laser irradiation of plants

J. Schou, A. Nordskov, L. Lading, T. Heisel[*] and S. Christensen[*] ([*]Danish Institute of Agricultural Sciences, Flakkebjerg)

E-mail: j.schou@risoe.dk

Processing, modification and cutting of surfaces of metals, insulators and organic materials by strong lasers have been applied for many years.[1] We have extended this application of intense lasers to cut organic tissue from plants of selected types. Samples of 5-20 cm plants in pots were exposed to a number of laser pulses or moved across a stationary pulsed laser beam with a preselected velocity. Such a laser cutting can be performed remotely and in a preset, well-controlled manner. It offers the possibility of weed control by laser irradiation as an alternative to that by pesticide spraying.

Figure 6 shows a charlock in a plastic pot cut by a laser beam through openings of the pot. The stalk has been cut at the branching point of the leaves about 10 mm from the soil. A more systematic study of the important parameters and of the possible applications for plant cutting by lasers will be carried out.

1. M. Allmen and A. Blatter, Laser-beam Interactions with Materials (Springer, 1995) pp. 1-194.

Figure 6. A charlock cut above 10 mm above the surface of the soil by a laser beam.

2.3 Lasers

2.3.1 New laser diode arrays with enhanced coherence properties

P. M. Petersen, S. Juul Jensen, M. Løbel (GIGA A/S) and P. M. Johansen
E-mail: paul.michael.petersen@risoe.dk

GaAlAs semiconductor laser diode arrays are commercially available with output power up to 20 W. These lasers systems are attractive because they can be operated with a low voltage and because they have a lifetime of more than 10,000 hours. The laser diode arrays, however, have a multimode non-diffraction limited output, which limits their usefulness in many practical applications. The purpose of the present project is to develop new high-power laser diode arrays with significantly improved spatial and temporal coherence properties.

At Risø National Laboratory a new high-power single-mode laser diode array with unique coherence properties has been invented.[1-5] In Figure 7 (a) the implementation of our laser system is shown. A GaAlAs laser diode array is coupled to the phase conjugate feedback system that comprises a rhodium doped $BaTiO_3$ crystal, a Fabry-Perot etalon and a spatial filter. This feedback system forces the laser diode array to operate in a single spatial and a single longitudinal mode. The optical wavelength spectra of the phase locked array and the freely running array, respectively, are shown in Figure 7 (b). If the etalon is replaced with a grating, the output wavelength is tunable.

We have demonstrated that, in comparison with the freely running laser diode array, the coherence length of the phase conjugate laser system has been increased by a factor of 70 and that the output has become almost diffraction limited. The latter implies that the laser beam can be focused to a small spot at the size of a wavelength. More than 80% of the total energy provided by the freely running laser diode array can be extracted from this single-mode laser system. Furthermore, the frequency can be tuned continuously over a range of 6 nm around a centre wavelength of 812 nm.

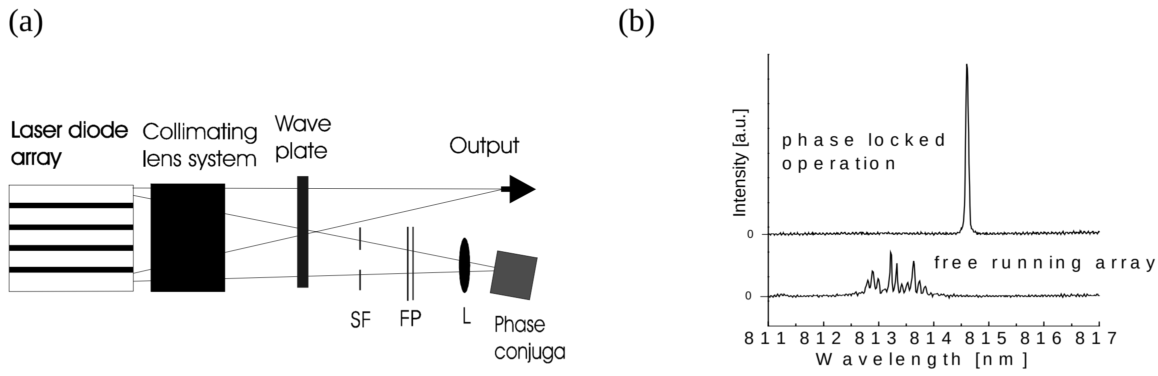


Figure 7. (a) Laser diode array with phase conjugate feedback. An GaAlAs laser diode array is coupled to a conjugate feedback system that contains a rhodium doped $BaTiO_3$ crystal, a Fabry-Perot etalon (FP), a lens (L), and a spatial filter (SF). (b) Optical wavelength spectra of phase locked array and free running array.

The characteristics of the new laser system are:

- Single longitudinal mode.
- Single spatial mode (1.4 the diffraction limit).
- A coherence length of 7 cm.
- Tunable output with a center wavelength of 812 nm and a minimum tuning range of 6 nm.

1. M. Løbel, P. M.Petersen and P. M.Johansen, “Tunable single-mode operation of a high-power laser diode array using an external cavity with a grating and a photorefractive phase conjugate mirror”, J. Opt. Soc. Am. B. **15**, pp. 2000-2005, 1998.
2. M. Løbel, P. M.Petersen and P. M.Johansen, "Suppressing self-induced frequency scanning of a diode laser array with phase conjugate feedback using counterbalance dispersion”, Appl. Phys. Lett. **72,** pp. 1263-1265, 1998.
3. M. Løbel, P. M.Petersen and P. M. Johansen, “Single-mode operation of a laser diode array with frequency selective phase-conjugate feedback”, Opt. Lett. **23**, pp. 825-827, 1998.
4. M. Løbel, P. M.Petersen and P. M.Johansen, “Physical origin of laser frequency scanning induced by photorefractive phase conjugate feedback”, J. Opt. Soc. Am. B. **16**, pp. 219-227, 1999.
5. P. M.Petersen, M. Løbel and P. M. Johansen, “Single-mode operation of laser diode arrays using photorefractive phase conjugators”, Invited paper, CLEO/Europe´98 Technical Digest, p. 236, 1998.

2.3.2 The coupled-cavity refractive index sensor (CRIS)

H. Imam, L. R. Lindvold and L. Lading
E-mail: husain.imam@risoe.dk

The accurate measurement of small changes in refractive index is important in the areas of chemistry and biochemistry. In chemical applications, *chromatography* and *electrophoresis* are methods of separating chemicals in a fluid phase, and refractive index is used as a means of classification. In biomedical applications, small changes in refractive index can determine whether a biochemical reaction has taken place and this is an important property for biomedical sensors.

A method of determining very small changes in refractive index has been developed utilising lasers. The principle lies behind the frequency characteristics of a laser cavity. The length of the cavity governs the frequency of a laser or, in essence, the optical path length between the resonating mirrors. When a substance is inserted into a laser cavity which has a different refractive index to the cavity refractive index, the optical path length changes. This change in optical path length results in a change in the lasing frequency. However, this change in frequency is very small compared with the actual lasing frequency of the laser.

It is possible to measure this small change in frequency (10 kHz - 1 MHz) by heterodyning this signal with another signal from a laser with an unaffected cavity. In this case, small changes in frequency due to refractive index changes in one cavity can be observed as a change in the *beat* frequency of the heterodyned signal. Figure 8 shows an experimental set-up used to measure small changes in refractive index due to the introduction of gases into the laser cavities. In theory, this so-called *CRIS* principle can measure changes in refractive index with a resolution of 10^{-12}. Based on crude experiments conducted recently, changes in refractive index of 10^{-9} have been obtained. The end goal is to manufacture a compact version of a sensor employing the CRIS principle using guided wave and laser diode technology. This is currently being pursued with industrial collaborators.

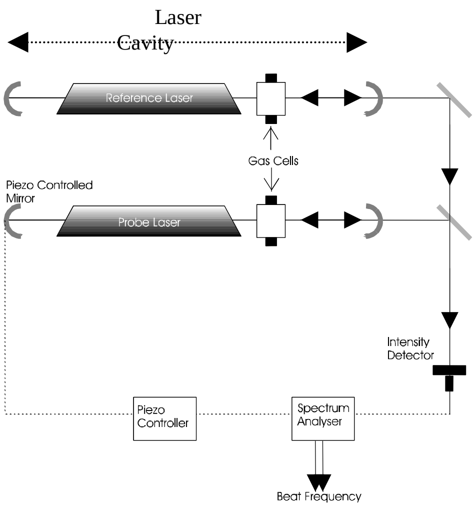


Figure 8. Bulk arrangement employing the CRIS principle.

2.4 Non-linear Optics

2.4.1 Two-step two-colour gated recording in photorefractive $La_3Ga_5SiO_{14}$ crystals doped with Pr^{3+}

T. Nikolajsen, P. M. Johansen, X. Yue[*], *D. Kip* and E. Krätzig*[*] ([*]Universität Osnabrück, Fachbereich Physik, D-49069 Osnabrück, Germany)
E-mails: thomas.nikolajsen@risoe.dk, per.michael.johansen@risoe.dk

Several different requirements have to be met in order for holographic information storage to find use in practical applications. One requirement is that erasure of stored information is avoided, on the other hand it is also desirable to have a reversible process where the data can be erased at will. In this report we investigate the possibility of using two-step excitation processes in praseodymium doped $La_3Ga_5SiO_{14}$ crystals for non-volatile gated recording using cw lasers.[1] The technique is based on gated recording. In gated recording, light with two different wavelengths is used for recording. The first wavelength is used to form the interference pattern of the hologram inside the crystal (writing beam) while the other wavelength is used for gating of the photorefractive process in the material allowing the interference pattern to be transformed into a refractive index modulation. In the experiments an Ar-ion laser operating at 488 nm is used for gating while a Ti-sapphire laser operating at 800 nm is used for writing. From figure 1 it can be seen how the sensitivity of the material toward writing with IR increases when blue light is applied simultaneously. After recording the recorded hologram can be read out using one of the IR writing beams only without noticeable erasure.

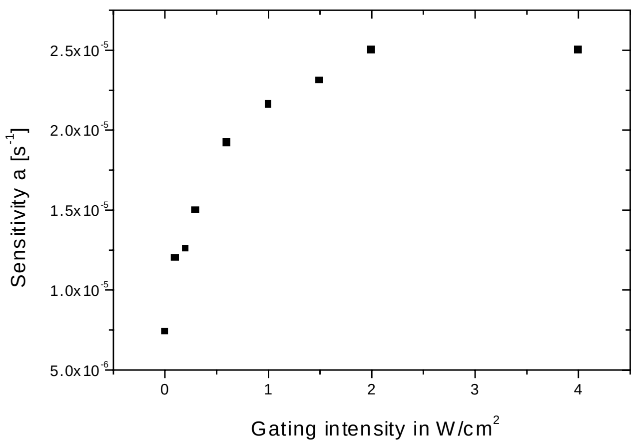


Figure 9. The figure shows the increase in photorefractive sensitivity when the writing process is gated with homogeneous illumination.

1. T. Nikolajsen, P. M. Johansen, V. M. Fridkin, T. Batizov and R. Djalalov , Opt. Lett. **23**, 1164, (1998).

2.4.2 Holographic storage of radiographs

P. M. Petersen, J. Limeres (Universidad Autonoma de Madrid) and P. E. Andersen
E-mail: paul.michael.petersen@risoe.dk

At Risø National Laboratory we have developed a holographic set-up for storage and analysis of images.[1-2] This kind of image storage is a new and attractive technology that may find commercial applications in the near future. The purpose has been to investigate the potential for storage of radiographs (X-ray pictures) in the holographic storage set-up.

The holographic storage set-up offers many advantages over conventional storage systems. In the holographic memory storage capacities of 100 Gbytes per cm^3 are possible and, due to the *parallel* recording of the stored images in these memories, transfer rates of more than 1 Gbyte per second may be obtained. Furthermore, the access time for stored pictures in the holographic memory is approximately 10 µs which is at least two orders of magnitude faster than for conventional *serial* digital storage of pictures in magnetic hard drives.

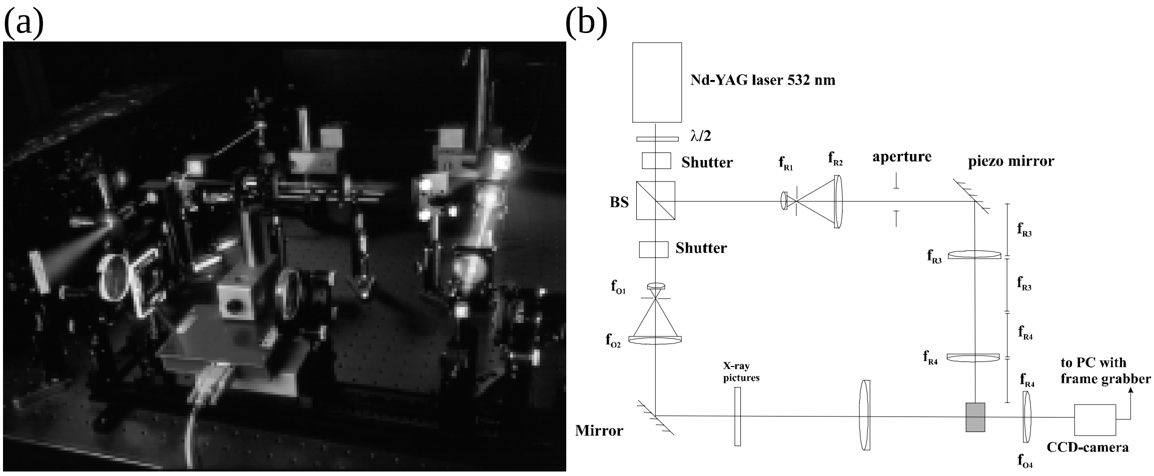


Figure 10. A fully automated holographic recording set-up used for investigating storage of X-ray pictures. In the setup multiple holograms are recorded in an $LiNbO_3$crystal . Each X-ray picture is stored into the crystal with one reference beam incident at a given angle and an image bearing object beam. The stored X-ray picture is read out by the reference beam and captured by a CCD camera. The reconstructed X-ray picture is analysed on a personal computer with framegrabber. (a) Photo of the holographic storage set-up. (b) Schematic diagram for the holographic set-up. A laser beam from a frequency doubled Nd-Yag laser is split into a reference beam and an object beam. The object beam is transmitted through the X-ray picture, and this picture is stored in the $LiNbO_3$ crystal as a hologram. BS is a beamsplitter, $\lambda/2$ is a half-wave plate, and f_i (i=R1,R2,R3,R4,O1,O2,O3,O4) are lenses.

An analogue holographic recording set-up has been constructed for investigating storage of dental radiographs. In the set-up, shown in Figure 10, multiple radiographs are recorded in an iron-doped lithium niobate ($LiNbO_3$) crystal using angular multiplexing. Each image is written into the crystal with one reference laser beam and one object laser beam incident at selected angles. The object beam is transmitted through the dental radiograph to be stored and the picture of the radiograph is imprinted on this beam as an amplitude modulation. Afterwards, the stored information is read out by the reference beam incident on the crystal at the previously selected angle. The reconstructed radiograph is captured using a CCD camera and is analysed on a personal computer with framegrabber.

The characteristics of the storage system are:

- 50 seconds recording time for a single dental radiograph.

- 10^{-7} diffraction efficiency of the individual holograms.
- Laser power 100 mW during recording.
- Spatial resolution: better than 100 lines pr. mm.
- Storage capacity: 20.000 radiographs in a 1 cm^3 $LiNbO_3$.
- Lifetime of stored information: 20-100 years.

1. J. Limeres, M. Carrascosa, P. E. Andersen and P. M. Petersen, "Nonlinear cross-talk between mutually incoherently recorded gratings in $BaTiO_3$", CLEO/Europe´98 Technical Digest, p. 224, 1998.
2. P. E. Andersen and P. M. Petersen, "Kinetics of higher-order combinational gratings in photorefractive media: diffusion regime", J. Opt. Soc. Am. B. **15**, pp. 2032-2036, 1998.

2.4.3 Fundamental characteristics of space-charge waves in photorefractive sillenite crystals

H. C. Pedersen, D. J. Webb, (University of Kent at Canterbury, UK) and P. M. Johansen
E-mails: henrik.pedersen@risoe.dk, per.michael.johansen@risoe.dk

One of the most characteristic parameters for space-charge waves propagating in photorefractive sillenite crystals is the quality factor, Q_K. $Q_K/2\pi$ notifies the number of wavelengths the wave is capable of travelling in free state before its amplitude is damped by a factor of 1/*e*. The magnitude of the quality factor therefore determines the efficiency of resonant excitation of space-charge waves as well as the instability conditions for the well-known parametric processes referred to as photorefractive parametric oscillation. In this work we have carried out a systematic series of measurements of Q_K for different experimental parameters and have compared the dependencies with theory.[1] The quality factor was derived from rise experiments in which a stationary holographic grating was transiently recorded by an optical interference pattern. When the pattern is turned on, two space-charge waves, a stationary one and a free, running eigenwave, are excited. From the beating between these two waves, which can be monitored by measuring the diffraction efficiency of the hologram, the quality factor may be derived. In Figure 11 a typical trace is shown. By performing similar measurements for different values of the space-charge wave period (fringe spacing) the data points in Figure 12 were obtained. The solid line is obtained theoretically. It is seen that a reasonable agreement with theory is obtained.

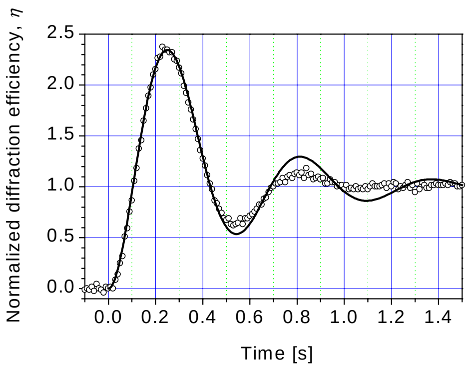


Figure 11. Transient rise of normalized diffraction efficiency; the open circles represent experiments, the solid line is obtained theoretically.

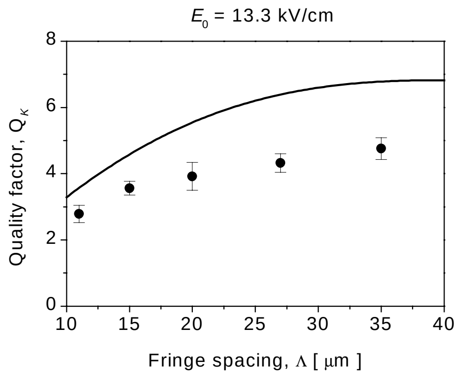


Figure 12. Quality factor versus fringe spacing for E_0 = 13.3 kV/cm.

1. H. C. Pedersen, D. J. Webb, and P. M. Johansen, "Fundamental characteristics of space-charge waves in photorefractive sillenite crystals," J. Opt. Soc. Am. B, vol. 15, p. 2573 (1998).

2.4.4 Photorefractive nonlinear optics: AC and DC field induced parametric processes

P. M. Johansen, H. C. Pedersen, E. V. Podivilov[*] and B. I. Sturman[*]
([*]Institute of Automation and Electrometry, Novosibirsk Russia)
E-mails: per.michael.johansen@risoe.dk, henrik.pedersen@risoe.dk

Photorefractive parametric processes have been the subject of intensive investigations during the past few years. A nonlinear theory of transversal parametric oscillation[1] has been devised. The theory is nonlinear in the sense that the nonlinear feedback from the parametric space-charge field waves, above threshold of their excitation, is taken into account. An analytical solution for the stationary state of parametric waves is derived. The stability of this state against small perturbations in amplitude and phase, so-called internal stability, and against excitation of new secondary waves, so-called external stability, is calculated. This leads to the conclusion that the stationary state of transversal parametric oscillation is stable within certain regions of internal and external parameters.

It has long been known that two-wave mixing has a certain influence on parametric processes in photorefractive sillenite crystals. This has led to a detailed experimental comparison of the two configurations with and without the presence of beam coupling to establish the fundamentals of this influence[2,3] in both the DC and AC applied field cases. In the first case it was shown that beam coupling has a great influence on, e.g., the transversal split of the **K**/2 subharmonic grating which is present only in the beam-coupling geometry. In the AC field case, however, the distinct subharmonic waves were found only in beam-coupling geometry whereas in the configuration without beam coupling a continuous spectrum of grating vectors between **0** and **K** was observed. Theoretically, the steady-state solutions for the AC field induced K/2 subharmonic grating has been calculated.[4] Increasing the optical contrast makes the K/2 subharmonic unstable against the excitation of the K/4 subharmonic.

Two different mathematical methods, the so-called cascading technique[5] and a Fourier method,[6],have been applied to yield solutions for the space-charge field induced in a photorefractive medium when a sinusoidal electric field and running light interference pattern are imposed simultaneously. The advantage of the developed cascading technique is a fast convergence to the exact solution and the fact that it can be applied to situations with more than one frequency involved. The Fourier method, on the other hand, is valid for all time scales, also to situations in which the conventional period-averaging technique does not apply. The influence of higher harmonic components on the fundamental photorefractive grating has been analysed numerically in the transient as well as the steady state cases.[7]

1. E. V. Podivilov, H. C. Pedersen, P. M. Johansen and B. I. Sturman, Phys. Rev. E **57**, p. 6112 (1998).
2. H. C. Pedersen, D. J. Webb and P. M. Johansen, J. Opt. Soc. B **15**, p. 2439 (1998).
3. H. C. Pedersen, P. M. Johansen and D. J. Webb, J. Opt. Soc. B **15**, p. 1528 (1998).
4. P. M. Johansen, H. C. Pedersen, E. V. Podivilov and B. I. Sturman, Phys. Rev. A **58**, p. 1601 (1998).
5. P. M. Johansen, H. C. Pedersen, T. G. Pedersen and J. Wyller, J. Opt. Soc. Am. B **15**, p. 1168 (1998).
6. P. M. Johansen and H. C. Pedersen, J. Opt. Soc. Am. B **15**, p. 1366 (1998).
7. H. C. Pedersen, P. M. Johansen, E. V. Podivilov and D. J. Webb, Opt. Commun. **154**, p. 93 (1998).

2.4.5 Diagnostic tools for plasma characterisation during laser ablation

B. Toftmann, J. Schou, B. Thestrup, A. Nordskov, O. Ellegaard (University of Odense, Odense, Denmark) T. N. Hansen and J. L. Lunney* (*Dept. of Physics, Trinity College, Dublin, Ireland)*
E-mail: j.schou@risoe.dk

Intense laser impact on solids leads not only to strong (thermal) evaporation of the irradiated solid, but also to the production of a plasma. Laser ablation has become a well-established fast method to fabricate multicomponent single films or film combinations of oxides, metals and polymers in laboratories, in particular because high-quality films can be produced even at room temperature substrates. This fabrication method, pulsed laser deposition (PLD), suffers still from laser beam control problems, which may limit the reproducibility of the film properties. We have recently studied the ion production, the energy and the angular distribution from the initial plasma plume in vacuum,[1] which is a much simpler case than laser ablation in a background atmosphere.

Another interesting plasma component, which might be used for plasma control as well, is the emitted electrons. We have studied the electron temperature based on the Langmuir probe theory. The most appropriate probe turned out to be a planar probe of dimension 5x5 mm^2, which is in fact simpler than probes of other geometries. We have measured the so-called I-V probe characteristic (Figure 13), from which the temperature can be derived in a semi-logarithmic plot. The temperature of the electrons in the probe direction for the pulse energy of 39 mJ is about 0.3 eV. This value should be compared with the average ion energy which is more than two orders of magnitude larger than the electron temperature.

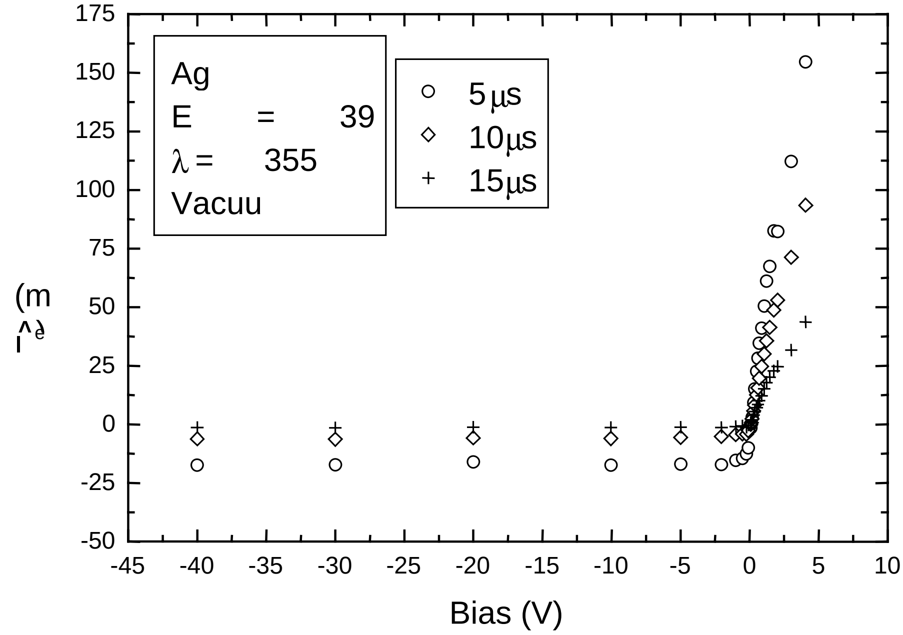


Figure 13. The probe current (I) as a function of probe voltage (V) for different time delays after the laser firing at a plane probe located 80 mm from a silver target with a direction from the normal of 23.5^o (laser fluence: 0.8 J/cm^2, laser wavelength: 335 nm).

1. T. N. Hansen, J. Schou and J. L. Lunney, Appl. Phys. Lett. **72**, 1829 (1998).

3. Optical Diagnostics and Information Processing

3.1 Introduction

S. G. Hanson
E-mail: steen.hanson@risoe.dk

The research in the programme aims at participating in scientific investigations of “light” and accompanying technologies with the purpose of conveying these concepts to industry and making them available to postgraduate students.

A strong demand has been put onto the programme for a large industrial impact, which has resulted in an increase in the field of industrial acquisition. Four major themes are addressed in the programme: infrared technology, medical optics, optical measurement techniques and knowledge based processing. Besides, a separate group has since 1978 performed accredited temperature calibration; an activity that has now been extended to cover infrared thermometers. The main activities in the year 1998 will be described below. Although the four themes might seem only slightly connected, great emphasis is put into coping with large programmes - either industrially or purely scientifically related - where a collective effort enhances the chance of success. Thus the field of medical optics will be the pivot point for many future projects. Knowledge-based processing as well as infrared technology are essential contributors to the prosperity of the field of medical optics, as is the use of miniaturised optical sensors.

In the field of infrared technology, the main objective is the use of fast, but low-resolution Fourier transform spectrometers (FTIRs) has shown unprecedented results, especially for simultaneous determination of transmission and emission of infrared radiation through hot exhaust gases. These investigations have been conducted in a large European programme.

A key issue in knowledge-based processing with data-driven models is to control the trade-off between the model sensitivity and the model fit. This investigation has successfully been initiated in an industrial Ph.D project at Intellix A/S, which is a Danish company specialised in developing expert systems and decision support products relying on RAM-based neural networks (also denoted n-tuple neural nets).

General support for the work with medical optics has been given by the Danish company Torsana A/S and by a special contribution by Risø National Laboratory. A Ph.D. study granted by the Danish Technical Research Council addressing a non-invasive method for tomography in human tissue has been carried on and a comprehensive theoretical description of the coherence properties of light reflected within turbid media has been presented.

A project employing concepts developed and patented at the laboratory has been commercialised, and comprehensive theoretical descriptions of the dynamical behaviour of speckle patterns have been finished. A recently developed phase-coding method for obtaining lossless projection of light by using a generalisation of the well-known Zernike phase contrast has been demonstrated for decrypting and visualising phase encrypted images.

The staff in the programme has victoriously managed to adjust to the demand for large industrial impact while at the same time maintain and augment their scientific productivity. Not to say that it has been without costs; an inspiring energy has been put forward and the hope for the coming year will be a continuation of this effort.

3.2 Infrared Technology

3.2.1 FTIR gas analysis

J. Bak and S. Clausen
E-mail: jimmy.bak@risoe.dk

The determination of gas temperatures and concentrations in combustion systems, flames, flares and chemical gaseous processes is crucial in order fully to understand and control the processes which take place in these systems. Fourier transform infrared spectroscopy (FTIR) is used for non-intrusive measurements to provide information about species concentrations and gas temperatures along a line of sight in hot gaseous systems. In 1998 the design and construction of a hot gas cell (T_{max}=1273 K) initiated a measuring programme that as a result gave more insight into FTIR gas analysis. Two of the results will shortly be described here .

In an earlier work we demonstrated that it was possible to take into account all parts in the experimental set-up that radiated thermally and to make a complete mathematical description of the gas radiance.[1] On the basis of this work it was then possible to show that Kirchhoff's radiation law was obeyed for a hot gas in an enclosure, see Figure 14. It is to our knowledge the first time that Kirchhoff's law, which is a cornerstone of radiative transfer calculations, is demonstrated experimentally for a gaseous sample.[2]

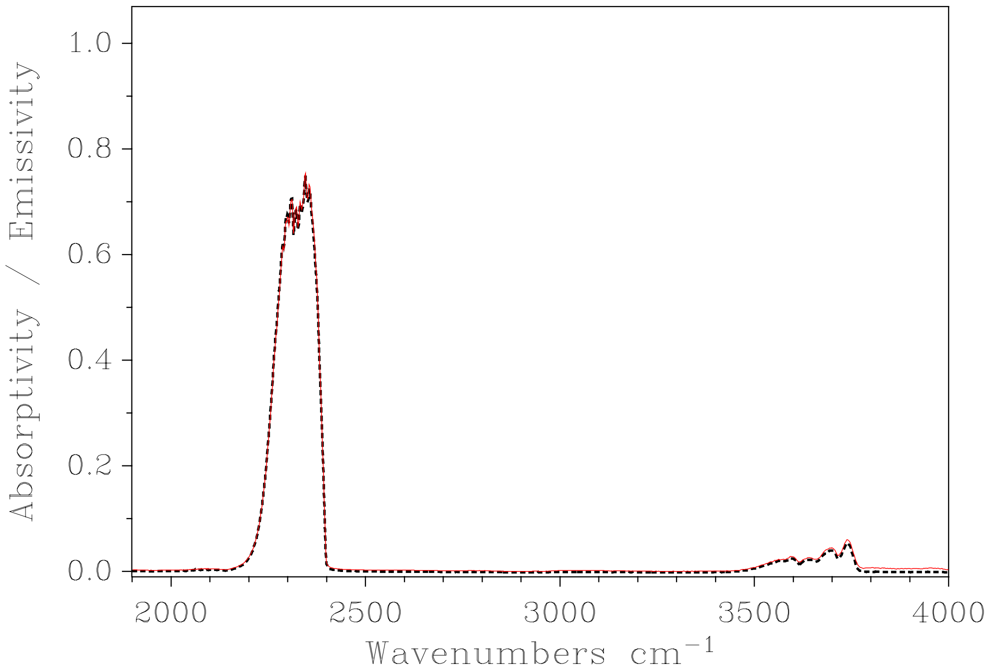


Figure 14. Absorbtivity (------) and emissivity (——) spectra of 0.5 vol % CO_2 at temperature 883 K. A high degree of coincidence between the spectral features of the absorptivity (α) and emissivity (ε) is observed, i.e. Kirchhoff's radiation law $\varepsilon = \alpha = 1\text{-}T$ is demonstrated.

The minimum amount of gaseous compounds that can be detected and quantified with FTIR spectrometers depends on the signal-to-noise ratio (SNR) of the measured gas spectra. In order to use low-resolution FTIR spectrometers to measure combustion gases like CO and CO_2 in emission and transmission spectrometry, an investigation of the SNR in gas spectra was carried out. Based on the findings in this work we concluded that the SNR increases as the spectral resolution is degraded due to a strong reduction in the root mean square (RMS) noise levels in the spectra. The relationship between spectral resolution and SNR is shown in Figure 15. In addition, we presented a method for calculating the SNR based on database data and measured single interferograms, respectively.[3-5]

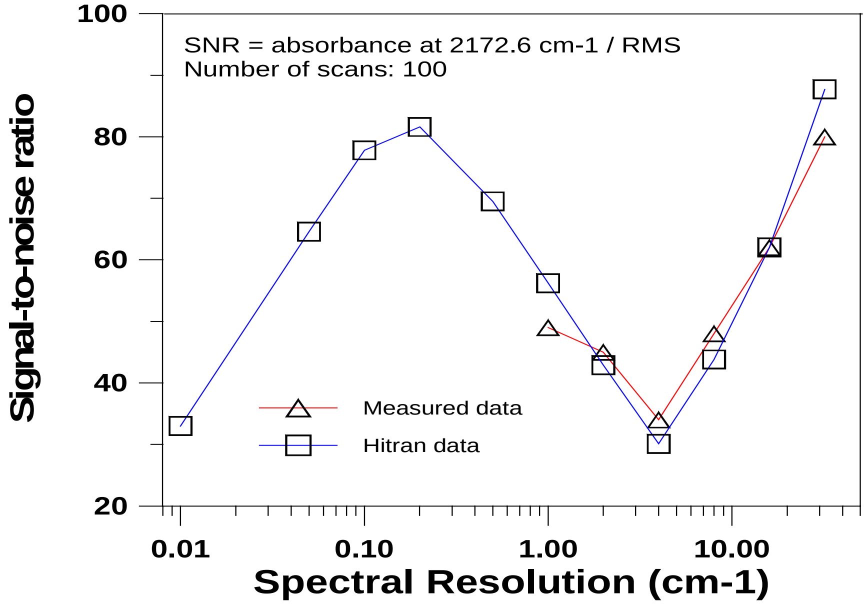


Figure 15. Signal-to-noise ratio of CO spectra as a function of spectral resolution at constant throughput and equal number of scans. The measured data are limited to 1 cm^{-1} which is the spectral resolution of the FTIR instrument. The minima of the signal-to-noise ratio value at 4 cm^{-1} should be noted which are due to the fact that the wave number spacing between adjacent rotational lines is only 3.81 cm^{-1}, i.e. the spectral lines collapse into a smooth envelope curve.

1. S. Clausen and J. Bak, J. Quant. Spectrosc. Radiat. Transfer **61**, No. 2, pp. 131-141, 1999.
2. J. Bak and S. Clausen, J. Quant. Spectrosc. Radiat. Transfer **61**, No. 4, 1999.
3. J. Bak and S. Clausen, submittted and accepted for publication in Appl. Spec.1999.
4. S. Clausen and J. Bak, "Infrared low resolution emission spectroscopy of hot gases", Orlando, SPIE **3383** (1998), pp. 133-139.
5. J. Bak and S. Clausen. Poster presented at the Pittcon98 Conference (abstract published), New Orleans, March 1998.

3.2.2 Aeroprofile project: fast simulation of infrared gas spectra using multivariate calibration methods

J. Bak and S. Clausen
E-mail: *jimmy.bak@risoe.dk*

A computer program was built to simulate CO gas spectra at a spectral resolution of 1 cm^{-1} at temperatures ranging from 295-845 K and concentrations from 5-400 mg/m^3 as input. The program is based on loadings and scores from three principal component regression (PCR) calibration models. Three sets of 12 Hitran simulated spectra, each set spanning the entire temperature range at constant concentrations: 50, 150 and 300 mg/m^3 were used as calibration spectra in the PCR temperature models. All the spectra were convoluted with a sinc squared instrumental line shape function and reduced in number of data points prior to PCR modelling. The simulated spectra, calculated on the basis of the PCR model parameters, were next scaled using the areas of the spectra to represent the input concentration. The deviation between simulated and calculated spectra is a fraction of 1% as can be been in Figure 16. The program can be used to simulate fast (7 ms) spectra which includes saving the simulated spectrum counting 962 data points to the hard disk. This is a great reduction in computing time compared with the time it takes to calculate each spectrum directly from the database followed by data processing. The simulation program can be used as a subroutine for calculating a composite CO spectrum representing a line of sight measurement through an exhaust gas in which the temperatures and gas concentrations vary.

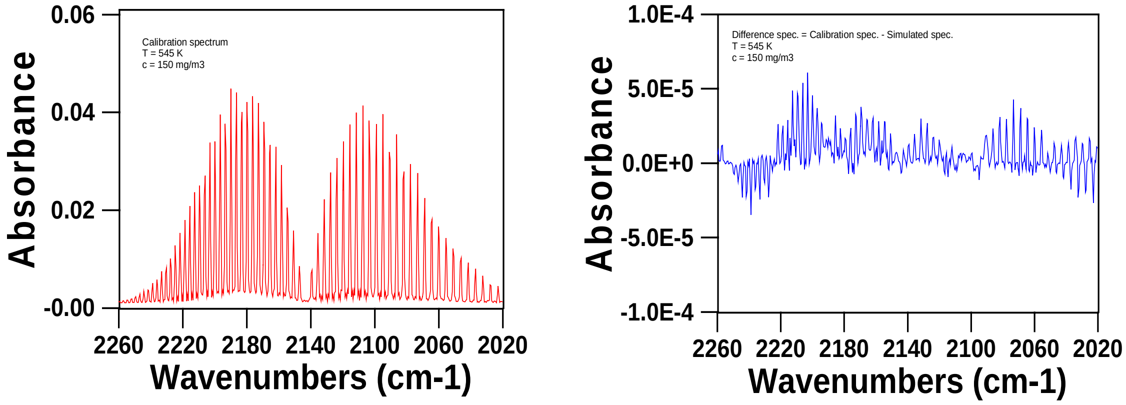


Figure 16. Figure 16 (left) shows the calibration spectrum (T = 545 K) and the difference (right) between the calibration spectra simulated by the inverse PCR temperature model with T = 545 K and c = 150 mg/m^3 given as input. The maximum deviation is 0.17 %.

1. J. Bak, “A rapid method for simulating gas spectra using reversed PCR temperature calibration models based on Hitran data”, to be submitted to Appl. Spec.

3.2.3 Infrared temperature calibration

S. Clausen
E-mail: sonnik.clausen@risoe.dk

A reference laboratory for calibration of infrared instruments was established at Risø in 1996. A traceable calibration of pyrometers and infrared thermometers is made with blackbodies in the temperature range -50 °C to 1600 °C. The work affects the following five main topics in reducing uncertainties of non-contact temperature measurements:

- calibration service of infrared thermometers for customers;
- temperature measurements for customers;
- research and development of new and improved methods for infrared temperature measurements;
- measurement of spectral emissivity of samples and coatings;
- consultative service and information.

Risø is involved in the EU project “Trirat” with participants from laboratories from most of Europe. The overall objective of the project is to provide improved, sub-Kelvin accuracy in infrared radiation thermometry at industrial levels in the range from -50 °C to 800 °C. The traceability is transferred from the highest metrological levels down to the industrial level. We work towards reaching sub-Kelvin accuracy of our calibration sources at temperatures in the range from -50 °C to 250 °C, tests[1] performed in 1998 in cooperation with the Danish Technological Institute showed that the accuracy of Risø's low-temperature blackbody is better than 0.1 °C. A high precision water heat pipe blackbody operating in the temperature range 50 – 250 °C was bought in 1998 to be used for calibration of infrared instruments, e.g. it will be used as reference blackbody in the "Aeroprofile" project (see 1.2.4).

With the combination of high-accuracy traceable blackbody sources and spectral measurements of infrared radiation with an FTIR spectrometer Risø has state-of-the-art calibration capabilities.

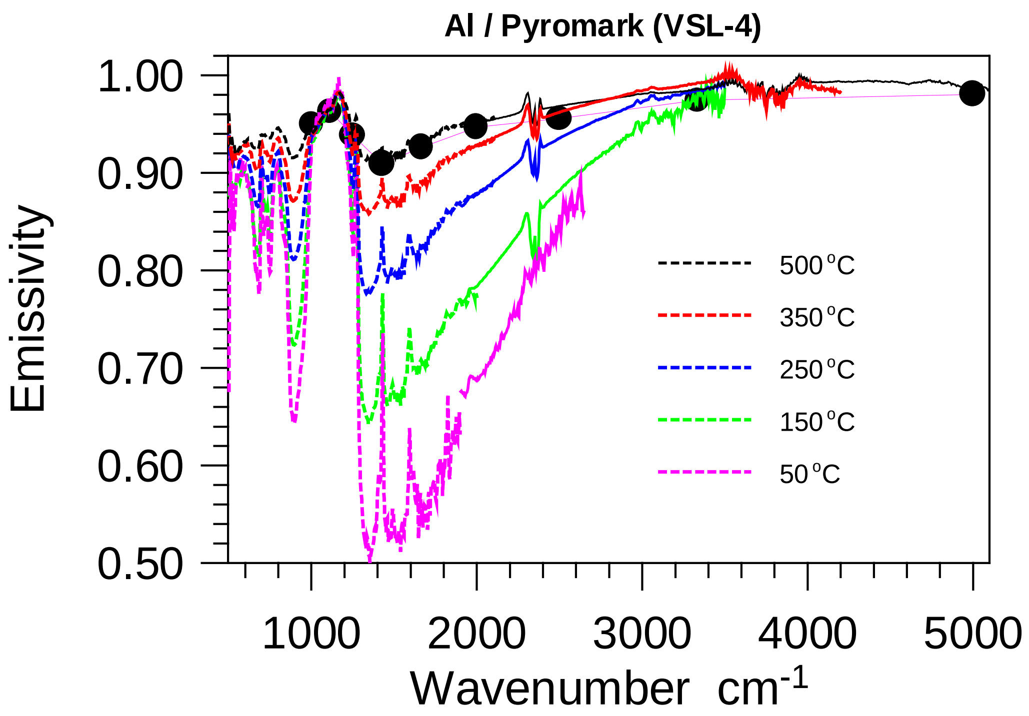


Figure 17. Measurements of spectral emissivity of aluminium sample coated with Pyromark obtained with an FTIR spectrometer. Dots are measurements made by IMGC at 500 °C with filters in front of a detector.

A two-temperature method has been developed for measuring the spectral emissivity with an FTIR spectrometer.[2] The samples studied have been prepared with the same characteristics as surfaces presently used or to be used in the near future for high-precision blackbodies. Measurements are obtained in the temperature range from 50 to 500 °C, and within a spectral range from 2 to 20 µm. The experiments show that the emissivity of coated surfaces can change significantly with temperature (Figure 17).

1. J. Nielsen, M. Adams and S. Clausen, "Reference Blackbody Radiators", report in TRIRAT.
2. M. Battuello, S. Clausen, J. Hameury and P. Bloembergen, "The Spectral Emissivity of Surface Coatings, Currently Applied in Blackbody Radiators, Covering the Spectral Range from 0.9 to 20 µm. An International Comparison. (Draft B)", to appear in Proceedings from the 7th International Symposium on Temperature and Thermal Measurements in Industry and Science, held in Delft, The Netherlands, 1-3 June 1999.

3.2.4 Aeroprofile project: high-temperature gas cell

S. Clausen and J. Bak
E-mail: sonnik.clausen@risoe.dk

The optical properties of hot gases must be determined in order to retrieve temperatures and chemical species in aircraft exhaust by non-intrusive FTIR measurements. Therefore, a new improved high-temperature gas cell has been built at Risø to be used for spectroscopic investigations of the transmissive and emissive behaviour of exhaust gases in the temperature range from ambient to 1000 K (upper limit 1273 K). The gas cell will be finally tested at Risø in 1999 and will then be brought to Deutsches Zentrum für Luft- und Raumfahrt (DLR) for comparison of results obtained with DLR's experimental set-up/gas cell and calculated model high-temperature spectra, respectively.

Features: The stainless steel gas cell (Figure 18) is spring-loaded to allow the approx. 10 mm expansion of the gas cell during heating. A uniform temperature profile, i.e. better than 3 K, is obtained using a three-zone electrically heated furnace. The temperature profile is measured by a number of calibrated sensors. Graphite sealed sapphire or calcium flouride windows are optional. The cell windows are tilted to reduce ripples due to backscattered radiation from the spectrometer in the spectra.

Figure 18. Cross-section of the new upgraded high-temperature gas cell at Risø. The optical path length of the cell (blue) is 500 mm. The hot gas cell has two heated window sections (green) to obtain a uniform temperature profile of the central section (blue).

3.3 Medical Optics

3.3.1 Optical coherence tomography with ultrahigh resolution for non-invasive medical diagnostics

L. Thrane, P. E. Andersen, S. Grüner Hanson, H. T. Yura (Electronic Technology Center, The Aerospace Corporation, Los Angeles, CA, USA) and P. Bjerring (Department of Dermatology, Marselisborg Hospital, University of Aarhus, Aarhus, Denmark)
E-mail: lars.thrane@risoe.dk

A new theoretical description of the optical coherence tomography (OCT) technique for imaging through highly scattering tissue, e.g. human skin, has been developed.[1] The description is based on the extended Huygens-Fresnel principle first described by Lutomirski and Yura[2] for beam propagation in the turbulent atmosphere.

OCT systems use low coherence interferometric techniques to obtain high-resolution reflectivity profiles of a sample. In the OCT system of interest, the cross-sectional imaging is performed by combined axial and lateral scanning of the tissue, while ensuring that the reference arm optical path length in the Michelson interferometer tracks the focal plane optical depth. The focal plane is assumed to coincide with a tissue discontinuity, e.g. the junction between epidermis and dermis in human skin. We have shown[1] that the mean square heterodyne signal current for light reflected at a given depth in the tissue can be written as the product of the mean square heterodyne signal current obtained for homogeneous media, and a heterodyne efficiency factor Ψ. The latter can physically be looked upon as the reduction in the heterodyne signal-to-noise ratio due to the scattering of the tissue.

Assuming diffuse backscattering from the tissue discontinuity and a distance between the focusing lens and the scattering medium, the so-called shower curtain effect (SCE) comes into play. This effect has to do with the position of the scattering medium relative to the focusing lens. The curves in Figure 19 show that inclusion of this effect leads to enhancement of the heterodyne signal.

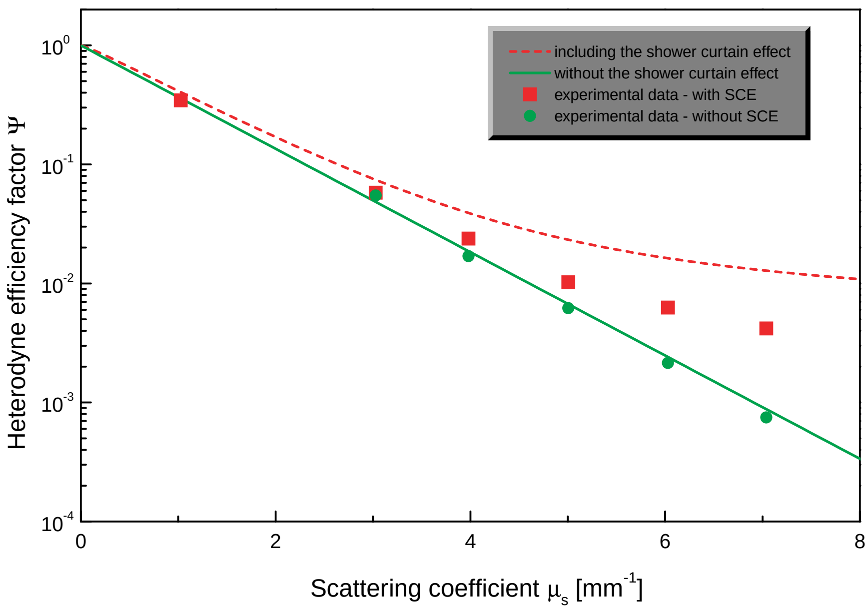
The existence of the shower curtain effect has been verified by a series of experiments that have been carried out using a cuvette with an aqueous suspension of microspheres as the scattering medium. The results are shown in Figure 19.

The theoretical model provides an adequate method of estimating the maximum probing depth in the tissue, and it may be used to optimise the performance of OCT systems.

The present research project is supported financially by the Danish Technical Research Council under grant no. 9601565.

1. L. Thrane, H. T. Yura, S. G. Hanson and P. E. Andersen, "Optical Coherence Tomography of Heterogeneous Tissue: Calculation of the Heterodyne Signal", (CTuE6), pp. 58, CLEO/Europe'98 Technical Digest (1998).

2. R. F. Lutomirski and H. T. Yura, "Propagation of a finite optical beam in an inhomogeneous medium", Appl. Opt. **10**, 1652-1658 (1971).



3.3.2 Photoacoustic imaging systems

P. E. Andersen, S. G. Hanson, L. R. Lindvold, B. Hurup Hansen and S. L. Jacques (Oregon Medical Laser Center, Portland, OR, USA)
E-mails: peter.andersen@risoe.dk, sjacques@ece.ogi.edu

The term *photoacoustic imaging* describes the generation and propagation of a stress wave due to absorption of laser light.[1] Typically, the laser illumination inducing the stress wave is a short pulsed laser source, e.g. a pulsed Nd:YAG laser. Photoacoustic techniques have previously been applied to perform concentration measurements in liquids and gases.[1] Recently, the technique has been used to determine the optical properties, i.e. the mean absorption and the reduced scattering coefficients, of biological tissue.[2] The photoacoustic technique is also suited for imaging purposes and, as an example, the technique has been proposed for three-dimensional imaging of blood vessels in tissue.[3]

The common aspect of photoacoustic systems for imaging and for determining tissue optically is the use of transducers, e.g. piezo-electric transducers,[2] to detect the stress wave. There is, however, a more sensitive method of detecting the stress wave based on an all-optical detection scheme.[4] The scheme is based on a dual-beam common-path interferometer, where light from the two arms in the interferometer is directed towards the object under investigation. A change of path length in one arm due to a change of the object is detected with respect to the other part of the object; hence a differential measurement is made. Several advantages are gained using this scheme: Firstly, it is highly sensitive to even minute path length changes, i.e. small stress wave amplitudes. Secondly, it provides a non-contact procedure which is important from a clinical point of view. Finally, the all-optical detection scheme may be integrated into a single holographic optical element.

Table 1. Comparison between the optical detection scheme and piezoelectric transducers for detecting the acoustic wave. The values for the optical detection scheme have been taken from Jacques *et al.*[5] and the values for the piezoelectric transducer have been adapted from Oraevsky *et al.*[2] [*The true value is probably greater than 6 bar.]

	Optical detection	**Piezoelectric transducer (values adapted from Ref. 2)**
Min. signal [mbar]	10-30	20-40
Linear dynamic range [bar]	0.03 to 33	0.04 to 6*

We have demonstrated[5] that the all-optical detection scheme improves the photoacoustic imaging system in terms of minimum detectable signal and linear dynamic range, see Table 1. We have also demonstrated the feasibility of the all-optical detection scheme for photoacoustic imaging using gel-water phantoms[5] and *in vitro* tissue samples.[6] An example of a raw image profile of an absorbing object buried in tissue is shown in Figure 20. We have observed and explained the occurrence of peaks in the detected signal, see Figure 20, as the irradiating beam was scanned across the edge of the absorber.[6] The explanation involves a change in the geometrical shape of the emanated stress wave combined with scattering of the irradiating laser pulse.[6] Finally, we have observed a broadening in the imaged profile of the absorber dependent on the tissue thickness as the phantom was scanned, see Figure 20. These observations were explained by scattering of the irradiating beam and attenuation of the stress wave in the tissue.[6]

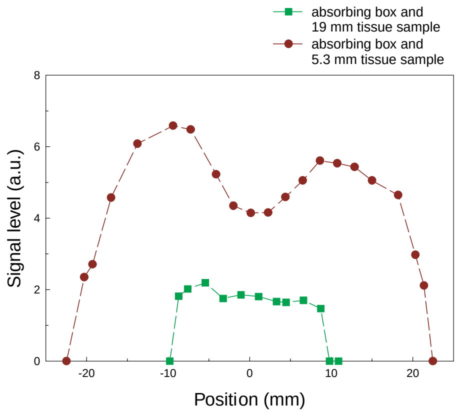


Figure 20. The photoacoustic signal as a function of position using a tissue sample, i.e. chicken breast absorbing box with thickness 1 mm, width 4 mm and length 10 mm. The absorber is scanned across the width. The circles correspond to the tissue sample thickness 5.3 mm, and the squares correspond to the tissue sample thickness 19 mm (Andersen *et al.*).

1. See, e.g., M. W. Sigrist, "Laser generation of acoustic waves in liquids and gases," *J. Appl. Phys.* **60**, R83-R121, 1986.
2. A. A. Oraevsky, S. L. Jacques and F. K. Tittel, "Measurement of tissue optical properties by time-resolved detection of laser-induced transient stress," *Appl. Opt.* **36**, pp. 402-415, 1997.
3. C. G. A. Hoelen, F. F.M. de Mul, R. Pongers and A. Dekker, "Three-dimensional photoacoustic imaging of blood vessels in tissue," *Opt. Lett.* **23**, pp. 648-650, 1998.
4. S. G. Hanson, L. R. Lindvold and B. H. Hansen, "Industrial implementation of diffractive optical elements for nondestructive testing," *SPIE Proc.* **2868**, pp. 216-224, 1996.
5. S. L. Jacques, P. E. Andersen, S. G. Hanson and L. R. Lindvold, "Non-contact detection of laser-induced acoustic waves from buried absorbing objects using a dual-beam common-path interferometer", *SPIE Proc.* **3254**, pp. 307-318, 1998.
6. P.E. Andersen, S. G. Hanson and S. L. Jacques, "Photoacoustic imaging of buried objects using an all-optical detection scheme", to appear in *SPIE Proc.* **3601**, published in 1999.

3.3.3 Homodyning of light scattered in turbid media

S. G. Hanson, I. Popov[*], N. V. Sidorovsky[*], I. L. Veselov[*]
([*]Vavilov Institute, St. Petersburg, Russia
E-mail: steen.hanson@risoe.dk

Non-invasive investigations of blood perfusion in human skin have been performed by use of the laser Doppler technique. A collimated laser beam impinges on the skin and the backscattered radiation is collected by a lens and sent to a detector. Some set-ups rely on having some part of the unperturbed laser beam being mixed with the scattered light. The Doppler shift due to scattering from moving blood cells reveals itself in the temporal response of the detector. Usually, the blood flow in the vessels in the upper skin layer is perpendicular to the scattering wave vector and, thus, a Doppler shift should not be present – at least for singularly scattered radiation. Nevertheless, the detector response is usually anticipated to give a good estimate of the blood flow in the sampled tissue.

To get a better understanding of the statistical behaviour of backscattered light from tissue, we have investigated the second-order correlation functions of the field in the focal plane for a target undergoing in-plane translation and in-plane rotation.[1] In the case of in-plane rotation the speckle velocity in the Fourier plane has been shown to be given by the angular velocity alone.[2] No dependence on the radial position of the measuring volume is encountered!

The above results have been applied for measurement in a turbulent liquid flow depicted in Figure 21. The spectral width has here[3] been shown to be directly related to the velocity gradients in the flow, i.e. the vorticity. Besides, the linear velocity as well as the vortex radius can be probed by the speckle method.

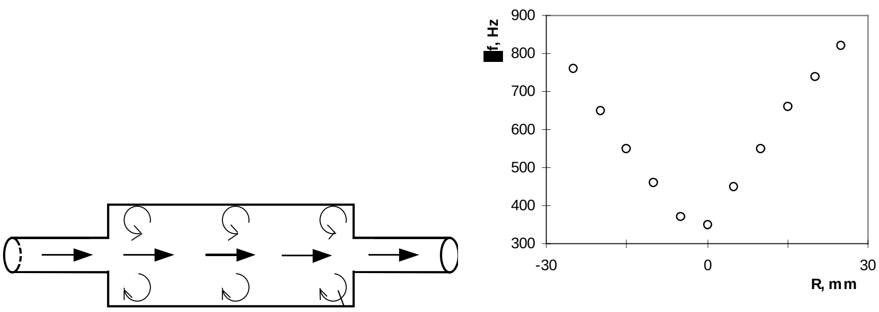


Figure 21. Test tube for doing the measurements (left) and the measured spectral width as a function of the radial position of the point of investigation.

1. I. A. Popov, N. V. Sidorovsky, I. L. Veselov and S. G. Hanson, Statistical properties of focal plane speckle. Opt. Commun. (1998) v. 156, pp. 16-21.
2. I. A. Popov, N. V. Sidorovsky, I. L. Veselov and S. G. Hanson, Measurement of the velocity gradient of a rotating body by means of a speckle method. In: 3. International conference on vibration measurements by laser techniques: Advances and applications. Proceedings, Ancona (IT), 16-19 Jun 1998. Tomasini, E.P. (ed.), (The International Society for Optical Engineering, Bellingham, WA, 1998) (SPIE Proceedings Series, 3411) pp. 328-338
3. I. Popov, N. Sidorovsky, I. Veselov and S. G. Hanson. Vortex monitoring in the turbulent liquid flow by means of a speckle method. Submitted to J. Opt. Soc. of America, **A**.

3.4 Optical Measurement Techniques

3.4.1 Laser anemometry for wind turbines

R. Skov Hansen, L. Lading and S. Frandsen (Wind Energy and Atmospheric Physics Department)
E-mail: rene.skov.hansen@risoe.dk

Wind turbines are becoming an important source of electric energy. The majority of wind turbines are connected to the electric grid. As the number of large turbines increases, the need for reliable local wind measurements for power curve determination and for advanced control becomes more important. We have investigated laser anemometry for this application.

A reference beam system based on backscattered light appears to be the most suitable configuration.[1] It is based on a CO_2 laser and is envisaged to be mounted on the top of the nacelle of the turbine. The requirements to the system are a measuring distance of 150 meters a spatial resolution somewhat smaller than the rotor diameter, which here implies an elongated measuring volume of 22 meters length and a cross section of about 2 cm as well as a transmitter diameter of about 10 cm.

A so-called autodyne configuration is being investigated. This system has a number of advantages for the present application in relation to the well established systems with external light beating. In the autodyne configuration the scattered light is fed back into the laser, thus modulating the laser output at a frequency given by the Doppler shift. The autodyne system is very simple and robust. Our investigations indicate that the performance in terms of signal-to-noise ratio is only slightly inferior to systems with external mixing. However, the optimum laser design is different from the optimum design for external mixing and maximum output power.

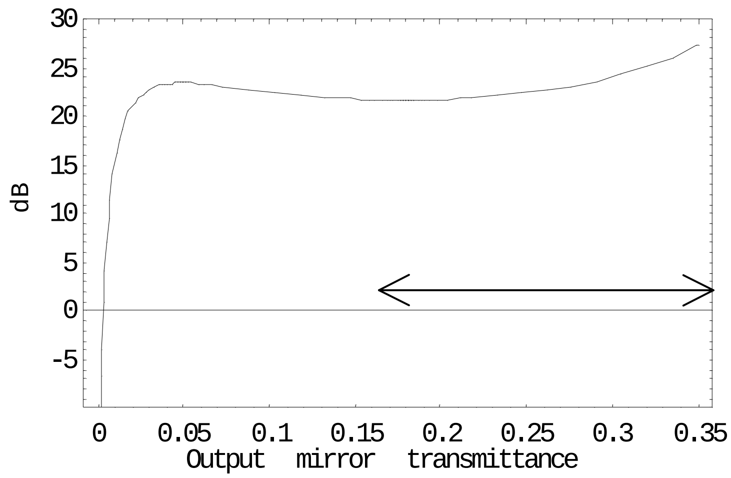


Figure 22. Signal-to-shot noise ratio for an autodyne system versus the output mirror transmittance. It is noted that the optimum output transmittance is different from the transmittance giving the maximum output power.

A waveguide laser is invesigated jointly with the manufacturer (Howden Lasers, UK). A coherence length larger than 200 m has been established. The noise of the laser, which is often a problem in reference beam systems, appears to be below the detector noise.

Current work is on the design of combined reflective and diffractive optics, which can be made very compact, as well as methods for the implementation of an autodyne system.

The EU under the Joule programme supports the project. The participants are Risø and three industrial companies.

1. The traditional CO_2 laser anemometer and a number of applications are e.g. described in: M. Vaughan and P. A. Forrester, “Laser Doppler Velocimetry Applied to the Measurement of Local and Global Wind”, Wind Engineering **13**, 1-15 (1989).

3.4.2 New phase encrypting method and system

J. Glückstad and P. Mogensen
E-mails: jesper.gluckstad@risoe.dk, paul.mogensen@risoe.dk

We have recently developed a phase-coding method for lossless projection of light by using a generalisation of the well-known Zernike phase contrast technique that breaks the small-phase-angle limitation of Zernike’s method.[1] By controlling the spatial average value of input phase modulated light combined with fixed pre-estimated phase retardation at the phase contrast filter, a purely phase based image formation was demonstrated experimentally.[2] Here we will outline an extended version of our method and demonstrate a scheme for decrypting and visualising phase encrypted images.[3]

Our new encryption scheme is based on a simple common-path interferometer configuration as shown in Figure 23. In this case, information in the form of an image is encrypted directly during recording by the use of a combined phase-encoding and phase-scrambling method. This encryption technique does not require the sophisticated, iterative and time-consuming optimisation algorithms associated with some current encryption techniques. In our configuration, pixels are independently encoded by a simple look-up table technique that can easily be performed on a standard personal computer. Optical decryption can subsequently be implemented by a phase-only key or, if desired, a combined phase/amplitude key. An advantage of this new method is that the encrypted information can be recorded and decrypted using either phase values, amplitude values or an arbitrary combination of these. Moreover, since the decryption is performed in a plane adjacent to the encrypted mask or an equivalent plane, the generation of speckles in the decrypted image is very strongly suppressed. Finally, there is no requirement for the positioning of a decrypting mask or spatial light modulator in the optical Fourier plane a fact that effectively dispenses with the need for costly, accurate three-dimensional mechanical positioning within the system.

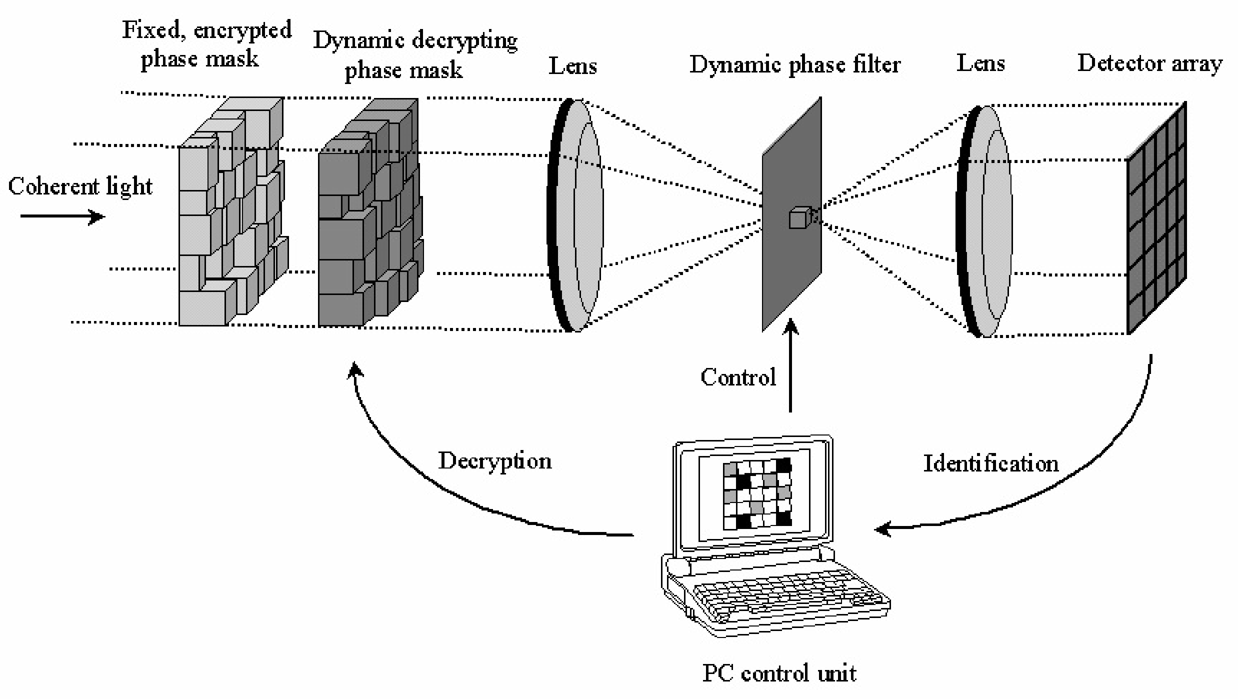


Figure 23. Set-up for decrypting an encrypted phase mask based on a common-path interferometer.

1. J. Glückstad, Opt. Comm. **130**, 225-230 (1996).
2. J. Glückstad, L. Lading, H. Toyoda and T. Hara, Optics Letters **22**, 1373-1375 (1997).
3. J. Glückstad, Patent Application: PA 1998 00869 (Priority date 3 July, 1998).

3.4.3 New chart for optimising common path interferometers

J. Glückstad
E-mail: jesper.gluckstad@risoe.dk

The visibility and irradiance of the measured intensity distribution in common-path interferometers, similar to the configuration shown in 3.4.2, can be modified in many ways. It is, however, a very complicated task to optimise interferometric filtering parameters because fringe visibility and irradiance are highly object dependent.[1] A recently demonstrated chart, illustrated in Figure 24 and originally proposed in Ref. 2, can effectively help in performing the optimisation and in guaranteeing optimum interferometric results.

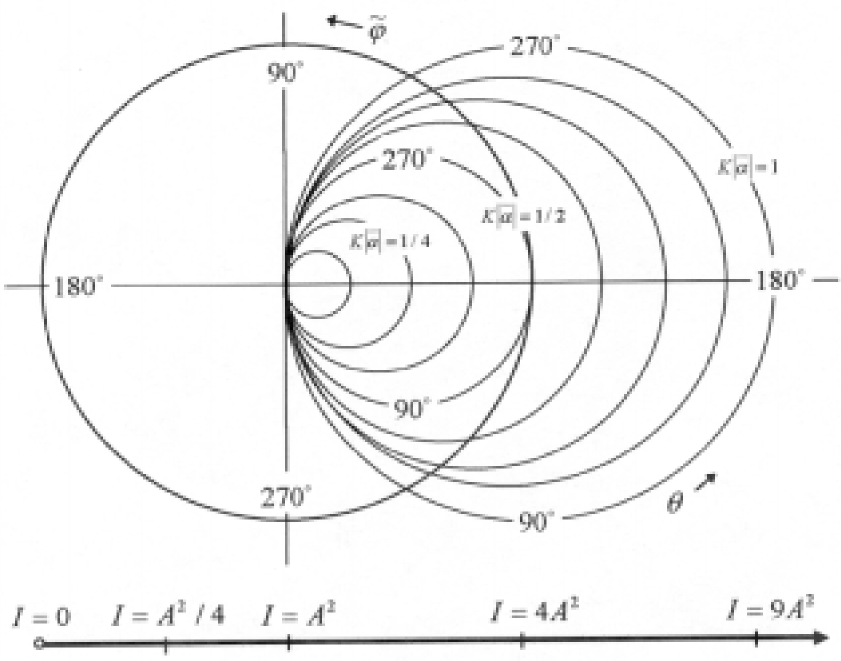


Figure 24. The new chart that can be used for graphical optimization of filter parameters in common-path interferometers.

The chart can be used in the following way: first we identify the relevant $K|\overline{\alpha}|$-circle corresponding to the spatial average value of the input phase object multiplied by a factor that depends on the lateral size of the zero-order centered filtering region; secondly we fix the zero-point of the quadratic intensity scale at the desired location in the chart. There are three filtering parameters to be optimised in the common-path interferometer: (1) damping, *A*, of any defocused light, (2) damping, *B*, of any focused light and (3) introducing a phase shift difference, θ, between the focused and the defocused light. The set of filtering parameters, $\left(A, B, \theta\right)$, is then found by a two-step procedure so that the orientation, θ, and radial scaling factor (given by the combined parameter *B/A*) of the $K|\overline{\alpha}|$-circle in consideration create a shift to the desired location of the fixed intensity zero-point. Keeping the intensity scale fixed around this point and subsequently rotating it we can directly obtain estimates for the phase-intensity mapping at the intersection points between the $\tilde{\phi}$-unity circle (indicating relative phase shift values of the input object) and the intensity scale. Figure 25 illustrates an example chart; a more detailed explanation of this and further examples can also be found in Ref. 2.

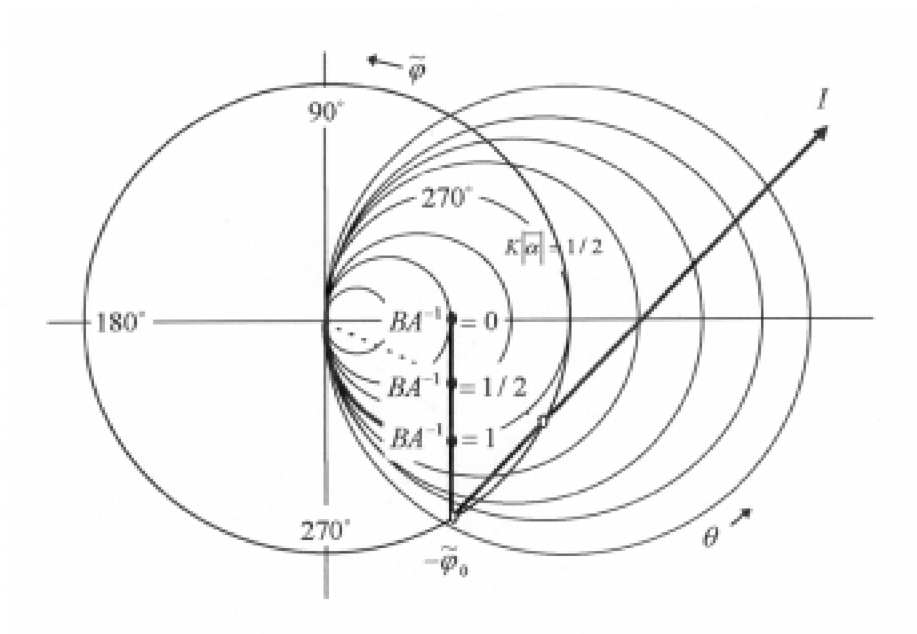


Figure 25. Example showing optimisation of filter parameters (A, B, θ) for $K|\bar{\alpha}| = 1/2$.

1. J. Glückstad, Opt. Comm. **147**, 16-19 (1998).
2. J. Glückstad, Appl. Opt. **37**, 34, 8151-8152 (1998).

3.4.4 Dynamic laser speckle in complex *ABCD* optical systems

H. T. Yura (Electronic Technology Center, The Aerospace Corporation, Los Angeles, California), B. Rose (Ibsen Micro Structures A/S) and S. G. Hanson
E-mail: steen.hanson@risoe.dk

The design and analysis of speckle-based systems for monitoring translations, vibrations, rotations and various other kinds of deformations heavily rely on knowing the dynamics of the speckle pattern. Any deformation will usually cause some sort of deformation in the speckle pattern, usually a space-dependent shift, together with a certain amount of speckle decorrelation. To design a system that is sensitive to only one specific deformation, proper understanding of the dynamics of speckle patterns is essential.

Within the framework of the complex *ABCD* matrix theory,[1] an exact analytical expression has been derived for the space-time lagged photocurrent covariance that is valid for arbitrary (complex) *ABCD* optical systems, i.e. systems that include Gaussian shaped apertures, and partially developed speckle.[2]

General expressions have been obtained for the mean spot size, the mean speckle size and the temporal coherence length. In addition, a general description of both speckle boiling and speckle translation in an arbitrary observation plane is given. Included in the analysis is the effect of a finite wavefront-curvature radius for the Gaussian shaped laser beam illumination of the target. The effects of diffraction and wavefront-curvature radius are discussed for imaging systems as well as for a Fourier transform system. It has been shown that whereas diffraction affects the speckle dynamics in both cases, a finite wavefront curvature only affects the speckle dynamics in the Fourier transform system. Furthermore, the effect of finite detector apertures is considered, where the effects of speckle averaging are included and discussed. In contrast to previous work, the obtained analytical results are expressed in a relatively compact form, yet contain all diffraction effects and apply to an arbitrary *ABCD* optical system.

With analytical expressions for time-lagged intensity- and field correlations we have obtained a strong tool in the design of speckle-based optical measurement systems.

1. H. T. Yura and S. G. Hanson, "Optical beam wave propagation through complex optical systems," J. Opt. Soc. Am. A **4**, 1931-1948 (1987).
2. H. T. Yura, B. Rose, S. G. Hanson, Dynamic laser speckle in complex *ABCD* optical systems. J. Opt. Soc. Am. A (1998) **15**, pp. 1160-1166.

3.4.5 Laser speckle angular displacement sensor: a theoretical and experimental study

S. Hanson, R. Skov Hansen, H. Imam, H. T. Yura (Electronic Technology Center, The Aerospace Corporation, Los Angeles, California) and B. Rose (Ibsen Micro Structures A/S)
E-mail: steen.hanson@risoe.dk

A novel method for measurement of angular displacement for arbitrarily shaped objects is presented, where the angular displacement is perpendicular to the optical axis. The method is based on Fourier transforming the scattered field from a single laser beam that illuminates the target. The angular distribution of the light field at the target is linearly mapped on a linear image sensor placed in the Fourier plane. Measuring this displacement facilitates the determination of the angular displacement of the target. It is demonstrated both theoretically and experimentally that the angular displacement sensor is insensitive to object shape and target distance if the linear image sensor is placed in the Fourier plane. A straightforward procedure to position the image sensor in the Fourier plane is presented. Any transverse or longitudinal movement of the target will give rise to partial speckle decorrelation, but will not affect the angular measurement. Furthermore, any change in the illuminating wavelength will not affect the angular measurements. Theoretically and experimentally it is shown that the method has a resolution of 0.3 mdeg (≈ 5 μrad) for small angular displacements and methods for further improvement in resolution are discussed. No special surface treatment is required for surfaces giving rise to fully developed speckle. The effect of partially developed speckle is discussed both theoretically and experimentally.[1]

Based on the method of complex ray matrices[2] an analytical expression for the time-lagged crosscovariance has been obtained. Figure 26 depicts the measured angular displacement and the Gaussian width of the crosscovariance function as a function of the applied rotation of a matte aluminum target with a diameter of 30 mm.

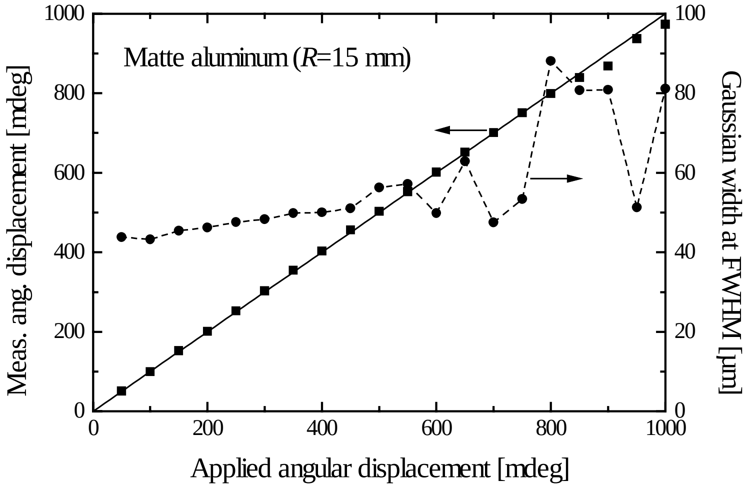


Figure 26. Measured angular displacements and Gaussian widths of the resulting crosscovariances versus applied angular displacement for a matte aluminum shaft (fully developed speckle field).

1. B. Rose, H. Imam, S. G. Hanson, H. T. Yura, R. S. Hansen, Laser-speckle angular-displacement sensor: Theoretical and experimental study. Appl. Opt. (1998) **37** pp. 2119-2129.

2. H.T. Yura and S.G. Hanson, "Optical beam propagation through complex optical systems", J. Opt. Soc. Am. A **4**, 1931-1948 (1987).

3.4.6 Non-contact laser speckle sensor for measuring one- and two-dimensional angular displacement

S. Hanson, H. Imam and B. Rose (Ibsen Micro Structures A/S)
E-mail: steen.hanson@risoe.dk

A method for measurement of angular displacement in one or two dimensions for arbitrarily shaped objects is presented. The method is based on Fourier transforming the scattered field from a single laser beam that illuminates the target. The angular distribution of the light field at the target is linearly mapped onto an array image sensor placed in the Fourier plane. Measuring this displacement facilitates the determination of the angular displacement. It is demonstrated both theoretically and experimentally that the angular displacement sensor is insensitive to object shape, target distance and any longitudinal or transversal movement of the target if the image sensor is placed in the Fourier plane. A straightforward procedure to place the image sensor in the Fourier plane is presented here. It is shown theoretically and experimentally that the method has a resolution of 0.3 mdeg for small angular displacements, and methods for further improvement in resolution are discussed. No special surface treatment is required for surfaces having irregularities of the order of or larger than the wavelength of the incident light. It is shown that this is the case for most surfaces of practical interest. Furthermore, it is shown that robust, non-contact optical systems for industrial applications can be produced.[1]

Figure 27 shows the two-dimensional crosscovariance between the speckle pattern before and after an angular deflection of the entire object. The position of maximum crosscovariance directly gives the two-dimensional angular deflection experienced by the target.

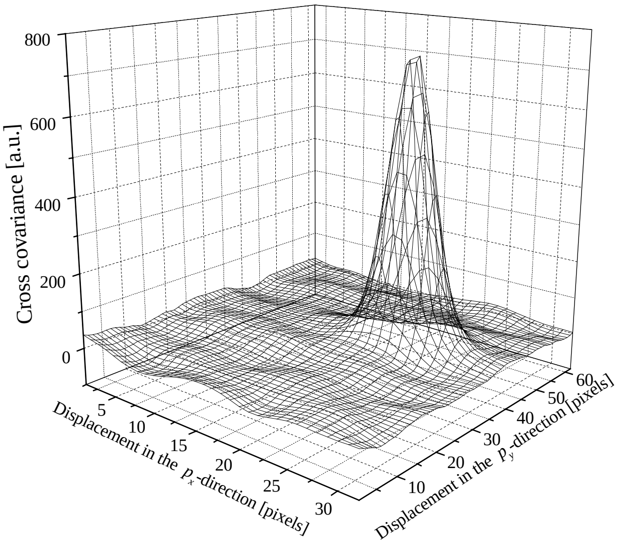


Figure 27. Resulting 2D crosscovariance for an angular displacement θ of 200 mdeg. The measurement was performed on a matte aluminum shaft with a radius R of 15 mm.

[1]. B. Rose, H. Imam, S. G. Hanson, Non-contact laser speckle sensor for measuring one- and two-dimensional angular displacement. J. Opt. (1998) **29** pp. 115-120.

3.4.7 A laser speckle sensor to measure the distribution of static torsion angles of twisted targets

H. Imam, S. Hanson, H. T. Yura (Electronic Technology Center, The Aerospace Corporation, Los Angeles, California) and B. Rose (Ibsen Micro Structures A/S)
E-mail: husain.imam@risoe.dk

A novel method for measuring the distribution of static torsion angles of twisted targets is presented. The method is based on Fourier transforming the scattered field in the direction perpendicular to the twist axis, while performing an imaging operation in the direction parallel to the axis, cf. Figure 28. The Fourier transform serves to map the angular distribution of the scattered light field at the target into a linear displacement on a two-dimensional array image sensor placed in the Fourier plane. Measuring this displacement facilitates the determination of the angular displacement of the target. A cylindrical lens serves to image the closely spaced lateral positions of the target along the twist axis onto corresponding lines of the two-dimensional image sensor. Thus, every single line of the image sensor measures the torsion angle of the corresponding surface position along the twist axis of the target. Experimentally, we measure the distribution of torsion angles in both uniform and non-uniform deformation zones. It is demonstrated theoretically as well as experimentally that the measurements are insensitive to object shape and target distance if the image sensor is placed exactly in the Fourier plane. A straightforward procedure to position the image sensor in the Fourier plane is presented. Furthermore, any transverse movement of the target will give rise to partial speckle decorrelation, but it will not affect the angular measurement. The method is insensitive to any wavelength change of the illuminating light source. No special surface treatment is required for surfaces giving rise to fully developed speckle.[1]

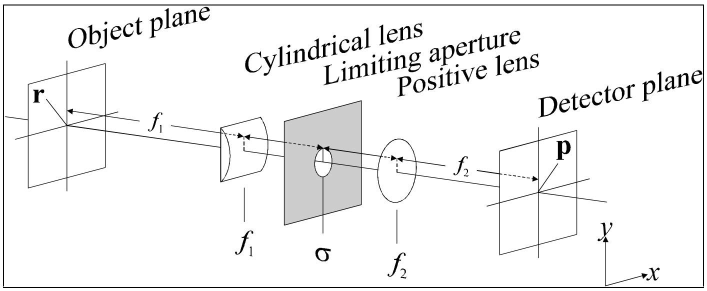


Figure 28. Combined Fourier transform and imaging system (receiver part of a torsion angle sensor) with a Gaussian shaped lens aperture.

Figure 29 shows an experiment carried out with a steel beam positioned along the y-axis. Applying a torsional force to the top of a steel beam will give rise to an axial distribution of angular deflections of the object. A single measurement performed with two recordings (before and after the torque is applied) provides a record of the distribution of the angular twist.

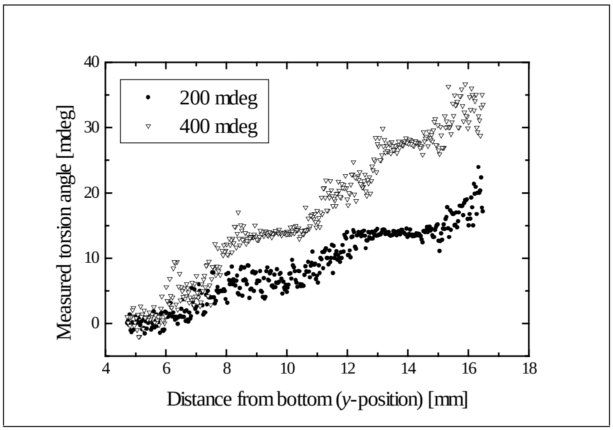


Figure 29. Measured torsion angles versus lateral position for various applied twists. The measurements were performed on a matte steel plate (fully developed speckle field) where non-uniform deformation was assumed.

[1]. B. Rose, H. Imam, S. G. Hanson, H. T. Yura, A laser speckle sensor to measure the distribution of static torsion angles of twisted targets. Meas. Sci. Technol. (1998) **9** pp. 42-49.

3.4.8 Speckle dynamics from rotating diffuse objects in complex *ABCD* optical systems

S. Hanson, H. T. Yura (Electronic Technology Center, The Aerospace Corporation, Los Angeles, California) and B. Rose (Ibsen Micro Structures A/S)
E-mail: steen.hanson@risoe.dk

The characteristics of a fully developed speckle pattern resulting from in-plane rotation of a diffuse object observed in an arbitrary observation plane are derived and discussed. Here we consider off-axis illumination, which is in contrast to previous work, where the illuminating beam was assumed to be parallel to the axis of rotation. The spatiotemporal characteristics of the observed pattern are interpreted in terms of speckle boiling, rotation and translation. For off-axis illumination it is shown theoretically and experimentally that for Fourier transform optical systems in-plane rotation causes the speckles to translate in a direction perpendicular to the direction of the surface motion, whereas for an imaging system the translation is parallel to the direction of the surface motion. Based on this, we discuss a novel method, which is independent of both the optical wavelength and the position of the laser spot on the object, for determining either the angular velocity or the corresponding in-plane displacement of the target object.[1]

Figure 30 shows the set-up with the speckles being detected in the origin of the coordinate system after passing an optical system, which is not depicted.

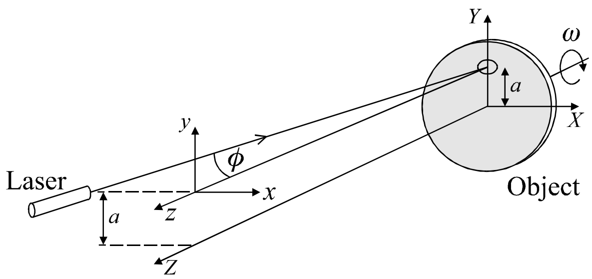


Figure 30. Off-axis illumination at position a along the *y*-axis of a flat diffuse target rotating about the *z*-axis.

The direction of movement of the speckles after having passed an optical system is depicted in Figure 31. The speckles are seen to move perpendicular to the direction of the object surface translation in the Fourier plane – in contradiction with common sense - whereas the speckles will move opposite to the surface movement in the image plane.

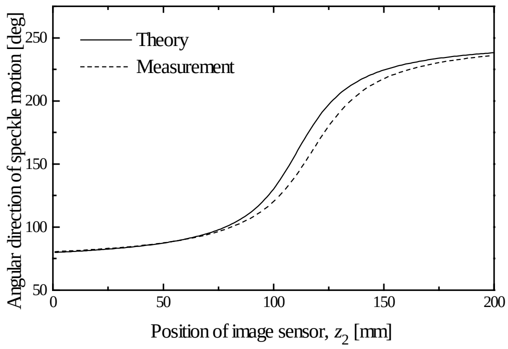


Figure 31. Angular direction of speckle motion with respect to the p_x-axis versus the position of the image sensor.

1. H. T. Yura, B. Rose, S. G. Hanson, Speckle dynamics from in-plane rotating diffuse objects in complex ABCD optical systems. J. Opt. Soc. Am. A (1998) **15** pp. 1167-1173.

3.4.9 Optical flow sensor

C. Dam-Hansen, J. Stubager, L. Lindvold, L. Lading and H. K. Brümmer* (* Kamstrup Energi, Industrivej 28, 8660 Skanderborg)*
E-mail: carsten.dam-hansen@risoe.dk

Sensors based on optical measurement technology are attractive for industrial use due to their non-invasive nature and their potentially high accuracy and dynamic range. It is, however, necessary to construct more compact and robust systems if these are to find a larger and more widespread use in industry. They must require a minimum of alignment, and low-cost large-scale production must be possible.

In this work optical flow sensors necessary for energy meters in district heating systems are being developed. The concept used is a backscattering laser time-of-flight system, where the total optical system is implemented in a single holographic optical element.[1] With this a compact, easily aligned and robust system is achieved, a laboratory implementation of which is shown in Figure 32.

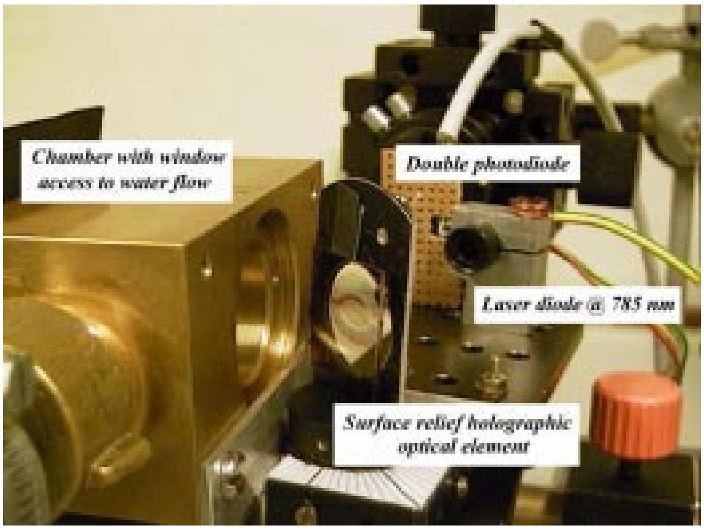


Figure 32. Implementation of a laser time-of-flight flow sensor, using a laser diode, a holographic optical element and a twin Si-PIN photodiode.

In order to make a low-cost, large-scale production of the optical system feasible, the holographic optical element is implemented as a surface relief hologram.[2] This can be replicated by injection moulding in polymer materials, a technology known from the fabrication of compact discs. High diffraction efficiency has been achieved in surface relief holograms with a high depth-to-period ratio and a large diffraction angle of around 90°, which further enables a high DC-rejection ratio of the system. An interferometric writing facility based on a HeCd-laser has been constructed for writing these elements in photoresist. Near-diffraction limited performance has been obtained with an aberration balancing scheme.

Development and optimisation of the new production method of injection moulding of the optical element are the subjects of the future work.

1. S. G. Hanson, L. R. Lindvold and L. Lading, “A surface velocimeter based on a holographic optical element and semiconductor components”, Meas. Sci. Technol. 69-78 (1996).
2. C. Dam-Hansen, J. Stubager, L. R. Lindvold and L. Lading, “Compact and low-cost holographic optical front end for an industrial laser time-of-flight flowsensor”, OPTO’98, Optische Sensorik Meβtechnik & Elektronik Proc., 7-10 (Erfurt, Germany, May 1998).

3.4.10 FreePen

S. Hanson, R. Skov Hansen, B. Hurup Hansen, E. Eilertsen and J. Thorsen
E-mail: steen.hanson@risoe.dk

An alternative to the conventional PC mouse has been introduced by the Danish company Kanitech A/S.[1] The input device is in the form of a pen, see Figure 33, named *FreePen*. Tracking of the rotation of the ball is achieved by a specially designed laser-based system with four detectors that monitor the reflected speckle pattern. A dedicated ASIC has been designed to perform the necessary decoding of the four detector signals to obtain the angular deflection of the ball in two dimensions.

A second ASIC facilitates the RF-transmission of the signals from the pen to the PC, where a receiver inserted in the serial port provides the information necessary for the “mouse”-driver to control the cursor.

Figure 33. *FreePen*: The optical system for tracking the rotation of the ball is placed below the three buttons at a distance of 17 mm. The optical head including laser and detectors has a diameter of 6.8 mm.

1. Kanitech A/S, Petersbjerggård 2, 6000 Kolding.

3.5 Knowledge-based Processing

3.5.1 Enhanced n-tuple based artificial neural networks

T. M. Jørgensen and C. Linneberg
E-mail: thomas.martini@risoe.dk

Knowledge discovery and data mining tools are methods for extracting information from large databases or data sets. The applied techniques span from linear discrimination techniques over decision trees to artificial neural networks. Applications of such techniques are broad and include credit scoring and fraud detection for the banking sector, finding the importance of process parameters for production plants, and interpretation of large data sets including biomedical data. It is important to develop data extracting methods that are relatively fast, robust and valid approaches over a large range of different applications. The so-called n-tuple classification device[1,2] has appealing characteristics such as fast training and recall times, but although it is competitive on many classification tasks the standard implementation has not proved to be a generally applicable tool. At Risø we have been working on enhancing the n-tuple classifier without destroying the basic advantages of the architecture. The benefit of the enhanced n-tuple nets has been verified by thorough studies on reference databases used for benchmarking (see Figure 1). As a result of the development two patent applications have been filed.

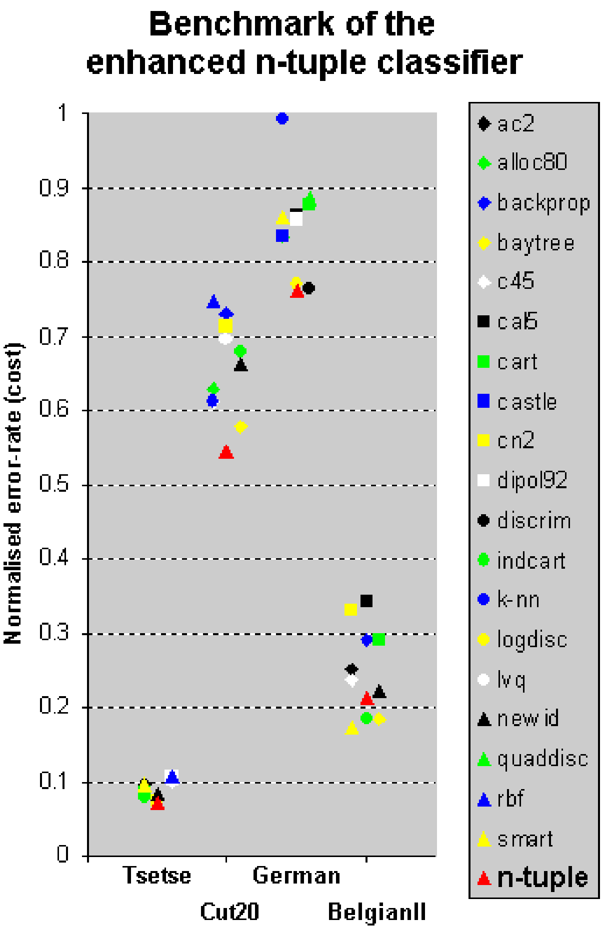


Figure 34. Comparison of an enhanced n-tuple net with the top ten algorithms as found in the StatLog project[4] for four different classification tasks (Tsetse Fly distribution, German credit, Cut 20 - segmenting of letters, BelgianII - stability in power systems). The normalised error rate should be as small as possible.

One possible use of neural networks technology is within the area of intelligent character recognition (ICR), where the goal is to make machines read handwritten text. ICR involves a segmentation as well as a classification step but, generally, the two steps cannot be performed independently. The classification step also has to act as feedback on the segmentation. Besides, discriminating between the possible characters the classification module therefore also has to recognise non-significant characters in order to guide the segmentation procedure. We have performed initial investigations of such an interaction scheme making use of the enhanced n-tuple classifier in combination with prior knowledge for segmenting overlapping and “touching” numerals.[3]

1. T. M. Jørgensen, "Optimisation of RAM nets using inhibition between classes". In: *RAM-Based Neural Networks*, ed. J. Austin. Singapore: World Scientific, 1998, pp. 123-129.
2. C. Linneberg, A.W. Andersen, T.M. Jørgensen and S. S. Christensen, "Detecting danger labels with RAM based neural networks". In: *RAM-Based Neural Networks*, ed. J. Austin. Singapore: World Scientific, 1998, pp. 205-212.
3. T. M. Jørgensen and C. Linneberg, "Segmentation-classification interaction for intelligent character recognition (ICR)". In: Annual meeting of the Danish Optical Society (DOPS), Aalborg (DK), 19-20 Nov 1998. (Aalborg Universitet, Aalborg, 1998) p. 22.
4. D. Michie, D.J. Spiegelhalter and C. C Taylor (eds.), “Machine Learning, Neural and Statistical Classification”, Prentice-Hall, 1994.

3.5.2 Industrial Ph.D. project on data-driven classification models based on RAM-based neural nets

C. Linneberg, T. M. Jørgensen and C. Liisberg (Intellix A/S)
E-mail: christian.linneberg@risoe.dk

Christian Linneberg has initiated an industrial Ph.D project at Intellix A/S, which is a company specialised in developing expert systems and decision support products based on RAM based neural networks (also denoted n-tuple neural nets). Agnar Höskuldsson and Bjarne Ersbøll from the Technical University of Denmark and Thomas Martini Jørgensen from Risø are supervisors on the project.

Intellix' main goal of the project is to ensure continuous development of the core algorithms of the learning based kernel within their software products. The industrial Ph.D. project is also an essential link in the collaboration between Risø and Intellix.

A key issue with data-driven models is to control the trade-off between the model sensitivity and the model fit. One of the goals of the project is to investigate the possibility of incorporating active learning principles that use information from the learned model to identify parts of the example space that should be further addressed. The so-called hybrid models, which combine different classification and regression approaches, are often beneficial. The project will explore the potential of fusing linear sub-space methods such as partial least square (PLS) techniques and neural networks. With such a combination the PLS-technique is used for variable selection and encoding for the neural network.

Although RAM-based learning schemes can be trained without intensive optimisation cycles, it is expected to be beneficial to incorporate optimisation schemes for choosing the weight connections between the network and the input data. The project will address the potential of using genetic algorithms for this task.

The project is closely integrated with Risø’s research effort in RAM-based neural networks.[1]

1. C. Linneberg and T.M. Jørgensen, Cross-validation techniques for n-tuple based neural networks, Proceedings of VI-DYNN'98, Stockholm, 1998.

4. Plasma and Fluid Dynamics

4.1 Introduction

J. P. Lynov
E-mail: jens-peter.lynov@risoe.dk

A unifying theme for the research performed in the Plasma and Fluid Dynamics programme is the dynamical behaviour of continuum systems. The continuum systems under investigation cover fluids, plasmas and optical media. Both linear and nonlinear problems are addressed in a combination of experimental, numerical and theoretical studies. Scientific computing in a broad sense plays a major part in these investigations and includes theoretical modelling of the physical phenomena, development of accurate and efficient numerical algorithms, visualisation and animation of the computed results and last, but not least, validation of the numerical results by detailed comparisons with carefully conducted experiments.

Due to the broad approach to the problems, the various projects are scientifically overlapping, not only inside the programme, but to a large extent also with projects in the rest of the department as well as in other departments at Risø. This overlap is considered a strength since it gives rise to considerable synergy between different parts of the laboratory.

The goals of the scientific studies are two-fold: on the one hand the investigations aim at achieving a deeper understanding of the fundamental behaviour of complex physical and technical systems; on the other hand the acquired knowledge is sought utilised in the definition and design of solutions to specific technological problems. In the following three subsections, descriptions of the scientific projects carried out during 1998 are collected under the headings: *Fusion plasma physics*, *Fluid dynamics* and *Optics*.

4.2 Fusion Plasma Physics

4.2.1 Theoretical analysis of two-point collective scattering correlation functions using a drift wave model

N. Heinemeier and M. Saffman
E-mail: mark.saffman@risoe.dk

Drift waves are believed to be responsible for a large part of the loss of particles and energy in fusion experiments. Because of this, the measurement of these waves is important. Collective light scattering is one of the methods used, and a two-point collective light scattering configuration is currently being used at the W7-AS experiment at IPP-Garching for this purpose. The basic idea in the two-point scheme is this: a small-scale structure is registered at one point using a collective light scattering system. The structure then moves with the flow to the measurement point of another similar system. Using the crosscorrelation of the photocurrents from the two systems to recognise the structure, the time-of-flight can be found. This is then used to estimate the group velocity of the large-scale structures in the flow.

We have calculated[1,2] the expected crosscorrelation function, using a drift wave dispersion model. This must be regarded as only a crude model, since many types of wave phenomena may contribute to experimentally observed signals. The calculations result in a closed expression for the correlation functions. The results, such as those shown in Figure 35, confirm the possibility of observing correlations due to drift waves. Furthermore, they provide quantitative estimates of the reduction in the correlation due to viscous dissipation and shear.

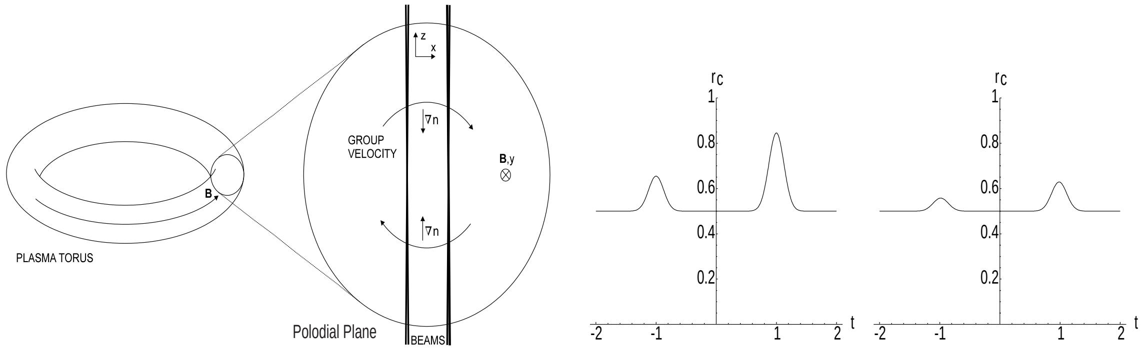


Figure 35. The geometry of drift wave measurements in the W7-AS stellarator (left). The beams all lie in the poloidal plane and are aligned along the x-direction. The main magnetic field is along z. This set-up is sensitive to drift waves propagating in the y-direction. The measurement volume is so elongated in the beam direction that group velocities in both the positive and the negative y-directions contribute to the signal. The crosscorrelation coefficients for a typical measurement system and plasma parameters are shown in the next two frames. The time is normalised to the time-of-flight. The centre picture shows the result assuming no viscous dissipation, and the right-hand picture shows the result for finite dissipation.

1. N. P. Heinemeier, “Flow speed measurement using two-point collective light scattering”, M.Sc. Thesis, Risø report Risø-R-1064 (1998).
2. N. Heinemeier and M. Saffman, “Theoretical analysis of two-point collective scattering correlation functions using a drift wave model”, International Conference on Plasma Physics, paper F071 (Prague, June, 1998).

4.2.2 Relationship between confinement and core plasma fluctuations in the W7-AS stellarator

S. Zoletnik, M. Saffman, W. Svendsen, M. Endler (Institut für Plasmaphysik, Garching, Germany), N. P. Basse and G. Kocsis*(*CAT_SCIENCE, Budapest, Hungary)*
E-mail: mark.saffman@risoe.dk

Core plasma electron density fluctuations have been measured with a two-channel CO_2 laser scattering diagnostic at the W7-AS stellarator experiment. The analysing wave number was equal for the two channels and can be varied in the range 10-130 cm^{-1}. Both channels integrate the fluctuations along vertical paths which can be offset relative to each other by a few centimeters either poloidally or toroidally.

The typical frequency spectra of the scattered signals show a turbulent character and extend to a few hundred kHz in ECRH and to 1 MHz in NBI heated discharges as shown in Figure 36. The presence of global modes in the plasma (e.g. Global Alfven Eigenmodes - GAE) causes the appearance of sharp lines in the frequency spectrum although these modes have a much longer poloidal wavelength than is directly detected by the CO_2 laser scattering diagnostic. Their appearance is possibly caused by modulation of the microturbulence level by the rotating mode and makes it possible for us to gain some information on the dependency of the local fluctuation amplitude on the plasma parameters.

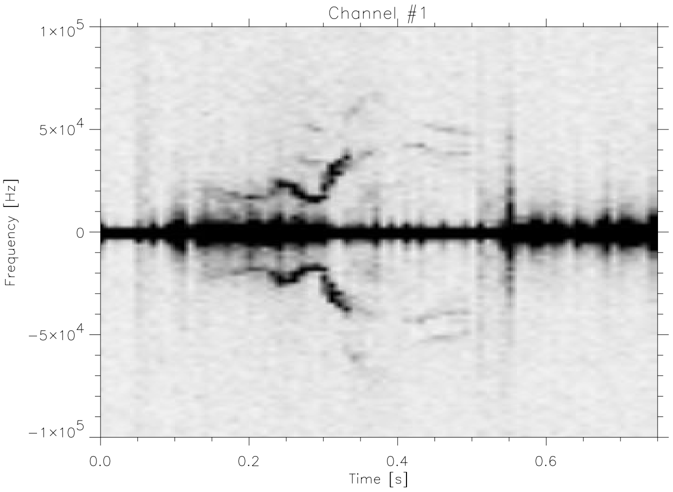


Figure 36. Time evolution of the power spectrum of the scattering signal in the presence of GAE activity. The GAE modes are the sharp lines at 20-40 kHz.

Changes in frequency spectra, crosscorrelation and scattering power were analysed at different types of confinement transitions: changes in response to magnetic configuration alterations, enhancement of confinement in high-density NBI discharges (H-NBI) and degradation of the confinement at the upper density limit of W7-AS. To gain additional information on the phenomena involved, the CO_2 laser scattering data are compared with fluctuation data obtained from other diagnostics: microwave scattering, Mirnov coils, Li-beam BES electron density fluctuation diagnostic, X-ray tomography and others. The results show pronounced changes both in frequency spectra and scattered power at confinement changes. Confinement degradations are usually accompanied by an increase in the scattered power.

Ongoing work is aimed at further characterising the distribution of turbulence in the core and edge regions of W7-AS under different heating scenarios.

4.2.3 Spectral time series analysis of plasma turbulence

T. Jessen and P. K. Michelsen
E-mail: thomas.jessen@risoe.dk

A hybrid Doppler/time-of-flight laser anemometer has been developed at Risø and is now in operation at the Wendelstein 7-AS stellarator.[1] The apparatus yields time series of the fluctuating plasma density in neighbouring measurement volumes, from which a subsequent correlation analysis allows extraction of density fluctuation velocities.

The associated data analysis and interpretation has resulted in the development and implementation of a suite of new spectral data analysis techniques.

We have solved the Hasegawa-Mima plasma drift wave equation using a high resolution Fourier-Galerkin method to obtain realistic model data for the analysis techniques. In particular, the effect of various experimental configurations can be isolated and investigated, and data interpretation can profitably be compared with the full field information provided by the simulations.

The Hasegawa-Mima model was solved for various scenarios, ranging from nearly linear conditions dominated by uncorrelated linear drift waves to strong turbulence dominated by spectral cascades, vortex merging and emergence of large coherent structures. The profound change in dynamics was found to imprint important signatures in sampled two-point time series. Spectral time series analysis is found to be a powerful and reliable tool to extract these signatures and, hence, illuminate key features of the underlying dynamics.

From the model simulation two time series of the plasma density at two probe positions are obtained. A preanalysis step involves decomposing each series into an ensemble of elementary series, filtered by a window weight function that minimises amplitude leakage. The data are subsequently fast Fourier transformed to frequency space, where the actual analysis is performed.

Autocorrelations are computed to estimate decorrelation times, while the crosscorrelation yields the time-of-flight of density fluctuations between the two probes and, as a result, estimates their typical propagation speed. A subtle correlation analysis is based on the crossseries coherence. Retaining only coherent frequencies, the phase velocity of individual frequency components can be computed and the dispersion relation recreated. From power spectra, the wave number spectrum can subsequently be resolved. Thus, two-probe measurements allow us to resolve fluctuations both temporally and spatially and to determine their relation.

Nonlinear wave dynamics is identified in the bispectrum that measures the wave triplet interactions. The bispectrum is found to be a useful indicator of nonlinear effects, capable of identifying important features such as three-wave interactions and spectral cascading.

The outlined data treatment techniques are currently being employed in the analysis of W7-AS fluctuation data. Ongoing research aims at enlarging the range of data analysis tools and enhancing their applicability by studying yet more realistic plasma models.

1. W. Svendsen *et al.*, "Collective scattering turbulence measurements at the W7-AS stellarator," Optics and Fluid Dynamics Department Annual Progress Report for 1997. Risø-R-1015.

4.2.4 Phase contrast methods applied to plasma diagnostics

J. Glückstad, L. Lading and P. C. Mogensen
E-mail: lars.lading@risoe.dk

Interaction between electromagnetic radiation and plasma provides one of the few methods by which direct information about the state of plasma can be obtained. Radiation from a CO_2 laser has the advantage of being readily available with high power and very good coherence properties. The frequency is far above the plasma frequency implying a relatively simple interaction, and the wavelength is so long that probing of collective phenomena is possible. Since the optical wavelength is shorter than the Debye length, forwardscattering is necessary.

From an optical point of view the plasma behaves as a weak dynamic phase object. Visualising spatial phase structures can in principle be performed with a Zernike phase-contrast method. However, for dynamic measurements it turns out that the modelling usually applied is inadequate: the dynamic information may not be present in the detector outputs. Let the impact of the plasma be described by a *transmission function*, $t(x,y)$, which is a pure phase object (no absorption); thus $t(x,y) = e^{i\varphi(x,y)}$, which is often approximated by

$$t(x,y) = e^{i\varphi(x,y)} \cong 1 + i\varphi(x,y)\,.$$

The detector responds to the intensity, i.e. the absolute square of the electric field. If φ is small, then φ^2 is negligible. The Zernike principle implies that the reference (the directly transmitted beam indicated with a "1") is phase shifted with a small retardation filter with little effect on the diffracted light (φ) so that an interference term between signal and reference appears. However, a complete analysis based on a system indicated in Figure 37 shows that the interference term will vanish. We have developed a new and improved model[1,2] and have investigated schemes where a spatial coding of the transmitted light in conjunction with a generalised phase contrast filter will make it possible to detect the dynamics of spatial structures.[3]

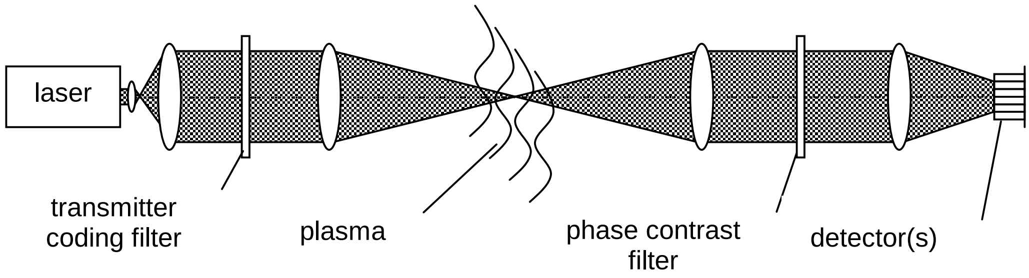


Figure 37. A general configuration with a spatial transmitter filter and a phase contrast filter in the receiver.

1. J. Glückstad, L. Lading, H. Toyoda and T. Hara, Lossless light projection. Opt. Lett. (1997) **22**, pp. 1373-1375.
2. J. Glückstad, Graphic method for analyzing common path interferometers. Appl. Opt. (1998) **37**, pp. 8151-8152.
3. J. Glückstad, L. Lading, Optimising visibility and irradiance in common path interferometers. In: Proceedings of international conference on optical technology and image processing in fluid, thermal, and combustionn flow. VSJ-SPIE '98, Yokohama (JP), 6-10 Dec 1998. (Visualization Society of Japan, Yokohama, 1998) AB 010.

4.2.5 Vortex merging as a spectral cascade mechanism in 2D turbulence

T. Jessen and P. K. Michelsen
E-mail: thomas.jessen@risoe.dk

A hallmark of two-dimensional turbulence is the inverse cascade of energy to large scales of motion, facilitated by the merging of like-signed vortices.

This process has been investigated by studying the vortex dynamics of various dipole and monopole collision events and by numerically solving the two-dimensional inviscid Navier-Stokes (or Euler) equations. A spectral Fourier-Galerkin method with cyclic boundary conditions was employed at high resolution (a minimum of 512^2 modes).

In the absence of viscosity, vortex merging is prohibited, but a similar phenomenon can be observed. Like-signed vortices can spiral into one another effectively forming a single vortex.

An example of a dipole collision is shown in Figure 38. Two stable Lamb dipoles were released on a collision course. Depending on the dipole alignment - ranging from head-on collision to near misses - the dipoles can undergo exchange scattering or pure scattering, i.e., the dipoles persist but may change partners by pairing up with the oppositely signed vortex of the other dipole. This is an indication of the robustness of dipole structures.

For the particular initial alignment shown in Figure 38, a point vortex model predicts a bound, but unstable, state. Our simulation indicates the merging of two like-signed vortices, surrounded by two satellite vortices in an unstable tripole formation. Careful inspection reveals that the vortices do not actually merge, but rather form interlocking spirals with extremely delicate vortex filaments.

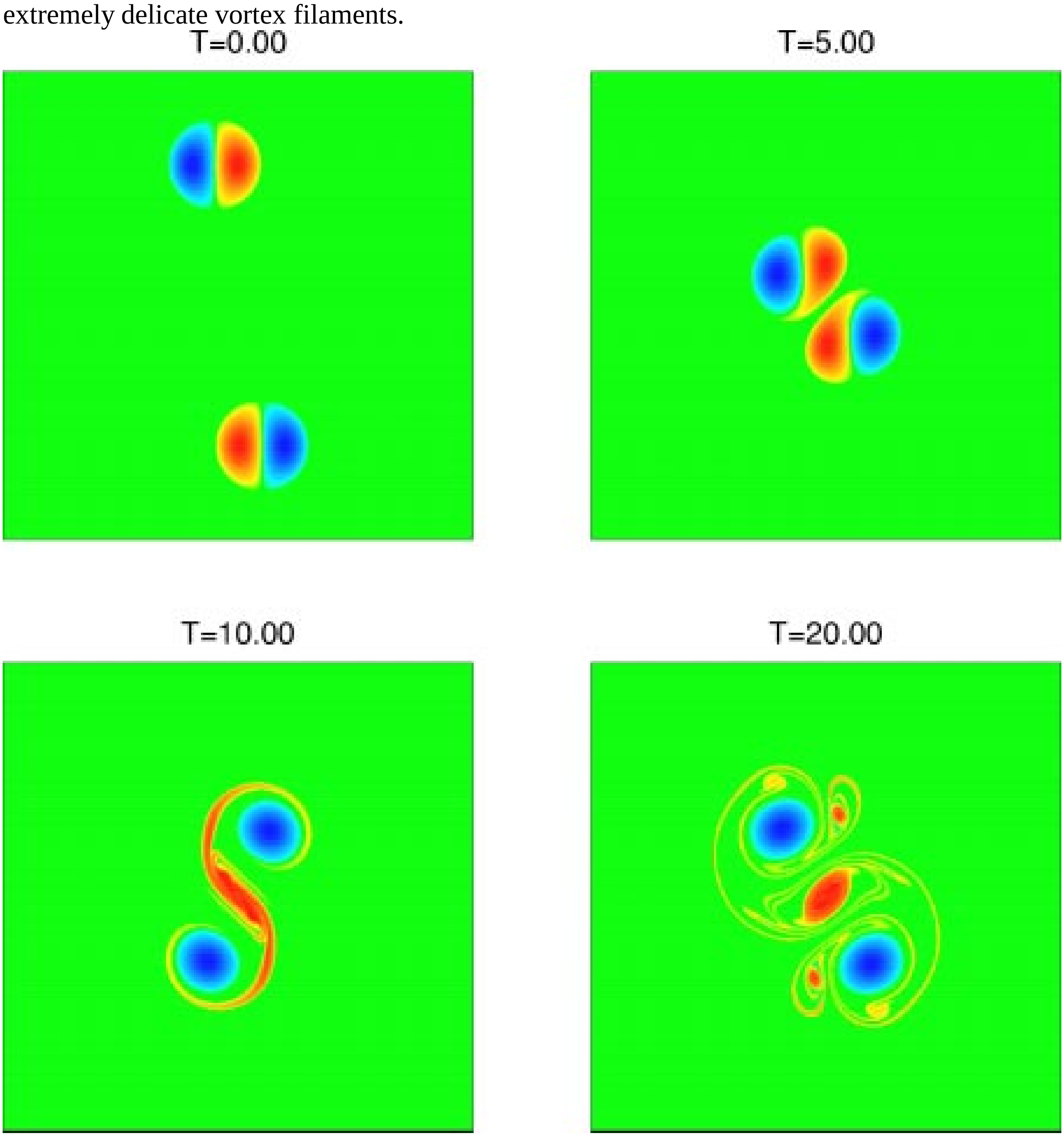


Figure 38. High-resolution numerical simulation of a dipole collision in an inviscid fluid.

4.2.6 Plasma simulations in cylindrical and toroidal geometry

V. Naulin, P. K. Michelsen and S. B. Korsholm
E-mail: volker.naulin@risoe.dk

The increase in available computational power over the last years sets the stage for more elaborate and complex plasma simulations in 3D. A goal of this project is to make the transition from two- and three-dimensional flat geometries to the complex curved geometry of real magnetic confinement systems. This step is necessary as the major phases of plasma discharges are possibly only explainable by the plasma interaction with the topology of the magnetic field. A parallel, finite-difference code is under development for that purpose. It honours the magnetic field configuration by using Glasser co-ordinates that have one co-ordinate aligned with the magnetic field. This allows the use of a rather rough resolution in that direction as the correlation length along the magnetic field lines is very long. The curvature as well as the magnetic shear are taken into account in the way they result from the MHD equilibrium. Numerical simulations up to now show the buildup of large structures on the weak magnetic field side and the long correlations along the magnetic field lines. Figure 39 shows a toroidal set-up, where these correlations can be seen.

Figure 39. Colour plot of the density calculated with the full toroidal code. The structures visible tend to align to the magnetic field, winding around the torus with a winding number of $q = 2.34$.

4.2.7 Motion of coherent structures in turbulence and relation to transport induced by higher order particle drifts

V. Naulin and J. J. Rasmussen
E-mail: volker.naulin@risoe.dk

In plasma physics usually only the ExB-drift is considered when fluxes are determined as the ExB-drift is the dominating particle velocity. However, when the phase shift between particle density fluctuations and fluctuations of the potential is small, the flux due to this drift approaches zero. In a system showing zero ExB-flux there is finite transport due to higher order drifts such as the non-linear polarisation drift. It was shown[1] that the flux connected to this drift is directly linked to the motion of non-linear coherent vortex structures and reflects the Reynolds stress. Moreover, these structures not only transport particles or heat, they also carry charge and are thus capable of organising large charge separations in the plasma leading to large-scale potential structures and, most often, to flows perpendicular to the background density gradient. These zonal flows play an important role in the formation of transport barriers and an understanding of their formation is consequently crucial for the progress in fusion research.

It could further be shown[1] that there is a difference in behaviour between isolated structures and structures moving in the turbulent velocity field generated by neighbouring structures. In the first case the structures arrange for an up-gradient transport of density, thus steepening the gradient. In the turbulence, however, the structures move opposite to the first case, thereby decreasing the density gradient.

1. V. Naulin, Europhysics Letters, **43,** September, 533 (1998).

4.2.8 Turbulent equipartition and the formation of transport barriers

V. Naulin, J. Nycander (FOA, Stockholm, Sweden) and J. J. Rasmussen
E-mail: volker.naulin@risoe.dk

Turbulent equipartition (TEP) is a powerful tool for predicting background profiles and gradients. It is, however, dependent on the presence of some kind of turbulence. We investigate a model system of 2D electrostatic pressure driven flute modes. A pinch flux is observed and for boxes of large aspect ratios the TEP profiles are approached. The turbulence is supplied via a Rayleigh-Taylor instability setting in when the pressure gradient exceeds the gradient of the magnetic field.

For small aspect ratios, however, the numerical simulations show the evolution of a poloidal shear flow. The curvature of the poloidal velocity leads to stabilisation of the instability and, thus, to a local reduction of the turbulence. In that region the transport then changes from being anomalous, i.e. fluctuation driven, to being diffusive. Therefore, a much steeper gradient evolves in the first region. Subsequently, short burst-like destabilisations occur which flatten out the profiles locally. The transport associated with these burst-like events propagates down the background gradient and has the properties of an avalanche-like event. A typical event of that type is shown in Figure 40.

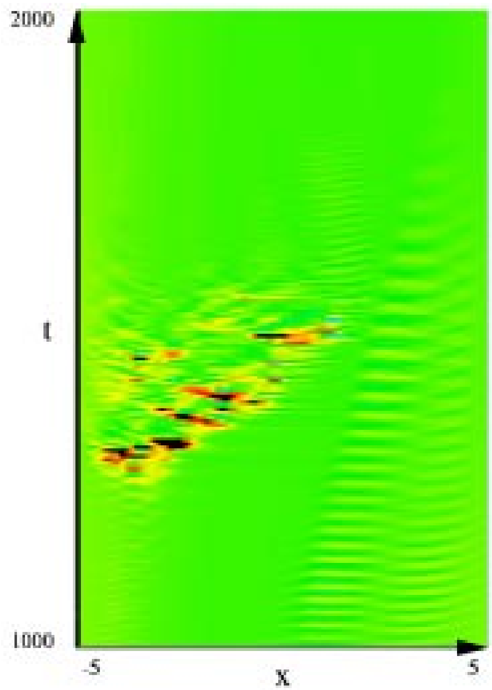


Figure 40. Poloidally averaged heat flow in the radial direction over time. The system is heated from the left and is in a state stabilised by a background shear flow. At t = 1250 local destabilisation causes a large heat flux. The disturbance moves from x = -4.5 to x = 0 in an avalanche-like fashion.

4.2.9 Three-dimensional drift wave simulations in a periodic geometry

S. B. Korsholm, P. K. Michelsen, V. Naulin and H. L. Pécseli (University of Oslo, Norway)
E-mail: soeren.korsholm@risoe.dk

Control of the transport of energy and particles out of fusion plasmas is a major concern in the development of a fusion reactor. This calls for investigations of the nature of turbulent transport. Resistive drift waves are believed to be important for the turbulent or *anomalous transport*. In the present work, drift waves have been investigated numerically in a periodic geometry in the scope of the Hasegawa-Wakatani model[1] and modifications thereof.

The Hasegawa-Wakatani model describes linearly unstable drift waves driven by the density gradient at the edge of the plasma. The model consists of two coupled non-linear partial differential equations in the perturbations of the density, n, and the electrostatic potential, ϕ. The model was investigated in a triply periodic geometry using Fourier spectral methods. After an initial exponential growth of the energy of the turbulence, the turbulent flow self-focusses into large magnetic field aligned coherent structures[2], so-called *convective cells*. To determine the effect of more physical boundary conditions, simulations were performed with damping applied at the boundaries of the simulation domain. A condensation of energy into convective cells is still present with damping applied, but it is much less profound. In Figure 41 the temporal evolution of the energy is presented in the cases with and without damping.

In the Hasegawa-Wakatani model the ion temperature is assumed to be negligible as compared with the electron temperature which is assumed constant. The result of assuming a finite but small ion temperature is that finite Larmor radius effects are retained. This modification to the Hasegawa-Wakatani model was investigated numerically but the results were not significantly different because non-linear effects soon become dominant to the finite Larmor radius effects.

In order to make a model with a wider range of validity the Hasegawa-Wakatani model was extended to include electron temperature perturbations as well as an electron temperature gradient. This was done by extending the set of equations by Braginskii's[3] equation for electron temperature. Now both the turbulent particle flux and the heat flux out of the plasma are calculated. The results of the numerical simulations of this model are very preliminary and it is still too early to draw any conclusions.

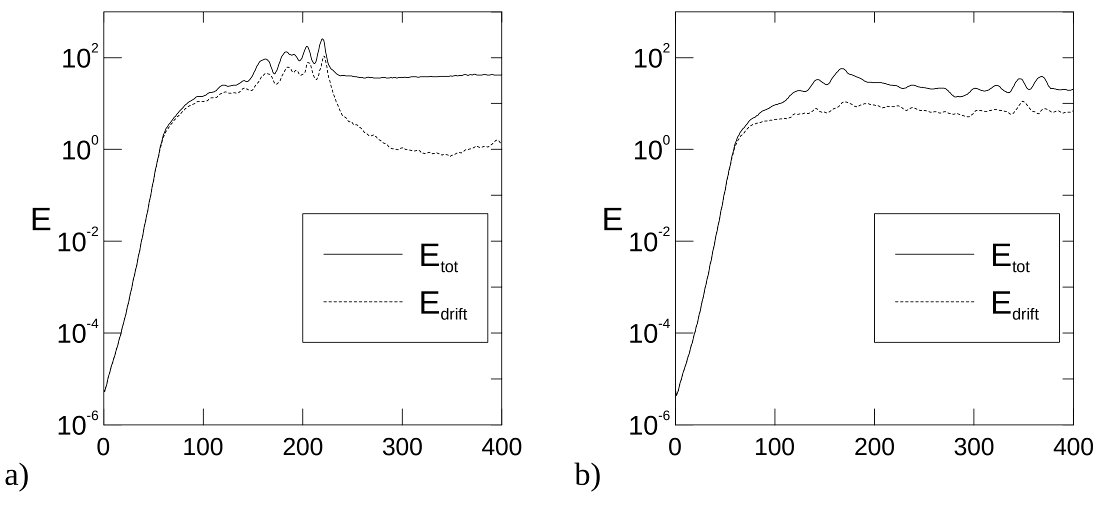


Figure 41. Plot of the evolution of the total and the drift wave energies of a) a non-damped and b) a damped simulation. The initial state is low-level noise and the resolution is 96^2*48.

1. A. Hasegawa and M. Wakatani, *Plasma Edge Turbulence*, Phys. Rev. Lett. **50**, 682 (1983).
2. See also animations at the homepage http://www.risoe.dk/euratom/plasmatheo.html.
3. S. I. Braginskii, *Transport Processes in a Plasma*, Rev. Plasma Phys. **1,** 205 (1965).

4.3 Fluid Dynamics

4.3.1 Velocity and particle motion measurements in microflows

J. A. van de Konijnenberg, B. O. Sass and B. Stenum
E-mail: johan.v.d.konijnenberg@risoe.dk

Particle motion in a viscous fluid is a topic with many practical applications. In our research we aim at understanding the behaviour of one or more particles in a branched channel filled with high-viscosity silicon fluid, for the purpose of optimising cell-sorting devices in biomedicine. In spite of the linearity of the Stokes equation describing creeping flow, the motion of particles in a viscous flow has proved to be challenging. In our group we study this problem experimentally and numerically; this section describes the experimental part. Two types of measurements have been carried out: (1) determination of velocity profiles and streamlines by seeding the flow with small particles and (2) determination of trajectories and rotation of large spherical particles.

The experimental set-up consists of a long plastic channel composed of three parallel joining sections of 2×2 cm each (our glass channel cracked over the full length when we used it for the first time). The channel is filled with silicon oil, put into motion by three separate pumps. The set-up is illuminated with a light sheet, the thickness of which can be varied. Both the velocity field and the trajectories of individual particles are determined by an established particle tracking technique.

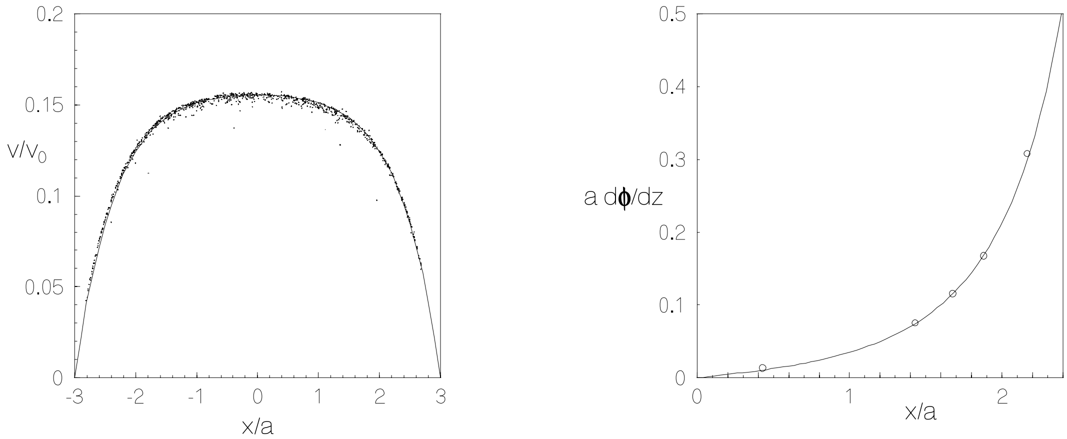


Figure 42. Left-hand side: vertical velocity profile in the rectangular section of the channel. Note the theoretical solution (solid line) which is hardly visible under the data points. Right-hand side: spin angular velocity of a large (radius 5 mm) spherical particle versus distance from the centre. The solid line represents ½ times the vorticity of the rectangular Poiseuille flow without particles. On both sides, x represents the distance from the centre measured along the longer side, and a = 1 cm.

Typical results are represented in Figure 42. Both figures concern flow in the rectangular section of the tube, i.e. far above the junction of the three parallel sections. The comparison with analytical results for rectangular Poiseuille flow is so favourable that we may rely on our set-up and experimental method for future measurements concerning large particles in the neighbourhood of the junction.

4.3.2 Flows in a large-scale flow switch model

B. Stenum, J. A. van de Konijnenberg and D. R. McCluskey
(Dantec Measurement Technology A/S)
E-mail: bjarne.stenum@risoe.dk

In a microchannel flow switch with multiple flow inlets, particles or cells can be guided to different outlets by varying the inlet flow configuration. Flows in channels of micrometer scales are characterised by small Reynolds numbers and are laminar. In our large-scale flow switch model (see 1.3.1) the flow induced by a switch of the inlet flows has been studied by concentration measurements using fluorescent dye and flow field measurements at finite Reynolds numbers with water as the working liquid. The inlet flow rate in the central channel was 0.7 ml/s and the inlets in the two outer channels were switched from 4.2 (left-hand side) and 0.7 ml/s (right-hand side) to 0.7 and 4.2 ml/s. For the dye studies, the central inlet was homogeneously dyed with a concentration of 23 ppm fluorescent dye. The flow field was illuminated by a 3 mm thick light sheet. By image processing the measured intensities were converted into dye concentrations. At constant inlets the flow appears laminar. However, immediately after changing the inlet conditions some mixing was observed, as can be seen in Figure 43. This mixing was found to start at the inlets from the three channels and evolve downstream as entrainment and roll-up like a vortical structure. The same flow evolution was studied by measuring the velocity fields using the Flowmap PIV system based on a cross correlation analysis. For these measurements the flow was seeded with 20 microns polymer particles and illuminated by a laser produced light sheet. The measurement of the velocity fields was triggered by the switch of the inlet flows in the two outer channels and 200 flow fields were measured at intervals of 0.4 s in one run. In the velocity fields a horizontal flow across the channel from the right-hand side to the left-hand side was observed immediately after the switch to the large inlet flow in the right-hand side channel. This cross-flow corresponds to the formation of the vortex-like structure observed in the dye studies and is clearly observed in the streamlines of the flow field. Thus, the concentration and the velocity measurements are complementary techniques.

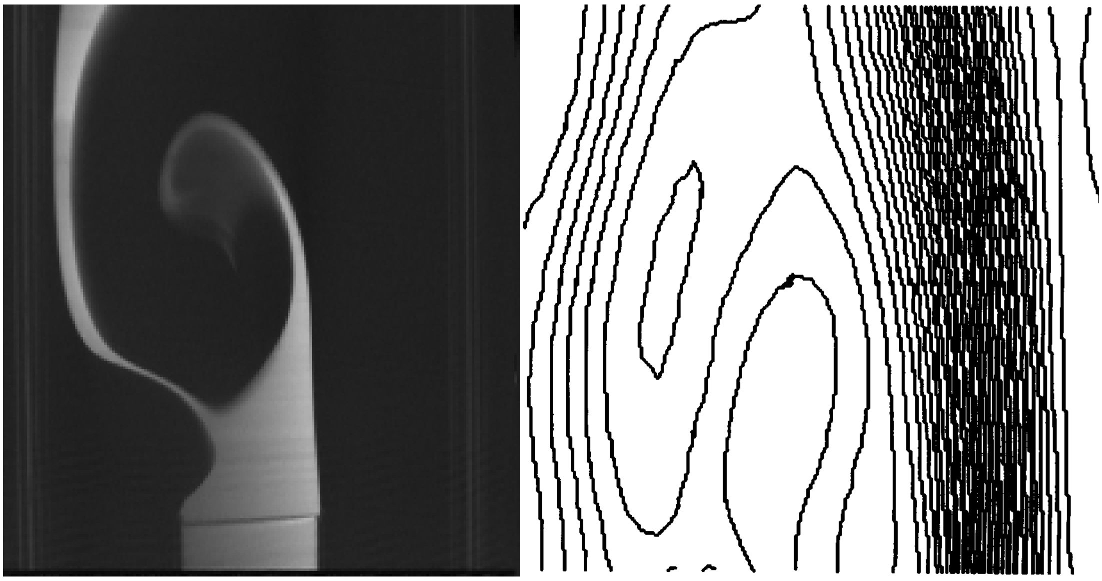


Figure 43. Normalised dye concentration and streamlines shoving the flow structure induced by changing the inlet conditions.

4.3.3 Experimental studies of particle motion in magnetic fluids exposed to an external magnet field

B. Stenum, J. A. van de Konijnenberg and V. O. Jensen
E-mail: bjarne.stenum@risoe.dk

Magnetic separation of particles or cells is important for biological and biomedical topics such as cell sorting in microchannel devices. In fluidic media exposed to an external static magnet field, the force on a paramagnetic particle is proportional to the gradient of the magnetic energy density ($\frac{B^2}{2\mu_0}$) and the difference between the susceptibilities of the particles and the media.

The dynamics of magnetic particles in a flow channel exposed to an external magnet field has been studied experimentally and numerically (see 1.3.4). The experiments were carried out in a vertical glass channel with a cross section of 10 mm $\times$ 10 mm and a length of 150 mm. The fluid can be injected into the channel through five tubes each of a diameter of 2.3 mm. The nozzle of the central inlet is 1.3 mm high while the inlets from the four other tubes take place at the level of the bottom plate. The central tube was also used for particle injection. The inlet flow rates are controlled by a tubing pump with four separate channels. The magnetic field was designed to a linear decrease of the magnetic energy density across the glass channels. Since we have not been able to find suitable paramagnetic particles, 2 mm diamagnetic polymer particles were utilised together with a paramagnetic fluid. The fluid was produced as a mixture of glycerol and a water solution of ion sulphate ensuring well-defined susceptibilities and densities of the particles and the fluid.

Initially the dynamics of particles rising in a resting fluid field was studied. The particles were localised with subpixel accuracy and tracked by digital image processing. Figure 44 shows the paths of rising particles without and with an external magnet. The particles' paths are seen to be reproducible. The paths of particles deflected by the magnet field are almost linear which indicates that the magnetic force and the gravity force are balanced by the drag force. The slope of the path was found to be in agreement with the ratio of the gravity force to the magnetic force.

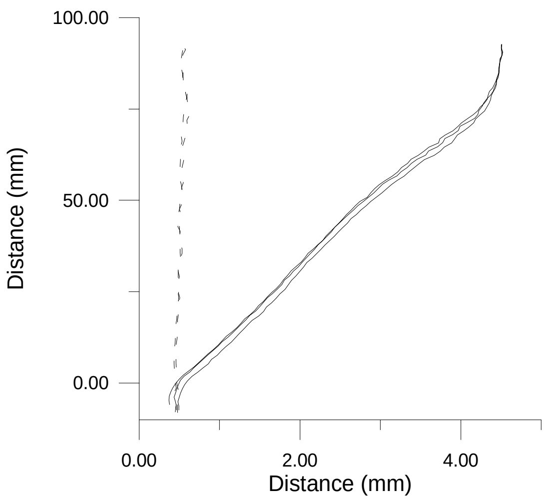


Figure 44. Paths of particles rising in a resting fluid in a glass channel without (dashed lines) and with an external magnet (solid lines). Large relative velocity.

4.3.4 Magnetic separation of particles in a rectangular microchannel

*S. Lomholt, J. P. Lynov and P. Telleman *(* Mikroelektronik Centret, Technical University of Denmark)*
E-mail: sune.lomholt@risoe.dk

Sorting of paramagnetically labelled cells or particles in microsystems is an important application for biological and biomedical use. The lack of information on the behaviour of magnetically labelled cells or particles in microfluidic structures has made it difficult to design sorter chips. Therefore a numerical study of magnetic separation of particles in a rectangular microchannel has been performed.[1]

The study considered the effects of varying either the flow rate or the magnetic field, and the results show that a successful separation is very dependent on the interaction time between the particle and the magnetic field. Thus an optimal separation rate requires a well-established relation between magnetic field and flow rate.

Another objective of the study was to investigate which forces on the particle are of importance and which are not. Usually magnetic separation studies only consider Stokes drag and maybe particle inertia, but other forces may be of importance as well. In our study the particle motion was modelled by an equation of motion given by Maxey and Riley[2] that includes buoyancy, added mass and Basset history force besides Stokes drag and particle inertia. A comparison of particle trajectories obtained with the Maxey and Riley equation with trajectories obtained with only Stokes drag is shown in Figure 45. The results show that if only Stokes drag is considered, the strength of the magnetic field is overestimated (the particles move closer to the wall) and may lead to a smaller separation rate. Hence it is necessary to consider the other forces, especially the Basset history force, in order to obtain a more correct relation between flow rate and magnetic field.

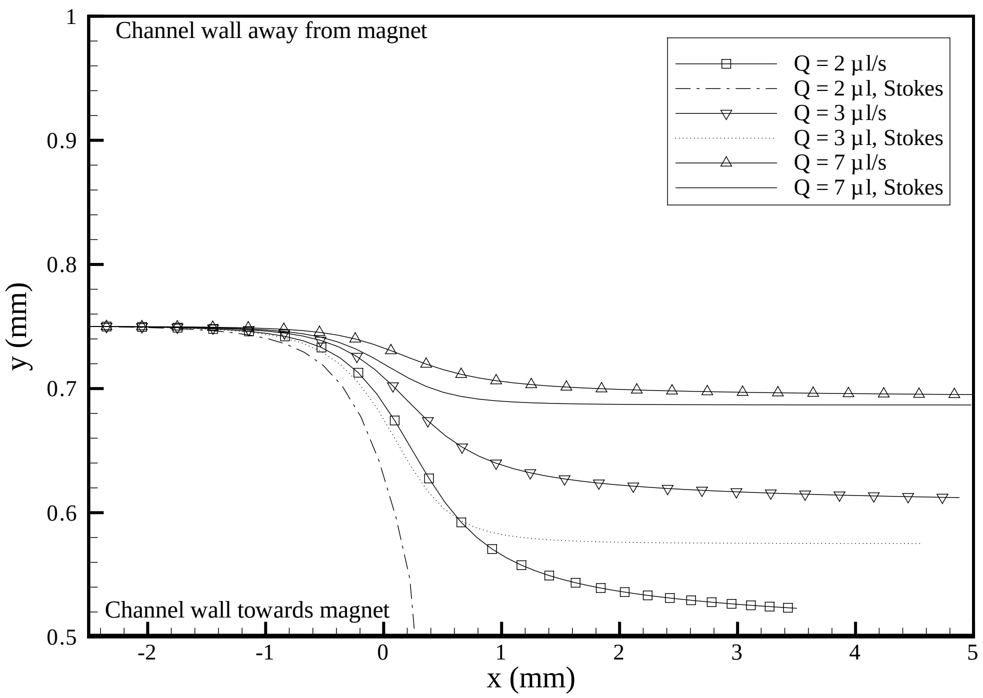


Figure 45. Comparison of trajectories for using only Stokes drag or using the Maxey and Riley equation.

1. S. Lomholt, J.P. Lynov and P. Telleman, "Numerical simulation of magnetic separation of particles in a rectangular microchannel", *Proceedings of the µTAS'98 Workshop*, Kluwer Academic Publishers (1998).
2. M.R. Maxey and J.J. Riley. "Equation of motion for a small rigid sphere in a nonuniform flow", *Phys. Fluids* **26** (4), 883-889 (1983).

4.3.5 Force coupling method for computing particle dynamics in microflows

S. Lomholt and M. Maxey (Department of Applied Mathematics, Brown University, Providence, USA)
E-mail: sune.lomholt@risoe.dk

The motion of rigid particles in a fluid flow is determined by solving the Navier-Stokes equations

$$\nabla \cdot \mathbf{u} = 0 \tag{1}$$

$$\frac{D\mathbf{u}}{Dt} = -\frac{\nabla p}{\rho} + \nu \nabla^2 \mathbf{u} \tag{2}$$

subject to the no-slip boundary condition at the particle surfaces

$$\mathbf{u} = \mathbf{v} + \mathbf{\Omega} \times (\mathbf{x} - \mathbf{Y}), \tag{3}$$

where $\mathbf{v}$, $\mathbf{\Omega}$ and $\mathbf{Y}$ are the velocity, angular velocity and position of the particle. Furthermore, the boundary conditions for the bounding geometry must be satisfied. The straightforward method is to do a direct simulation where the flow around the particles is fully resolved. This requires a new mesh for each time step and if a particle is close to a wall or another particle a very fine mesh is needed in order to resolve the flow. Therefore direct simulations are extremely computationally expensive and the number of particles will be limited.

An alternative method is force coupling, where the no-slip boundary condition of the particles is approximated by specifying a force in the flow at the position of the particle. The momentum equation (2) becomes

$$\frac{D\mathbf{u}}{Dt} = -\frac{\nabla p}{\rho} + \nu \nabla^2 \mathbf{u} + \sum_{n=1}^{N} \mathbf{F}^n \Delta\left(\mathbf{x} - \mathbf{Y}^n\right), \qquad (4)$$

where $\mathbf{F}^n$ is the force exerted by particle n on the fluid, due to the no-slip boundary condition, and $\Delta\left(\mathbf{x}-\mathbf{Y}^n\right)=\left(2\pi\sigma^2\right)^{-3/2}\exp\left(-\left(\mathbf{x}-\mathbf{Y}^n\right)/2\sigma^2\right)$ is a Gaussian function that localises the effect of the force. This first-order approximation only includes the force from the particle on the fluid due to translation. Higher order approximations can be obtained by adding the forces due to rotation, interaction, etc. The length scale σ is a parameter that may be used to ensure numerical resolution and to reflect the finite size of the particle. With the localised force representation specified in this way it applies to spherical particles, while elliptical particles require two length scales σ_1 and σ_2. Even more complex particles require three length scales. The method has been tested in a three-dimensional channel flow for three different cases.

The first case was a sedimenting particle and for this case the channel centre line acts as an equilibrium, i.e. regardless of the initial position of the particle the final position is on the centre line.

The second case was a particle suspended in an upward Couette flow. A particle with a density larger than the fluid will lag the fluid whereas a lighter particle will lead the fluid. Due to this lag or lead velocity the particles will move towards one of the walls. The heavier particles will move towards higher fluid velocity and find equilibrium between the centre line and the moving wall. This equilibrium depends on how heavy the particle is; a slightly heavier particle will move further away than a very heavy particle. Similarly, the light particles will find an equilibrium between the centre line and the wall.

The last case was a particle suspended in an upward Poiseuille flow. Heavy particles move to an equilibrium closer to the centre line than the neutrally buoyant particles, while very heavy particles find equilibrium at the centre line or close to the centre line. Lightparticles on the other hand tend to find their equilibria away from the centre line.

All the cases show qualitative agreement with earlier results in literature.

4.3.6 Three-dimensional aspects of flows in a rotating parabolic vessel

J. A. van de Konijnenberg, J. J. Rasmussen and B. Stenum
E-mail: johan.v.d.konijnenberg@risoe.dk

In previous investigations we have studied the evolution of a shear flow in a parabolic tank. To summarise those results, a large parabolic bowl is partially filled with water and made to rotate so fast that the curvature of the free surface matches that of the parabolic tank. Thus, the water forms a layer with uniform thickness. When the fluid is in solid-body rotation, the central part of the parabolic bowl is given an additional rotation. Almost immediately a shear layer is formed above the differentially rotating section. At sufficiently large differential rotation rates, this shear layer rolls up into a sequence of vortices (part of Figure 46). Many aspects of these vortices can be understood in terms of the two-dimensional vorticity equation, extended with a term representing bottom friction according to the theory of linear Ekman layers. However, it is known that this representation has its limitations. In particular, the secondary flow in the centra of the vortices is only partially understood. For this reason we made close-up visualisation of one of the (cyclonic) vortex centra (part of Figure 46) using a fluorescent dye, initially spread within a thin layer at the bottom.

Figure 46 reveals two things: (1) an upward flow in the middle of the cyclonic vortices. This upward flow occurs above the slit, apparently only at the few places where there is no radial flow. As the upward flow carries the fluorescent dye, the vortex centra become visible as eye-like rings. (2) a vertical orientation of the dye columns. Similar evidence comes from pictures taken at different angles or with a vertical light sheet. Thus, the vortices are aligned with the rotation axis, and not with the local normal to the parabolic surface. This observation has proved to be highly counterintuitive to many shallow-water zealots, but agrees with the Taylor-Proudman theorem.

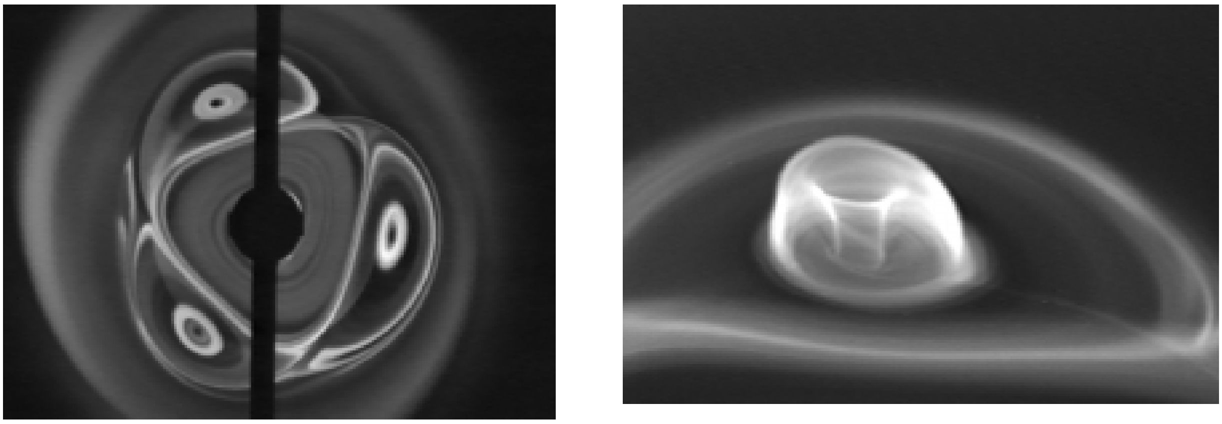


Figure 46. Visualisation of a mode three with a telelens from above (left) or with a macrolens under approximately 45° (right).

4.3.7 Periodically driven flows

F. Okkels, B. Stenum and J. Juul Rasmussen
E-mail: fridolin.okkels@risoe.dk

The studies on the circular shear flow in the rotating parabolic tank have been extended to include studies of periodically driven flows produced by a periodic motion of the central inner part of the bottom. Depending on the motion of the inner part relative to the outer part a time-varying shear flow can be formed. Contrary to the chain of stationary vortices created by a constant angular velocity difference, the periodic forcing continuously produces small eddies, which interact mutually, creating a very dynamic state. This experiment may be thought of as a frequency-response study of 2D vortex dynamics and interactions.

By gradually increasing the frequency and the amplitude of the forcing, the state of the flow changes from a stationary radially symmetric flow to a time-periodic regular flow, which then becomes unstable. The flow field is measured either by advection of a passive tracer, which in this case is a fluorescein, or by particle tracking from which the entire velocity field can be reproduced. From these data preliminary numerical analyses have been used to study the basic statistical properties and the detailed advection properties of the flow. Some theoretical considerations have been made concerning the parameters that characterise the different states, e.g. the Reynolds number. In the regime of regular dynamics a variety of different states are seen having different configurations and numbers of vortices; an example is shown in Figure 47.

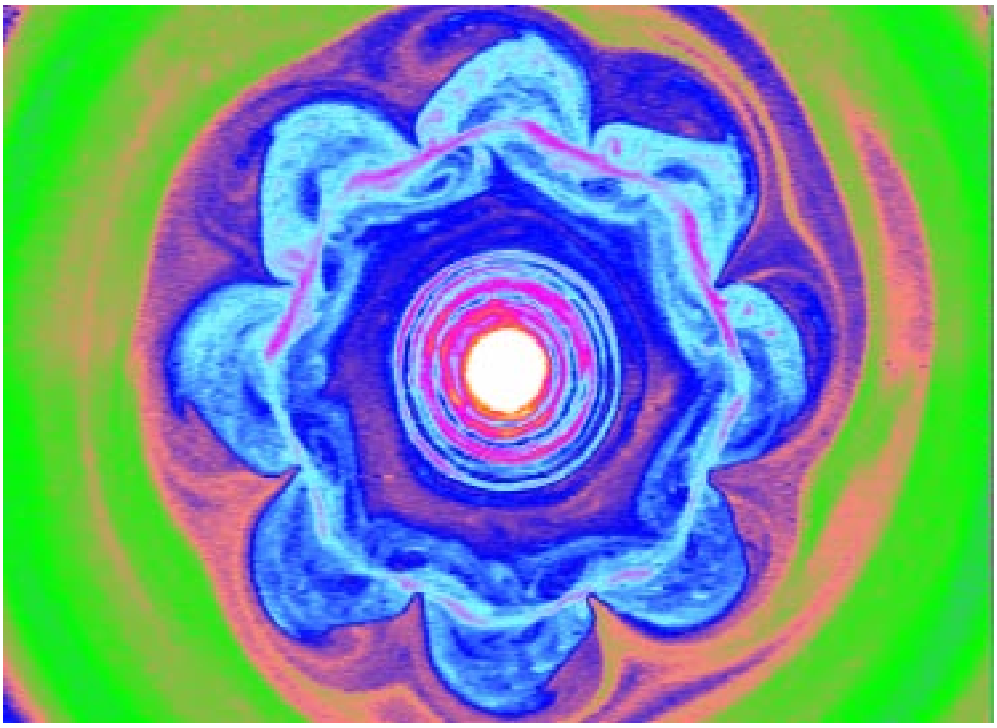


Figure 47. False colour image of the advection of fluorescein during regular dynamics.

4.3.8 Spin-up in a circular tank with a sloping bottom

J. A. van de Konijnenberg, V. Naulin, J. Juul Rasmussen, B. Stenum and G. J. F. van Heijst
(Eindhoven University of Technology, The Netherlands)
E-mail: johan.v.d.konijnenberg@risoe.dk

The adaptation process of a fluid to a change of angular velocity of its container is known as spin-up. Apart from its interest from a fundamental point of view, spin-up is relevant for various fields related to vortex dynamics. In particular, the presence of a sloping bottom gives rise to the same dynamics that is encountered in plasmas with inhomogeneous density, as well as the atmosphere of the Earth and other planets; in all three cases the equation of motion contains a term that represents the so-called β-effect. Spin-up in a circular tank with a sloping bottom has been studied analytically in the limit $\Delta\Omega/\Omega \rightarrow 0$, where $\Delta\Omega$ is the increase in angular velocity of the tank, and Ω is the final angular velocity. However, experiments in this field are scarce and misinterpreted and numerical simulations have never been performed. In our research we try to gain insight into the mentioned spin-up process by comparing analytical, experimental and numerical results.

The experiments were performed in a circular tank with a diameter of 40 cm and depth of 20 cm. In this tank a number of false bottoms could be placed to get the desired slope. The tank is placed on a turntable and is filled with water up to a transparent rigid lid. The measurements consist of dye visualisations and tracking of neutrally buoyant particles. For the latter purpose the tank is illuminated with a horizontal light sheet and is viewed from above with a co-rotating camera. The fluid is seeded with small bright particles, about five hundred in an illuminated cross section. From the particle trajectories we derive the velocity, the vorticity and the stream function. The numerical method consists of a two-dimensional finite-difference method, based on the vorticity equation with extra terms representing Ekman suction and the β-effect. For moderate slopes there is a good agreement between the experiments and the simulations.

One particular conclusion is the recognition that more than one mechanism can lead to vortex separation. In the inviscid theory the flow is expanded in Rossby wave modes, each of which has a phase velocity in the 'westward' direction, with the shallow part of the tank being the 'north' part. The flow as a whole also has the character of a propagating wave and shows separation from the sidewall and the alternating generation of cyclonic and anticyclonic vortices in the 'eastern' part of the tank. In reality, viscous effects play an important role, enhancing separation from the sidewall and vortex formation. Another conclusion is that there is a profound difference between spin-up and spin-down. Whereas spin-up generally leads to vortex separation, an intricate velocity field and abundant vortex motion, the flow retains its initial single-cell appearance during spin-down.

1. J. Pedlosky and H. P. Greenspan, J. Fluid Mech. **27**, part 2, 291-304 (1967).

4.3.9 Particle tracking in two-dimensional flow field

A. H. Nielsen and J. J. Rasmussen
E-mail: anders.h.nielsen@risoe.dk

Particle tracking is an important tool to determine the transport and mixing properties of a flow field. Generally we solve the Navier-Stokes equation in the Eulerian framework where the flow field is known at all times in a (fixed) spatial grid. The fluid inside a small element located at a grid point will consist of different fluid particles at different times. The information about how these particles is transported or convected by the flow field is not directly present in this framework.

We have investigated the particle dynamics in a circular shear flow. These investigations are closely related to the experimental investigations in our parabolic vessel. We have solved the two-dimensional Navier-Stokes equation using a pseudo-spectral method. As expanding functions we use Chebyshev polynomials and Fourier modes. To follow the trajectories of the particles we evaluate the full spectral expansion of the velocity field. Hereby we use all the information stored in the flow field. Such evaluations are quite expensive in terms of computer time and 200-300 particles take as much CPU time as solving the Navier-Stokes equation itself. An example of our particle tracking is shown in Figure 48 that displays the time evolution of an unstable axisymmetric annular shear flow developing seven vortices. In the initial flow field 16,000 particles are inserted and traced. The particles are divided into four groups labelled with different colours. Red and green particles are located inside the shear whereas blue and turquoise colours are located just outside the shear. During the creation of the vortices we observe no radial mixing but close examinations of single-particle trajectories reveal strong azimuthal mixing.

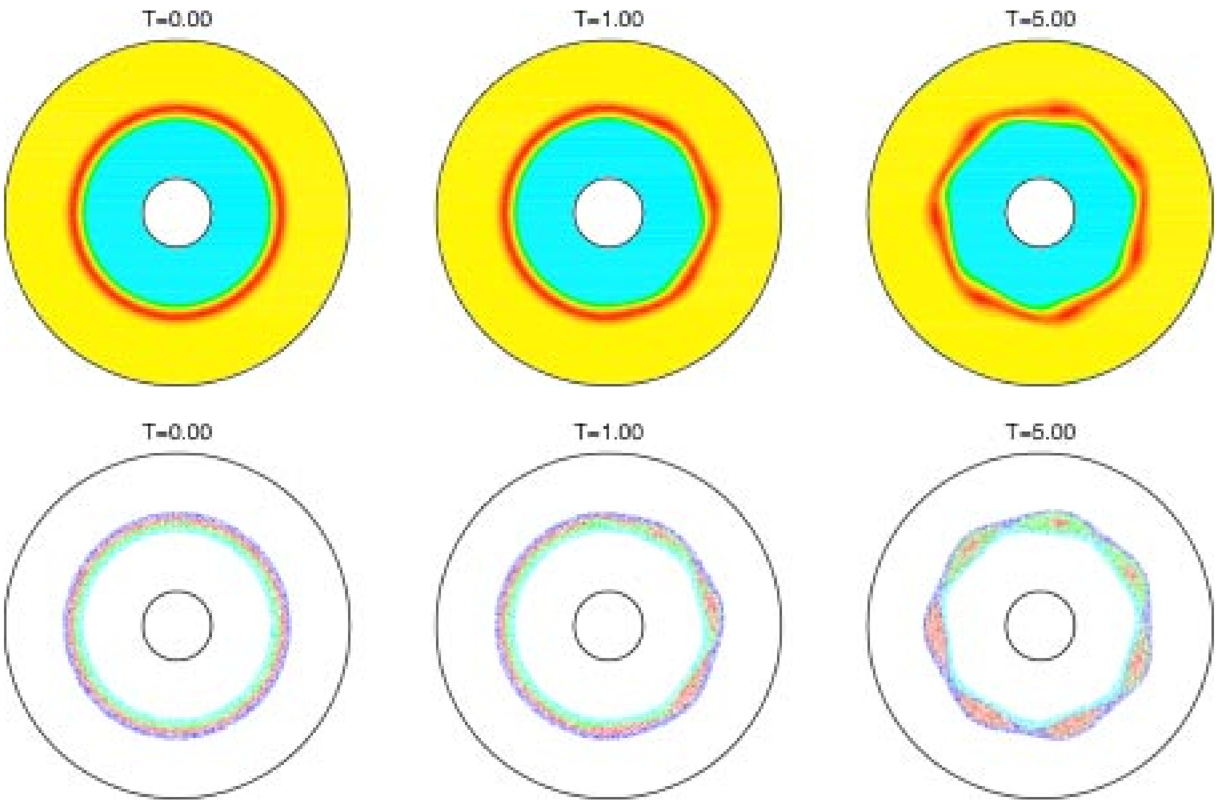


Figure 48. Time evolution of an unstable shear annular flow for a Reynolds number of Re = 101.2. Top figure displays the vorticity distribution and the bottom figure displays 16,000 particles divided into four groups.

4.3.10 Two-dimensional turbulence in bounded flows

A. H. Nielsen, J. J. Rasmussen, D. J. Torres (Physics Dept. and Geophysical Research Center, New Mexico Tech, USA), H. J. H. Clercx (University of Technology, Eindhoven, The Netherlands) and E. A. Coutsias (University of New Mexico, Albuerqueque, USA)
E-mail: anders.h.nielsen@risoe.dk

Two-dimensional turbulence in unbounded or double periodic domains in neutral fluids as well as in plasmas has been investigated intensively during the last decades by means of numerical simulations. These flows exhibit an inverse cascade of energy, and for decaying turbulence coherent structures comparable with the size of the domain will eventually emerge. Thus, the presence of boundaries and the conditions imposed on them will play a significant role in the evolution of the turbulence and the coherent structures.

In this project we numerically investigate decaying turbulence on circular and square bounded domains and compare with results obtained from double periodic geometries. The model equations are the Navier-Stokes equations that are solved using a pseudospectral method. For bounded flows we investigate two different kinds of boundary conditions, no-slip and free-slip. From random (turbulent) initial conditions we observe that the flow organises into large coherent structure(s), see Figure 49, regardless of the boundary conditions. Furthermore, we observe a relative spin-up of the flow as the normalised angular momentum increases with time. For the no-slip boundary condition strong boundary layers are observed; these layers are not present using the free-slip boundary condition.

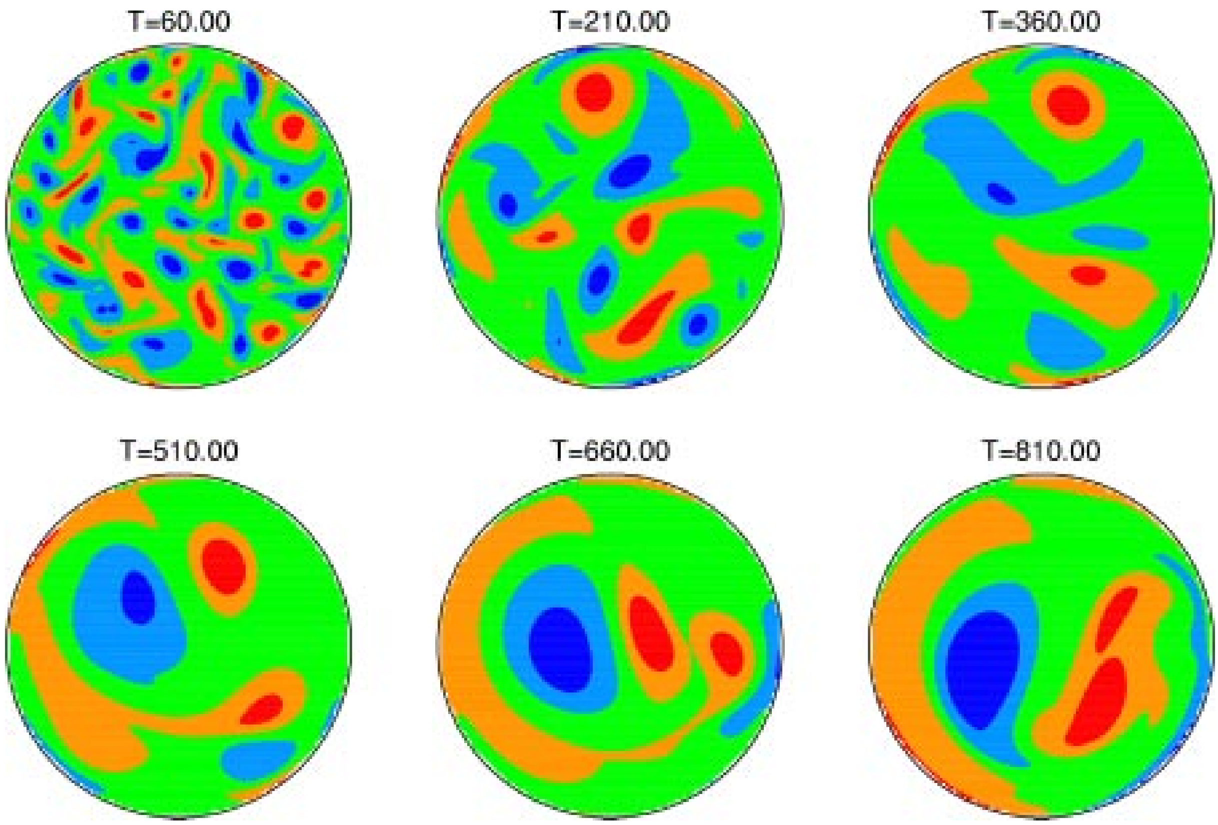


Figure 49. Time evolution of a flow initialised with random initial conditions and for no-slip boundary conditions. Red colours correspond to positive values, whereas blue colours correspond to negative values. Limits are adjusted to the individual pictures. Spectral evolution M = 1024, N = 512 and Reynolds number Re = 4950.

4.3.11 Formation of monopolar and tripolar vortices by self-organisation in two dimensional flows

A. H. Nielsen, J. J. Rasmussen and M. R. Schmidt
E-mail: jens.juul.rasmussen@risoe.dk

The formation of vortices from localised perturbation in a two-dimensional flow is investigated theoretically and by direct numerical solutions of the two-dimensional Navier-Stokes equations. We consider the evolution of a turbulent patch characterised by its energy and enstrophy. In previous studies[1] we have investigated the formation of dipolar vortices evolving from a turbulent patch with a finite linear momentum, but with no angular momentum. Here we consider the opposite case: the patch has a net angular momentum, but no linear momentum. It is constructed from fluctuations with random phases and an isotropic energy spectrum. This may model the turbulent patch that appears when a rotating or stratified fluid is stirred locally. Depending on the initial condition the patch is found to organise into a non-shielded monopolar vortex for patches with a finite circulation, or into a tripolar vortex for patches with zero circulation. In both cases the functional relationship between the vorticity and the stream function is in general non-linear with a cubic form. The development is qualitatively described as self-organisation in a viscid flow following the approach employed by Leith,[2] where the self-organised structure is characterised by minimalising of the enstrophy for a fixed energy. Figure 50 shows the formation of a tripolar vortex for the case where the initial patch has zero circulation.

1. A.H. Nielsen, J. Juul Rasmussen and M.R. Schmidt, Physica Scripta **T63,** 49-58 (1996); A.H. Nielsen and J. Juul Rasmussen, Phys. Fluids, **9,** 982-991 (1997).
2. C.E. Leith, Phys. Fluids, **27,** 1388-1395(1984).

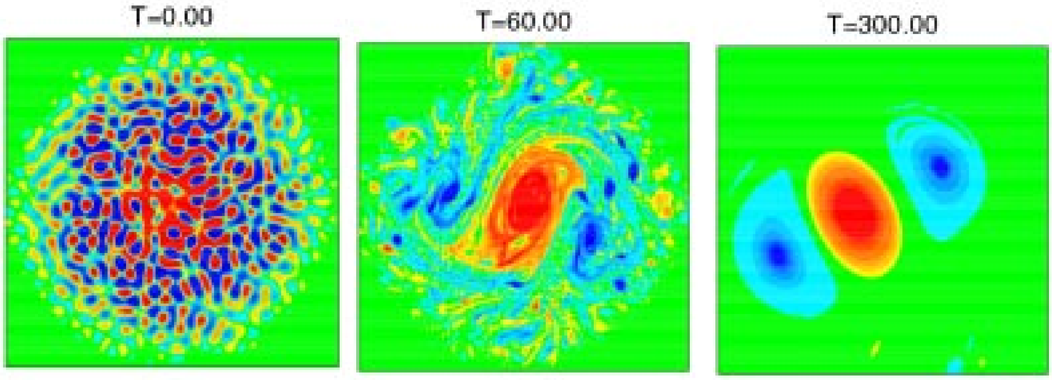


Figure 50. Evolution of a turbulent patch with finite angular momentum, but with zero net circulation.

4.3.12 Numerical studies of monopolar vortices interacting with a continental shelf

A. H. Nielsen, H. J. H. Clercx, G. J. F. van Heijst* and L. Z. Sanson* (* University of Technology, Eindhoven, The Netherlands)*
E-mail: anders.h.nielsen@risoe.dk

Oceanic monopolar vortices interacting with a continental shelf are studied numerically using an accurate spectral computer scheme on a bounded domain. Knowledge of the time evolution for these monopoles is important for a better understanding of transport processes in large-scale geophysical flows and for their role in environmental issues.

An important parameter for the dynamics of vortex flows at intermediate latitudes is the gradient of the Coriolis parameter with respect to the latitude, the so-called β-parameter. A characteristic dynamical feature of the present β-effect is that monopolar vortices on the northern hemisphere move to the northwest (for cyclones). Oceanic vortices can thus meet and interact with bottom topographies or boundaries of a basin, resulting in strong horizontal mixing.

The Vortex Dynamics Group at Eindhoven has studied such phenomena experimentally in a rotating water tank and numerically using a finite-difference scheme. In order to study the transport properties of these flows, a bounded pseudospectral code, developed in the Optics and Fluid Dynamics Department, has been modified to solve the shallow water equations where the effect of bottom topographies and background rotation is taken into account. With a highly accurate passive particle tracer detailed information about the transport can be extracted.

4.4 Optics

4.4.1 Modelling of diffractive optical elements

P. G. Dinesen, J. S. Hesthaven (Brown University, Rhode Island, USA) and J. P. Lynov
E-mail: jens-peter.lynov@risoe.dk

In recent years diffractive optical elements (DOEs) have attracted much attention, in particular in the context of miniturisation of optical sensor systems. In such systems bulk optics may be replaced by diffractive optics thus reducing the size and increasing the robustness of the system.

The modelling of DOEs remains a significant challenge since the vectorial nature of the optical field propagating in such elements must be taken into account. To address this issue, we have employed a new spectral method due to its superior characteristics such as the absence of numerical dispersion and the low number of points needed to resolve the electromagnetic propagation accurately.

Figure 51 shows a schematic example of a focusing grating coupler where part of a guided field propagating in a thin film waveguide is radiated into free space due to the surface relief in the top cladding layer of the waveguide. The dashed box indicates the spectral computational domain.

To reduce the computational requirements, the spectral method, which is used to calculate the field propagation in the waveguide and its near vicinity, is combined with a near- and far-field integration method. Equivalent sources are calculated on a virtual aperture surrounding the dielectric layers, and from these sources the radiated field can be calculated in any distance

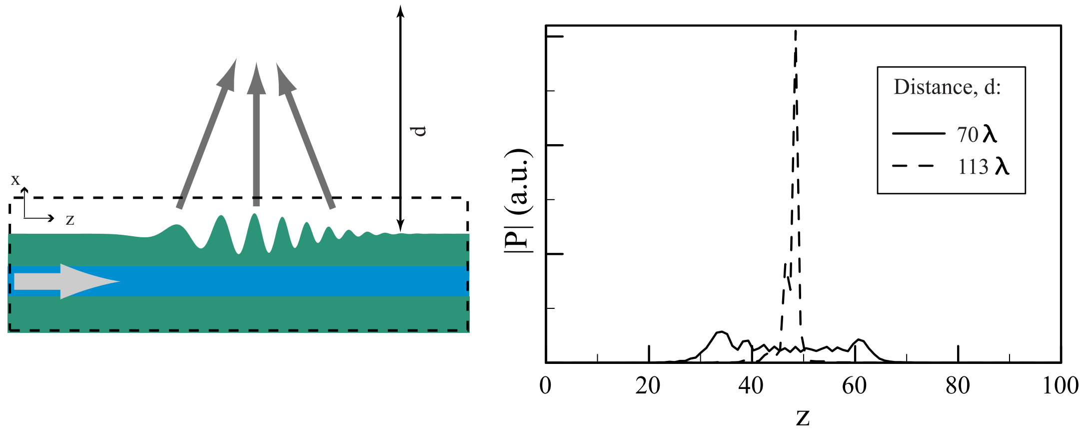


Figure 51. Schematic illustration of a focusing grating coupler. Indicated by dashed box is the spectral computational domain, whose boundary is at the same time the virtual aperture used in a free-space integration technique to find the radiated field anywhere outside the computational domain. An example output is shown to the right illustrating the focusing properties of the coupler.

from the grating coupler by integration without extending the spectral computational domain.

The spectral method has been verified examining various test cases such as a simple thin film waveguide. The validity of the free-space integration technique has also been established

Figure 51 also shows cross sections of the output from a focusing grating coupler at two different distances from the surface along x. The total length of the grating coupler is 80 λ, and the period of the surface relief is chosen so that the radiation angle of the main diffraction order is parallel to the surface normal. It is seen that at a distance of d = 113 λ from the surface the beam is much more narrow than at a distance of 70 λ, illustrating the focusing properties of the grating coupler.

4.4.2 Transverse modulational instability of counterpropagating quasi-phase-matched beams in a quadratically nonlinear medium

P. M. Lushnikov (Landau Institute for Theoretical Physics, Russia),
P. Lodahl and M. Saffman
E-mail: mark.saffman@risoe.dk

In the past few years pattern formation in parametric $\chi^{(2)}$ media with nonlinear polarisation that is a quadratic function of the optical fields has been investigated extensively. Convective modulational instability was observed in a forward-propagating travelling-wave interaction. To generate patterns it is necessary to provide feedback such that the system exhibits absolute instability. One way of introducing feedback is to allow the interacting beams to counterpropagate. Although backward parametric interactions were proposed in the 1960's, there is not sufficient birefringence in available materials for phase matching of a fundamental wave E_1 at frequency ω_1 with a counterpropagating second harmonic E_2 at frequency $\omega_2 = 2\omega_1$. Studies of pattern formation in quadratic media to date have therefore been based on mean-field analysis of an intracavity geometry in which the cavity provides the feedback necessary for absolute instability.

In this work[1] we study transverse instability in a bulk quadratic medium of length L without a cavity as shown in Figure 52. The absence of cavity effects allows the transverse instability to be studied in a more basic form. To provide the necessary coupling between counterpropagating beams we consider a backward quasi-phase-matched interaction in a periodically poled material. Quasi-phase matching relaxes restrictions on the choice of wavelength and allows access to the largest components of the electro-optic tensor in a given material. When the counterpropagating pump beams have equal intensities, we find a simple dispersion relation that describes the presence of absolute instability for nonzero phase mismatch. It is shown that threshold powers for observation of the transverse instability by use of, for example, periodically poled $LiNbO_3$ are in the range of a few megawatts and are thus accessible with pulsed lasers.

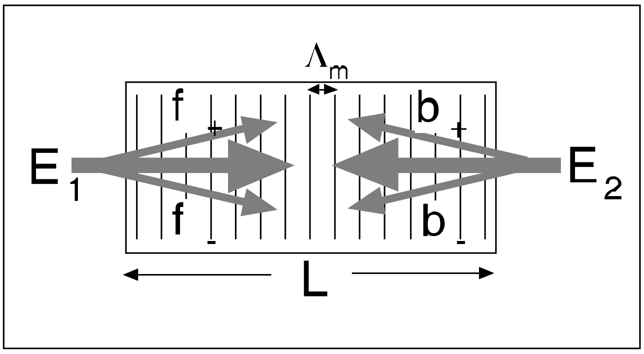


Figure 52. Interaction of counterpropagating fundamental E_1 and second harmonic E_2, which are beams in a $\chi^{(2)}$ medium poled with period Λm. Spatial sidebands of amplitude f and b are generated inside the medium.

1. P. M. Lushnikov, P. Lodahl and M. Saffman, "Transverse modulational instability of counterpropagating quasi-phase-matched beams in a quadratically nonlinear medium" Opt. Lett. **23**, 1650-1652 (1998).

4.4.3 Structure of spatial solitons in photorefractive media

M. Saffman and A. A. Zozulya (Worcester Polytechnic Institute, USA)
E-mail: mark.saffman@risoe.dk

Because of their stability and robustness, optical solitons have attracted considerable attention in recent years. While temporal solitons are applicable in data transmission systems, their spatial counterparts are ideally suited for all-optical switching and beam manipulation. Spatial soliton circuitry is based on the ability to implement logic operations by allowing solitons to interact in a nonlinear medium, as well as the possibility of soliton induced waveguides being used to guide and switch additional optical beams.

Photorefractive media have proven well-suited for studies of the properties and interaction of spatial solitons. The properties of one-dimensional spatial solitons in photorefractive media are close to those of one-dimensional solitons in more common Kerr type media with saturable nonlinearity. On the other hand in two-transverse dimensions photorefractive media exhibit an unusual form of optical nonlinearity that results in elliptically shaped solitons[1] when the nonlinearity is self-focusing, and soliton instability in the case of defocusing nonlinearity.[2] There has, however, been considerable controversy about the structure of two-dimensional photorefractive solitons. Other groups have reported the observation of circular solitons for both focusing and defocusing nonlinearities.

In the present work[3] an analytical study is made of the equations describing photorefractive solitons in the drift approximation. It is demonstrated that there are no localised, self-channelled solutions with a radially symmetric intensity profile. This conclusion holds, even when allowing for an arbitrary spatial distribution of the phase of the optical field. The apparent discrepancy with experimental results presented by others is clarified by numerical solutions of the governing equations. These solutions demonstrate that while a beam may appear to self-focus initially in a relatively thin medium, propagation over longer distances results in the inevitable decay of vortex solitons in photorefractive media.

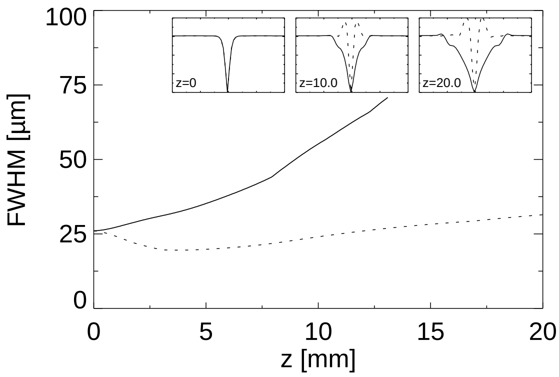


Figure 53. Evolution of the core of a unit-charged vortex. The diameters were measured along the *x* (solid curve) and the *y* (dotted curve) coordinates. The insets show the intensity profiles along *x* and *y* in the central portion of the beam.

1. A. A. Zozulya, D. Z. Anderson, A. V. Mamaev and M. Saffman, “Self-focusing and soliton formation in media with anisotropic nonlocal material response”, Europhys. Lett. **36**, 419-424 (1996).
2. A. V. Mamaev, M. Saffman and A. A. Zozulya, “Vortex evolution and bound pair formation in anisotropic nonlinear media”, Phys. Rev. Lett. **77**, 4544-4547 (1996).
3. M. Saffman and A. A. Zozulya, “Circular solitons do not exist in photorefractive media”, Opt. Lett. **23**, 1579-1581 (1998).

4.4.4 Self-induced dipole force and filamentation instability of a matter wave

M. Saffman
E-mail: mark.saffman@risoe.dk

Tremendous advances in the manipulation of atomic motion by resonant and near-resonant interaction with optical fields have been made in recent years. Atomic analogues of a number of well known optical devices and effects including interferometers, frequency shifters, fibre guiding and lasers have been demonstrated. Until now experimental attention has focused on the regime of *linear* atom-light interactions where the atomic dynamics are driven by externally specified optical fields. As has been discussed theoretically by several groups, dipole-dipole interactions lead to light mediated nonlinearity in ultracold atomic beams where the thermal de Broglie wavelength is large compared with the average interatomic spacing. The resulting nonlinear Schrödinger equation for the atomic evolution suggests the possibility of observing nonlinear effects such as atomic self-focusing and solitons, in copropagating matter and optical waves.

In this work[1] coupled equations are formulated that describe the joint evolution of copropagating matter and optical waves. Including the effects of diffraction and nonlinearity in the evolution of both the optical and atomic fields leads to new physical phenomena. The dipole-dipole nonlinearity is only significant when the matter wave has long-range spatial coherence, such that the dimensionless phase space density is of order unity. However, even in the limit of short coherence length where the phase space density is small, the single atom dipole nonlinearity can lead to strong perturbation of the atomic motion. Being proportional to the gradient of the intensity, dipole forces occur only in spatially inhomogeneous fields. Spatial gradients grow on an initially homogeneous background due to modulational instability under conditions of nonlinear self-focusing of the optical field. The spatial gradients result in dipole forces so that the atomic motion may be subject to forces nonlinear in the atomic density. The nonlinear stage of the instability of copropagating optical and matter waves leads to filamentation of the atomic beam, as shown in Figure 54. The coupled evolution equations also predict the possibility of self-trapped propagation, for particular initial conditions, of both the optical and the atomic fields.

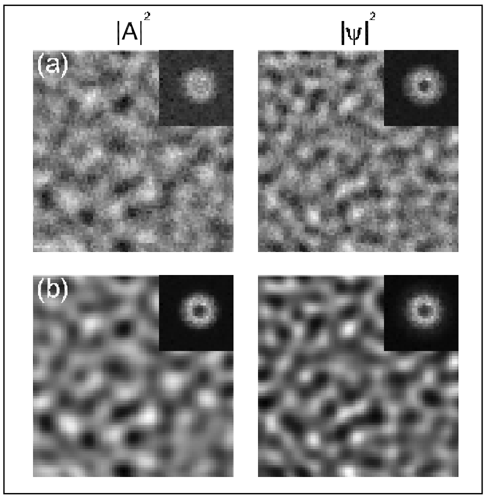


Figure 54. Filamentation patterns, starting from homogeneous fields perturbed by noise at normalised propagation lengths of 55 (a), and 110 (b). Optical field (left column) and atomic field (right column). The insets show the spatial power spectrum.

1. M. Saffman, "Self-induced dipole force and filamentation instability of a matter wave", Phys. Rev. Lett. **81**, 65-68 (1998).

4.4.5 Spatial structures in singly resonant second harmonic generation

P. Lodahl and M. Saffman
E-mail: mark.saffman@risoe.dk

Optical pattern formation has been studied intensively in the last few years. Although the field started with studies of instabilities in cubically nonlinear media, much recent attention has been directed at interactions governed by quadratic nonlinearity. One motivation for studying spatial instabilities in quadratic $\chi^{(2)}$ media is that they are well suited for producing non-classical states of light. Strong non-classical temporal correlations have been generated using both optical parametric oscillation and the reverse process of second harmonic generation (SHG). Since these devices can also be used for creating spatial structures, there is a clear prospect of obtaining patterns with non-classical spatial correlations, as has been emphasised by Lugiato and coworkers.

From an experimental point of view it is important to look for simple configurations, and this makes singly resonant SHG interesting. In this configuration the fundamental field is resonated in a cavity, while the second harmonic escapes freely. Both bistability and non-classical light have already been demonstrated experimentally. In the present work we have performed an analytical and numerical study of transverse instabilities in the singly resonant configuration. Depending on the parameters chosen either periodic spatial patterns or localised excitations (cavity solitons) are predicted. Figure 55 shows examples of both types of structures. Experimental work is in progress towards observing these structures.

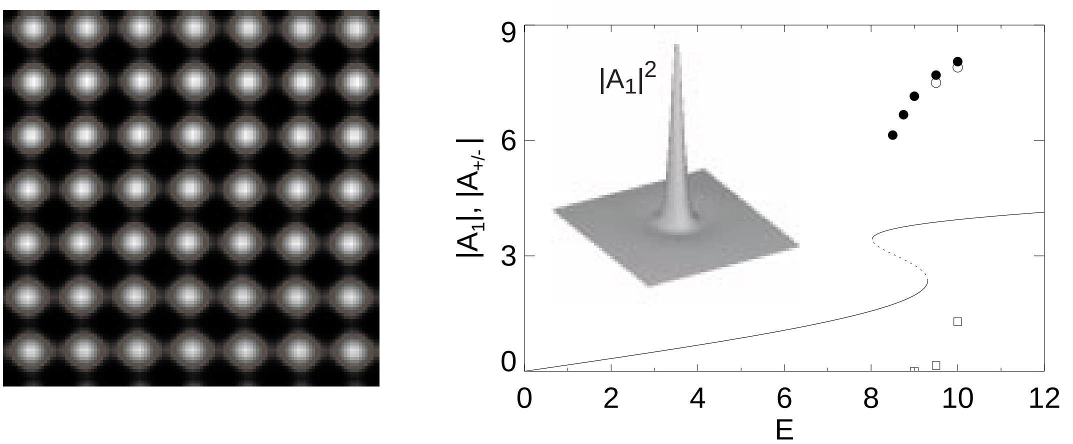


Figure 55. Square patterns (left) and cavity solitons (right) obtained by numerical solution of a mean-field model of singly resonant SHG. The cavity solitons are seen to exist for parameters where the intracavity field *A* is a bistable function of the driving field *E*.

1. P. Lodahl and M. Saffman, "Pattern formation in singly resonant second harmonic generation with competing parametric oscillation", submitted (1998).

4.4.6 Fusion, collapse and stationary bound states of interacting light beams in bulk cubic media

O. Bang (The Australian National University, Canberra, Australia), L. Bergé (CEA/Bruyéres-le-Châtel, France), M. R. Schmidt, and J. J. Rasmussen
E-mail: jens.juul.rasmussen@risoe.dk

The interaction between two localised light beams propagating in a bulk (two transverse dimensions) non-linear Kerr medium is investigated theoretically and numerically. For the case where the beams are incoherently coupled through the cross-phase modulation, their evolution is governed by two coupled non-linear Schrödinger (NLS) equations. The different types of stationary solitary wave solutions are found. The direct numerical solutions of the coupled NLS equations indicate that these soliton solutions are unstable. For the interaction of two beams we have derived sufficient conditions for when the wave function is bound to collapse or spread out, and the regimes of different dynamical behaviour are described (these results are also generalised to the interaction of an arbitrary number of beams[1]). Numerical solutions with overlapping beams confirm these predictions, and it is only for the cases when the initial beams and the coupled equations are symmetric that the conditions are also necessary. For beams that are initially separated in space we predict and confirm numerically the power-dependent characteristic initial separations that divide the phase space into collapsing and diffracting regimes, and further divide each of these regimes into subregimes of coupled (fusion) and uncoupled dynamics. Close to the threshold of collapse we observe that the wave beams can cross several times before eventually collapsing or diffracting.

For the coherent interaction between two light beams (the beams are described by one NLS equation) fusion and subsequent collapse can also be found.[2] However, for that case the relative phase between the beams plays a crucial role (i.e., two identical beams of opposite phase will never merge) and only for the case of symmetric initial conditions will the behaviour be similar to the incoherent interaction. For the case of beams having different initial power the phases of the beams evolve differently and a phase difference will result, leading to very complex interactions. Still, a critical separation distance can be identified below which the beams will merge and ultimately collapse, but the collapse does not take place at the position of the their "centre of mass". The resulting collapsing beam gains a chirp that makes it move. We also "measured" the power transfer during the merging and collapse which indicated a transfer of power from the weak to the strong beam. The evolution of beams of different initial phases was also investigated and different scenarios ranging from merging and collapse to repulsion were observed. In contrast to the case of equal beams, two beams of different intensity with initial opposite phase may also merge and collapse if their separation is below a critical value, since their phase difference will change.

1. L. Bergé, Phys. Rev E **58,** 6606-6625 (1998).
2. L. Bergé, M. R. Schmidt, J. Juul Rasmussen, K.Ø. Rasmussen and P. L. Christiansen, P.L., J. Opt. Soc. Am. B **14**, 2550-2562 (1997).

4.4.7 Control of self-focusing of light beams in bulk cubic media with varying non-linear refractive index

V. K. Mezentsev (Institute for Automation and Electrometry, Novosibirsk, Russia), L. Bergé (CEA/Bruyéres-le-Châtel, France), P. L. Christiansen (IMM, The Technical University of Denmark, Lyngby), Yu. B. Gaididei (Institute for Theoretical Physics, Kiev, Ukraine) and J. J. Rasmussen
E-mail: jens.juul.rasmussen@risoe.dk

Self-trapping and self-focusing of intense optical beams propagating in a bulk (two transverse dimensions) diffractive, non-linear Kerr medium may result in a catastrophic collapse for beam intensities above a critical value. This will have damaging effects on the medium. For intensities below this critical value the beam will simply diffract and spread out. We have investigated the possibility for avoiding the collapse and for forming a stable beam in media with a periodically varying non-linear coefficient (or a periodically varying diffraction constant) by exploiting the ideas for obtaining so-called dispersion managed solitons[1] in non-linear optical fibres. By means of analytical estimates based on a variational approach we have obtained the conditions for obtaining "stable" beams with constant radius and intensity averaged over the period of the variation of the non-linear coefficient. This result is confirmed by numerical solutions of the two-dimensional cubic non-linear Schrödinger equation with varying non-linear coefficient.

1. S.K. Turitsyn, V.K. Mezentsev and E.G. Shapiro, Optical Fiber Technology **4**, 384–452 (1998).

4.4.8 Dynamics of solitons in higher order non-linear Schrödinger equations

V. I. Karpman (Racah Institute of Physics, Hebrew University, Jerusalem, Israel), A. Shagalov (Institute for Metal Physics, Ekaterinburg, Russia) and J. J. Rasmussen
E-mail: jens.juul.rasmussen@risoe.dk

The evolution of localised soliton solutions to the generalised non-linear Schrödinger (G-NLS) equation is investigated analytically and numerically. The G-NLS equation describes, e.g., the evolution of ultrashort pulses in optical waveguides. Using suitable normalisations the equation reads:

$$iu_t + \tfrac{1}{2}u_{\xi\xi} + |u|^4 u = -i\alpha u_{\xi\xi\xi} + i\beta|u|^2 u_\xi + i\gamma\left(|u|^2\right)_\xi u,$$

where the coefficients, α, β and γ are real. In particular, we have focussed our attention on the influence of higher order dispersive effects. The third-order dispersion, with the coefficient α, is found to give rise to radiation from the localised pulse, and this effect will hinder the formation of a completely stationary solution. However, a quasi-steady pulse with a weak tail of radiation is found numerically to evolve from initial conditions corresponding to the soliton solution in the absence of the third-order dispersive term. The asymptotic state is shown in Figure 56. The spectrum of the radiation agrees with theoretical predictions. Furthermore, we found that the third-order dispersive term can arrest the wave collapse that appears in the cases of the quintic non-linearity.

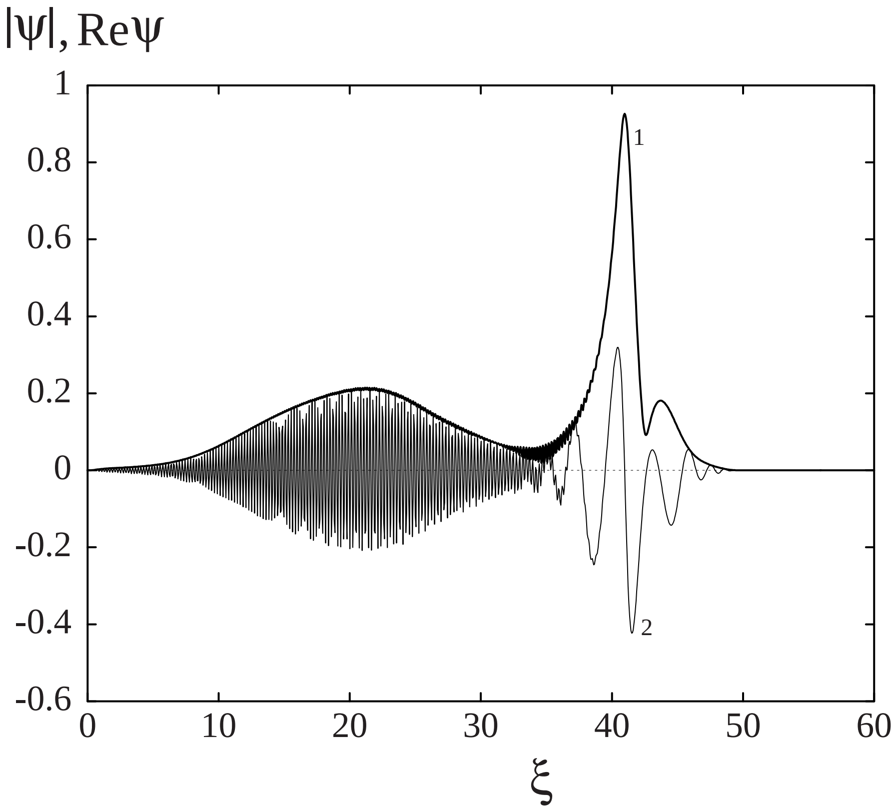


Figure 56. The asymptotic evolution of a solitary solution to the G-NLS equation for an initial condition corresponding to a soliton solution of the G-NLS for $\alpha = 0$; $\alpha = 0.02$; $\beta = \gamma = 1$. The curve labelled 1 is showing $|\psi|$ and 2 is showing $\mathrm{Re}\psi$.

4.4.9 Polaron dynamics in two-dimensional anharmonic Holstein model

Y. Zolotaryuk, P. L. Christiansen* (*IMM, The Technical University of Denmark, Lyngby) and J. J. Rasmussen*
E-mail: jens.juul.rasmussen@risoe.dk

The *polaron* concept is ubiquitous in physics as designating, e.g., an extra electron or a hole localised within a potential well that it creates by displacing the atoms surrounding it or, more generally, any quantum particle or quasi-particle interacting with atoms. Several studies have recently been devoted to the dynamical properties of polarons. We have investigated the polaron dynamics on a two-dimensional lattice using the so-called Holstein model with realistic on-site potential that contains anharmonicity. The potential is modelled using the logarithmic approximation, which allows us to employ a variational approach to find the polaron solutions analytically. The analytical estimates suggest the existence of standing wide polarons, contrary to the case with on-site harmonic potential, where only narrow polarons exist. Direct numerical solutions of the model equations confirm these estimates and provide strong indications for the stability of these polaron solutions. We have also investigated moving polaron solutions and find that they can propagate over large distances without changing shape or velocity. Initial investigations of the collision of two moving polarons show that the interaction is close to being elastic at least for the interaction of polarons of large relative velocity.

5. Publications and Educational Activities

5.1 Optical Materials

5.1.1 International publications

Archut, A.; Vogtle, F.; De Cola, L.; Azzellini, G.C.; Balzani, V.; Ramanujam, P.S.; Berg, R.H., Azobenzene-functionalized cascade molecules: Photoswitchable supramolecular systems. Chemistry - Eur. J. (1998) v. 4 p. 699-706.

Ellegaard, O.; Schou, J., Ablation of volatile films by laser heating of substrates. J. Appl. Phys. (1998) v. 83 p. 1078-1086.

Hansen, T.N.; Schou, J.; Lunney, J.G., Angle-resolved energy distributions of laser ablated silver ions in vacuum. Appl. Phys. Lett. (1998) v. 72 p. 1829-1831.

Hanson, S.G.; Lindvold, L.; Hansen, B.H., Robust optical systems for nondestructive testing based on laser diodes and diffractive optical elements. Opt. Lasers Eng. (1998) v. 30 p. 179-189.

Hildebrandt, R.; Hegelich, M.; Keller, H.-M.; Marowsky, G.; Hvilsted, S.; Holme, N.C.R.; Ramanujam, P.S., Time-resolved investigation of photoinduced birefringence in azobenzene side-chain polyester films. Phys. Rev. Lett. (1998) v. 81 p. 5548-5551.

Holme, N.C.R.; Norris, T.B.; Pedersen, M.; Hvilsted, S:; Ramanujam, P.S., Time resolved spectroscopy of azobenzene. Polym. Prep. (1998) v. 39 (no.2) p. 334-335.

Holme, N.C.R.; Norris, T.B.; Pedersen, M.; Hvilsted, S.; Ramanujam, P.S., Time resolved spectroscopy of azobenzene. Abstr. Pap. Am. Chem. Soc. (1998) v. 216 p. 430-POLY.

Hvilsted, S.; Pedersen, M.; Holme, N.C.R.; Ramanujam, P.S., Azobenzene side-chain liquid crystalline polyesters with outstanding optical storage properties. Turk. J. Chem. (1998) v. 22 p. 33-45.

Hvilsted, S.; Pedersen, M.; Holme, N.C.R.; Ramanujam, P.S., The importance of the substituent on azobenzene side-chain polyester optical storage materials. Polym. Prep. (1998) v. 39 (no.2) p. 298-299.

Hvilsted, S.; Pedersen, M.; Holme, N.C.R.; Ramanujam, P.S., The importance of the substituent on azobenzene side-chain polyester optical storage materials. Abstr. Pap. Am. Chem. Soc. (1998) v. 216 p. 201-POLY.

Johansen, P.M.; Pedersen, H.C.; Pedersen, T.G.; Wyller, J., Cascading solution of the space-charge field problem in ac field biased photorefractive media. J. Opt. Soc. Am. B (1998) v. 15 p. 1168-1176.

Johansen, P.M.; Pedersen, H.C., Photorefractive space-charge field with running grating and applied sinusoidal ac electric field: Solution for all time scales. J. Opt. Soc. Am. B (1998) v. 15 p. 1366-1374.

Johansen, P.M.; Pedersen, H.C.; Podivilov, E.V.; Sturman, B.I., Steady-state analysis of ac subharmonic generation in photorefractive sillenite crystals. Phys. Rev. A (1998) v. 58 p. 1601-1604.

Kulinna, C.; Hvilsted, S.; Hendann, C.; Siesler, H.W.; Ramanujam, P.S., Selectively deuterated liquid crystalline cyanoazobenzene side-chain polyesters. 3. Investigations of laser induced segmental mobility by Fourier transform infrared spectroscopy. Macromolecules (1998) v. 31 p. 2141-2151.

Løbel, M., Wavelength selectivity of the complex grating structure formed in a photorefractive phase conjugator. J. Appl. Phys. (1998) v. 84 p. 3483-3490.

Løbel, M.; Petersen, P.M.; Johansen, P.M., Suppressing self-induced frequency scanning of a phase conjugate diode laser array with using counterbalance dispersion. Appl. Phys. Lett. (1998) v. 72 p. 1263-1265.

Løbel, M.; Petersen, P.M.; Johansen, P.M., Single-mode operation of a laser-diode array with frequency-selective phase-conjugate feedback. Opt. Lett. (1998) v. 23 p. 825-827.

Løbel, M.; Petersen, P.M.; Johansen, P.M., Tunable single-mode operation of a high-power laser-diode array by use of an external cavity with a grating and a photorefractive phase-conjugate mirror. J. Opt. Soc. Am. B (1998) v. 15 p. 2000-2005.

Madsen, S.; Holme, N.C.R.; Ramanujam, P.S.; Hvilsted, S.; Hvam, J.M.; Smith, S.J., Optimizing the fabrication of aluminum-coated fiber probes and their application to optical near-field lithography. Ultramicroscopy (1998) v. 71 p. 65-71.

Naydenova, I.; Nikolova, L.; Todorov, T.; Holme, N.C.R.; Ramanujam, P.S.; Hvilsted, S., Diffraction from polarization holographic gratings with surface relief in side-chain azobenzene polyesters. J. Opt. Soc. Am. B (1998) v. 15 p. 1257-1265.

Nikolajsen, T.; Johansen, P.M.; Dubovik, E.; Batirov, T.; Djalalov, R., Photorefractive two-step recording in a piezoelectric $La_3Ga_5SiO_{14}$ crystal doped with praseodymium. Opt. Lett. (1998) v. 23 p. 1164-1166.

Pedersen, H.C.; Johansen, P.M.; Webb, D.J., Photorefractive subharmonics - a beam-coupling effect?. J. Opt. Soc. Am. B (1998) v. 15 p. 1528-1532.

Pedersen, H.C.; Johansen, P.M.; Podivilov, E.V.; Webb, D.J., Excitation of higher harmonic gratings in AC-field biased photorefractive crystals. Opt. Commun. (1998) v. 154 p. 93-99.

Pedersen, H.C.; Webb, D.J.; Johansen, P.M., Influence of beam-coupling on photorefractive parametric oscillation in a dc-field-biased $Bi_{12}SiO_{20}$. J. Opt. Soc. Am. B (1998) v. 15 p. 2439-2445.

Pedersen, H.C.; Webb, D.J.; Johansen, P.M., Fundamental characteristics of space-charge waves in photorefractive sillenite crystals. J. Opt. Soc. Am. B (1998) v. 15 p. 2573-2580.

Pedersen, T.G.; Johansen, P.M.; Holme, N.C.R.; Ramanujam, P.S.; Hvilsted, S., Mean-field theory of photoinduced formation of surface reliefs in side-chain azobenzene polymers. Phys. Rev. Lett. (1998) v. 80 p. 89-92.

Pedersen, T.G.; Johansen, P.M.; Holme, N.C.R.; Ramanujam, P.S.; Hvilsted, S., Theoretical model of photoinduced anisotropy in liquid-crystalline azobenzene side-chain polyesters. J. Opt. Soc. Am. B (1998) v. 15 p. 1120-1129.

Pedersen, T.G.; Johansen, P.M., Mean-field theory of optical storage in liquid crystalline side-chain polymers. Opt. Mater. (1998) v. 9 p. 212-215.

Pedersen, T.G.; Ramanujam, P.S.; Johansen, P.M.; Hvilsted, S., Quantum theory and experimental studies of absorption spectra and photoisomerization of azobenzene polymers. J. Opt. Soc. Am. B (1998) v. 15 p. 2721-2730.

Podivilov, E.V.; Pedersen, H.C.; Johansen, P.M.; Sturman, B.I., Transversal parametric oscillation and its external stability in photorefractive sillenite crystals. Phys. Rev. E (1998) v. 57 p. 6112-6126.

Ramanujam, P.S.; Holme, N.C.R.; Nikolova, L.; Hvilsted, S.; Pedersen, M.; Berg, R.H.; Rasmussen, P.H., Surface relief in azobenzene polymers. Polym. Prep. (1998) v. 39 (no.2) p. 290-291.

Ramanujam, P.S.; Holme, N.C.R.; Nikolova, L.; Hvilsted, S.; Pedersen, M.; Berg, R.H.; Rasmussen, P.H., Surface relief in azobenzene polymers. Abstr. Pap. Am. Chem. Soc. (1998) v. 216 p. 197-POLY.

Rasmussen, P.H.; Ramanujam, P.S.; Hvilsted, S.; Berg, R.H., Prolin-baserede DNO-strukturer. DK patentansøgning PA 1998 00855.

Schou, J.; Heisel, T., Methods and an apparatus for severing or damaging unwanted plants. DK patentansøgning PA 1998 00953.

Schou, J.; Thestrup, B.; Svendsen, W.; Stenum, B.; Ellegaard, O.; Pedrys, R.; Warczak, B., Sputtering of surfaces of the solid hydrogens. J. Low Temp. Phys. (1998) v. 111 p. 569-576.

Svendsen, W.; Schou, J.; Hansen, T.N.; Ellegaard, O., Angular distributions of emitted particles by laser ablation of silver at 355 nm. Appl. Phys. A (1998) v. 66 p. 493-497.

5.1.2 Danish publications

Løbel, M.B.H., Improvement of the coherence characteristics of laser diode arrays using photorefractive phase conjugation. Risø-R-1038(EN) (1998) 147 p. (ph.d. thesis).

5.1.3 Conference lectures

Hvilsted, S.; Pedersen, M.; Holme, N.C.R.; Ramanujam, P.S., Quantification of optical storage properties of azobenzene polymer film materials. In: World polymer congress. MACRO 98. 37. International symposium on macromolecules. Preprints, Gold Coast, Queensland (AU), 12-17 Jul 1998. (International Union of Pure and Applied Chemistry (IUPAC), Gold Coast, 1998) p. 329.

Johansen, P.M.; Pedersen, H.C.; Podivilov, E.V., Subharmonics in photorefractive sillenites generated by running grating and dc electric field and by ac square wave field. In: IPC'98. Proceedings. 1998 International photonics conference, Taipei (TW), 15-18 Dec 1998. (National Taiwan University, College of Electrical Engineering, Taipei (TW), 1998) p. 25-27.

Ramanujam, P.S.; Berg, R.H.; Hvilsted, S., Holographic memories. In: Photonics-98. Vol. 3. International conference on fiber optics and photonics, New Delhi (IN), 14-18 Dec 1998. Sharma, A.; Ghatak, A. (eds.), (Viva Books, New Delhi, 1999) p. 953-957.

5.1.4 Publications for a broader readership

Løbel, M.; Petersen, P.M.; Johansen, P.M., Single-mode high-power semiconductor lasers using phase conjugation. DOPS-Nyt (1998) v. 13 (no.3) p. 6-10.

5.1.5 Unpublished Danish lectures

Ellegaard, O.; Schou, J., Can molecular dynamic simulations be used for laser ablation?. LASER '98, Nyborg (DK), 22-23 Jan 1998. Unpublished.

Hansen, T.N.; Shen, Y.Q.; Lunney, J.G.; Schou, J., Laser ablation of silver in a background gas. LASER '98, Nyborg (DK), 22-23 Jan 1998. Unpublished.

Johansen, P.M., Space charge dynamics in photorefractive media. Graduate school in nonlinear science. Minicourse on spatial nonlinear optics, Risø (DK), 27-28 May 1998. Unpublished.

Johansen, P.M., Optical materials: Linear and non-linear effects. Møde på Kemisk Institut, Århus Universitet, Århus (DK), 9 Jun 1998. Unpublished. Abstract available.

Pedrys, R.; Krok, F.; Warczak, B.; Schou, J., Emission of D_2O molecules from heavy water ice induced by electron and slow ion impact. Meeting of the Danish Sputtering Club, Odense (DK), 11 Nov 1998. Unpublished.

Schou, J.; Hansen, T.N.; Toftmann Christensen, B.; Nordskov, A.; Ellegaard, O.; Lunney, J.G., Emission of neutrals, ions and electrons from laser ablated silver at 355 nm. In: Danish Physical Society annual meeting 1998. Book of abstracts. Annual meeting of the Danish Physical Society, Nyborg (DK), 3-4 Jun 1998. (HCØ Tryk, København, 1998) p. AF17P.

Schou, J.; Thestrup, B.; Nordskov, A.; Larsen, N.B., Production of thin films of ITO by laser ablation. LASER '98, Nyborg (DK), 22-23 Jan 1998. Unpublished.

Schou, J.; Thestrup, B.; Toftmann, B.; Ellegaard, O.; Hansen, T.N.; Lunney, J., Ion-gas atom collisions during laser ablation of silver. In: Annual meeting of the Danish Optical Society. (DOPS), Aalborg (DK), 19-20 Nov 1998. (Aalborg Universitet, Aalborg, 1998) p. 25.

Thestrup, B.; Schou, J.; Nordskov, A.; Larsen, N.B., A study on indium tin oxide films produced by laser ablation in different background gases. In: Danish Physical Society annual meeting 1998. Book of abstracts. Annual meeting of the Danish Physical Society, Nyborg (DK), 3-4 Jun 1998. (HCØ Tryk, København, 1998) p. AF16P.

Thestrup, B.; Schou, J.; Nordskov, A.; Larsen, N.B., Background gas effects on deposition of ITO films by pulsed laser deposition. In: Annual meeting of the Danish Optical Society. (DOPS), Aalborg (DK), 19-20 Nov 1998. (Aalborg Universitet, Aalborg, 1998) p. 21.

Thestrup, B.; Schou, J.; Nordskov, A.; Larsen, N.B., Pulsed laser deposition of ITO in different background gases. Meeting of the Danish Sputtering Club, Odense (DK), 11 Nov 1998. Unpublished.

5.1.6 Unpublished international lectures

Berg, R.H.; Ramanujam, P.S.; Hvilsted, S.; Rasmussen, P.H., Peptide-based designs for DNA recognition and optical information storage. In: Funktionen auf der Nanoskala. Jahreskolloquium des SFB 239 und des Graduiertenkollegs 328, Ulm (DE), 27-28 Nov 1998. (Universität Ulm, Ulm, 1998) 1 p.

Berg, R.H.; Rasmussen, P.H.; Ramanujam, P.S.; Hvilsted, S., Peptides for optical data storage and DNA recognition. In: Program and proceedings. 41. Annual meeting. Canadian federation of Biological Societies, Edmonton (CA), 17-20 Jun 1998. (Canadian Federation of Biological Societies, Edmonton, 1998) 1 p.

Hansen, T.N.; Christensen, B.T.; Lunney, J.G.; Schou, J., Ion dynamics and electron temperature of laser produced plasmas in vacuum and low pressure gas. In: Extended abstracts. 14. European conference on the atomic and molecular physics of ionised gases. ESCAMPIG 98, Dublin (IE), 26-29 Aug 1998. (European Physical Society, Geneva, 1998) (Europhysics conference abstracts vol. 22H) p. 446-447.

Hansen, T.N.; Schou, J.; Lunney, J.G., Ion time-of-flight study of laser ablation of silver in low pressure gases. E-MRS Spring meeting 1998, Strasbourg (FR), 16-19 Jun 1998. Unpublished. Abstract available.

Hansen, T.N.; Schou, J.; Ellegaard, O.; Toftmann Christensen, B.; Lunney, J.G., Dynamics of laser ablation plasma in vacuum and low pressure gases. Gordon research conference on laser interactions with materials, Andover, NH (US), 7-12 Jun 1998. Unpublished. Abstract available.

Hvilsted, S.; Hendann, C.; Kulinna, C.; Ramanujam, P.S., Laser-induced segmental mobility in azobenzene side-chain polyester optical storage materials. COST 518 workshop on molecular materials and functional polymers for advanced devices, Bratislava (SK), 21-22 May 1998. Unpublished. Abstract available.

Hvilsted, S.; Holme, N.C.R.; Ramanujam, P.S., Processes of importance for the holographic storage in azobenzene side-chain LC polyesters. COST action 518. Molecular materials and functional polymers for advanced devices. Working Group 3: Functional polymers, Varenna (IT), 17-18 Sep 1998. Unpublished. Abstract available.

Hvilsted, S.; Pedersen, M.; Holme, N.C.R.; Ramanujam, P.S., Azobenzene side-chain polyesters - challenging materials for optical information storage. Sino - Danish seminar on polymer research: Functional polymers. Danish Polymer Center, Roskilde (DK), 15-16 Jun 1998. Unpublished. Abstract available.

Hvilsted, S.; Ramanujam, P.S., Prodigious optical storage polyesters - The matrix-integrated azobenzene puzzle. Conference on unifying principles for engineering soft materials. Risø National Laboratory; University of Minnesota, Roskilde (DK), 22-25 Jun 1998. Unpublished. Abstract available.

Hvilsted, S.; Ramanujam, P.S., Azobenzene side-chain polymers - a prodigious potential for optical information storage. 2. Workshop on non equilibrium phenomena in supercooled fluids, glasses and amorphous materials, Pisa (IT), 27 Sep - 2 Oct 1998. Unpublished. Abstract available.

Petersen, P.M., Optical storage in photorefractive materials. Materials for optical storage, Risø (DK), 10 Mar 1998. Unpublished.

Petersen, P.M., New laser systems using phase conjugate feedback. Nordic Graduate Physics program, visit to Risø, Risø (DK), 11 Sep 1998. Unpublished.

Petersen, P.M.; Løbel, M.; Johansen, P.M., Single-mode operation of laser diode arrays using photorefractive phase conjugators (Invited paper). In: CLEO/Europe'98. Technical digest. Conference on lasers and electro-optics-Europe, Glasgow (GB), 14-18 Sep 1998. (IEEE, Piscataway, NJ, 1998) p. 236.

Petersen, P.M.; Løbel, M.; Johansen, P.M., Single mode operation of laser diode arrays using frequency selective phase conjugate feedback. In: Programme and book of abstracts. Workshop on "Applications of nonlinear phenomena", Limerick (IE), 12-13 Jun 1998. (University of Limerick, Limerick, 1998) 1 p.

Ramanujam, P.S., Optical information storage in azobenzene side-chain polyesters. Materials for optical storage, Risø (DK), 10 Mar 1998. Unpublished.

Ramanujam, P.S., Optical storage. Nordic Graduate Physics program, visit to Risø, Risø (DK), 11 Sep 1998. Unpublished.

Ramanujam, P.S., Holographic storage in azobenzene polymers. Lecture at the Department of Physics and Mathematical Physics, University of Adelaide, Adelaide (AU), 27 Jul 1998. Unpublished. Abstract available.

Thestrup, B., Laser ablation. Nordic Graduate Physics program, visit to Risø, Risø (DK), 11 Sep 1998. Unpublished.

Thestrup, B.; Schou, J.; Nordskov, A.; Larsen, N.B., Indium tin oxide films produced by laser ablation in different background gases. Gordon research conference on laser interactions with materials, Andover, NH (US), 7-12 Jun 1998. Unpublished. Abstract available.

Thestrup, B.; Schou, J.; Nordskov, A.; Larsen, N.B., Electrical and optical properties of thin indium tin oxides films produced by pulsed laser deposition in oxygen or rare gas atmospheres. International conference on solid films and surfaces. ICSFS 9, København (DK), 6-10 Jul 1998. Unpublished. Abstract available.

Toftmann Christensen, B.; Hansen, T.N.; Schou, J.; Lunney, J.G., Electron temperatures of laser-induced plasmas. SASP 98. Symposium on atomic and surface physics and related topics, Going (AT), 25-30 Jan 1998. Unpublished. Abstract available.

5.1.7 Internal reports

Bidrag til Forskningscenter Risøs 3-årsplan 1997-1999 fra Afdelingen for Optik og Fluid Dynamik. Risø-Dok-470 (1996) 32 p.

5.2 Optical Diagnostics and Information Processing

5.2.1 International publications

Andersen, P.E.; Petersen, P.M., Kinetics of higher order combinational gratings in photorefractive media: Diffusion regime. J. Opt. Soc. Am. B (1998) v. 15 p. 2032-2036.

Bak, J., Measurements of impurities in strongly absorbing powdery materials by DRIFTS. Internet J. Vib. Spectrosc. (1998) v. 2 (no.4).

Dam, J.S.; Andersen, P.E.; Dalgaard, T.; Fabricius, P.E., Determination of tissue optical properties from diffuse reflectance profiles by multivariate calibration. Appl. Opt. (1998) v. 37 p. 772-778.

Glückstad, J., Pattern generation by inverse phase contrast. Comment. Opt. Commun. (1998) v. 147 p. 16-18.

Glückstad, J., Graphic method for analyzing common path interferometers. Opt. Photonics News (1998) v. 9 (no.8) p. 2 p.

Glückstad, J., Graphic method for analyzing common path interferometers. Appl. Opt. (1998) v. 37 p. 8151-8152.

Glückstad, J., An optical image encryption/decryption method and system. DK patentansøgning PA 1998 00869.

Hanson, S.G.; Lindvold, L.; Hansen, B.H., Robust optical systems for nondestructive testing based on laser diodes and diffractive optical elements. Opt. Lasers Eng. (1998) v. 30 p. 179-189.

Jørgensen, T.M., Optimisation of RAM nets using inhibition between classes. In: RAM-based neutral networks. Austin, J. (ed.), (World Scientific, Singapore, 1998) (Progress in neutal processing, 9) p. 123-129.

Jørgensen, T.M.; Christensen, S.S.; Liisberg, C., Cross-validation and information measures for RAM based neural networks. In: RAM-based neutral networks. Austin, J. (ed.), (World Scientific, Singapore, 1998) (Progress in neural processing, 9) p. 78-88.

Jørgensen, T.M.; Linneberg, C., LUT netværk. DK patentansøgning PA 1998 00162.

Lading, L.; Lindvold L., Detection of a substance by refractive index change. DK patentansøgning 0091/98 (23.1.1998).

Linneberg, C.; Andersen, A.W.; Jørgensen, T.M.; Christensen, S.S., Detecting danger labels with ram based neural networks. In: RAM-based neutral networks. Austin, J. (ed.), (World Scientific, Singapore, 1998) (Progress in neural processing, 9) p. 205-212.

Linneberg, C.; Jørgensen, T.M., N-tuple or Ram based neural network classification system and method. DK patentansøgning PA 1998 00883.

Popov, I.A.; Sidorovsky, N.V.; Veselov, I.L.; Hanson, S.G., Statistical properties of focal plane speckle. Opt. Commun. (1998) v. 156 p. 16-21.

Rose, B.; Imam, H.; Hanson, S.G.; Yura, H.T., A laser speckle sensor to measure the distribution of static torsion angles of twisted targets. Meas. Sci. Technol. (1998) v. 9 p. 42-49.

Rose, B.; Imam, H.; Hanson, S.G.; Yura, H.T.; Hansen, R.S., Laser-speckle angular-displacement sensor: Theoretical and experimental study. Appl. Opt. (1998) v. 37 p. 2119-2129.

Rose, B.; Imam, H.; Hanson, S.G., Non-contact laser speckle sensor for measuring one- and two-dimensional angular displacement. J. Opt. (1998) v. 29 p. 115-120.

Yura, H.T.; Rose, B.; Hanson, S.G., Speckle dynamics from in-plane rotating diffuse objects in complex ABCD optical systems. J. Opt. Soc. Am. A (1998) v. 15 p. 1167-1173.

Yura, H.T.; Rose, B.; Hanson, S.G., Dynamic laser speckle in complex ABCD optical systems. J. Opt. Soc. Am. A (1998) v. 15 p. 1160-1166.

5.2.2 Danish publications

Clausen, S.; Bak, J. (eds.), AEROPROFILE - er i luften. (Forskningscenter Risø. IR-Spektroskopigruppen, Roskilde, 1998) (Industriel IR-analyse. Nyhedsbrev, august 1998) 2 p.

Rose, B., Dynamic laser speckle: Physics and applications. (Technical University of Denmark. Mikroelektronik Centret, Lyngby, 1998) 116 p. (ph.d. thesis).

5.2.3 Conference lectures

Clausen, S.; Bak, J., Infrared low resolution emission spectroscopy of hot gases. In: Electro-optical technology for remote chemical detection and identification 3. Proceedings, Orlando, FL (US), 13 Apr 1998. Fallahi, M.; Howden, E. (eds.), (The International Society for Optical Engineering, Bellingham, WA, 1998) (SPIE Proceedings Series, 3383) p. 133-139.

Dam-Hansen, C., Advanced optical flowsensor for industrial use based on a holographical optical element (invited talk). In: Proceedings. Seminar: Laser Doppler velocimetry and other advanced measurement methods to improve the accuracy of district heating meter measurement and calibration. One-day conference: Remote reading and communication with district heating meters, Århus (DK), 12-13 Aug 1998. (Danish Technological Institute, DTI Energy, Taastrup, 1998) (Nordisk energiforskningssamarbejde) 12 p.

Dam-Hansen, C.; Stubager, J.; Lindvold, L.; Lading, L., Compact and low cost holographic optical front end for an industrial laser time-of-flight flowsensor. In: OPTO 98. Proceedings. 3. International congress and exhibition on optoelectronics, optical sensors and measuring techniques, Erfurt (DE), 18-20 May 1998. (ACS Organisations GmbH, Wunstorf, 1998) p. 7-10.

Glückstad, J., Phase-only light projection (invited paper). In: Projection displays 4. Proceedings, San Jose, CA (US), 24-30 Jan 1998. Ming H. Wu (ed.), (The International Society for Optical Engineering, Bellingham, WA, 1998) (SPIE Proceedings Series, 3296) p. 154-160.

Glückstad, J.; Lading, J., Optimising visibility and irradiance in common path interferometers. In: Proceedings of international conference on optical technology and image processing in fluid, thermal, and combustionn flow. VSJ-SPIE '98, Yokohama (JP), 6-10 Dec 1998. (Visualization Society of Japan, Yokohama, 1998) AB 010.

Jacques, S.L.; Andersen, P.E.; Hanson, S.G.; Lindvold, L., Non-contact detection of laser-induced acoustic waves from buried absorbing objects using a dual-beam common-path interferometer. In: Laser-tissue interaction 9. Proceedings, San Jose, CA (US), 27-29 Jan 1998. Jacques, S.L. (ed.), (The International Society for Optical Engineering, Bellingham, WA, 1998) (SPIE Proceedings Series, 3254) p. 307-318.

Kaiser, N.E., Nøjagtige temperaturmålinger med Pt 100 modstandstermometre. In: Den 20. nordiske konferanse måleteknikk og kalibrering. Jubileumskonferanse, Stenungsund (SE), 15-18 Nov 1998. (NIF, Oslo, 1998) p. Paper 36.

Lindvold, L.; Lading, L., Evanescent field sensing: Cavity-coupled refractive index sensor (CRIS). In: Proceedings. Miniaturized systems with micro-optics and micromechanics 3, San Jose, CA (US), 24-30 Jan 1998. Mottamedi, E.; Goering, R. (eds.), (The International Society for Optical Engineering, Bellingham, WA, 1998) (SPIE Proceedings Series, 3276) p. 220-227.

Popov, I.A.; Sidorovsky, N.V.; Veselov, I.L.; Hanson, S.G., Measurement of the velocity gradient of a rotating body by means of a speckle method. In: 3. International conference on vibration measurements by laser techniques: Advances and applications. Proceedings, Ancona (IT), 16-19 Jun 1998. Tomasini, E.P. (ed.), (The International Society for Optical Engineering, Bellingham, WA, 1998) (SPIE Proceedings Series, 3411) p. 328-338.

Toyoda, H.; Glückstad, J., Liquid crystal phase-contrast pattern projection. In: Optics in computing '98. Proceedings, Brügge (BE), 17-20 Jun 1998. Chavel,P.; Miller, D.A.B.; Thienpont, H. (eds.), (The International Society for Optical Engineering, Bellingham, WA, 1998) (SPIE Proceedings Series, 3490) P85.

5.2.4 Publications for a broader readership

Andersen, P.E., Har du set DOPS' homepage?. DOPS-Nyt (1998) v. 13 (no.1) p. 4-6.

Dam-Hansen, C., Præcise og billige vandmålere. Risønyt (1998) (no.1) p. 9.

Dam-Hansen, C., En optisk flowsensor til industriel brug. DOPS-Nyt (1998) v. 13 (no.3) p. 11-15.

Hanson, S.G., "Speckles" er forskernes nye måleværktøj. Risønyt (1998) (no.3) p. 7-8.

Lindvold, L.; Rasmussen, E., Gennembrud for SDC-DanDisc og Risø. Risønyt (1998) (no.1) p. 7-8.

5.2.5 Unpublished Danish lectures

Andersen, P.E., Diffuse reflectance from multilayered skin structures (invited paper). LASER '98, Nyborg (DK), 22-23 Jan 1998. Unpublished.

Clausen, S., Optisk måling af temperatur- og procesforhold i forbrændingsanlæg. Måleteknik, København (DK), 26 May 1998. Unpublished.

Clausen, S., Industriel gasanalyse med FTIR. Gasanalyse ved Fouriertransform spektroskopi. Temamøde i IGAS, København (DK), 6 Oct 1998. Unpublished.

Dam-Hansen, C., Compact optical flowsensors. LASER '98, Nyborg (DK), 22-23 Jan 1998. Unpublished.

Glückstad, J., An optical 'Smith chart'. In: Annual meeting of the Danish Optical Society. (DOPS), Aalborg (DK), 19-20 Nov 1998. (Aalborg Universitet, Aalborg, 1998) p. 24.

Hanson, S.G., Festtale for dimitterede civilingeniører. Dimission af civilingeniører, Ålborg (DK), 30 Jun 1998. Unpublished.

Jacques, S.; Andersen, P.E.; Hanson, S.G.; Lindvold, L., Photoacoustic probing of human tissue. LASER '98, Nyborg (DK), 22-23 Jan 1998. Unpublished.

Jørgensen, T.M., Tne n-tuple classification concept. Seminar at Torsana, Skodsborg (DK), 23 Oct 1998. Unpublished.

Jørgensen, T.M.; Linneberg, C., Segmentation-classification interaction for intelligent character recognition (ICR). In: Annual meeting of the Danish Optical Society. (DOPS), Aalborg (DK), 19-20 Nov 1998. (Aalborg Universitet, Aalborg, 1998) p. 22.

Kaiser, N.E.; Andersen, F., Temperatur. Måling af temperatur og kalibrering af termometre. Bie & Berntsen A/S seminar, Rødovre (DK), 5 Nov 1998. Unpublished.

Kaiser, N.E.; Andersen, F., Temperatur. Måling af temperatur og kalibrering af termometre. Bie & Berntsen A/S seminar, Rødovre (DK), 10 Nov 1998. Unpublished.

Kaiser, N.E.; Andersen, F., Temperatur. Måling af temperatur og kalibrering af termometre. Bie & Berntsen A/S seminar, Rødovre (DK), 26 Nov 1998. Unpublished.

Kaiser, N.E.; Andersen, F., Temperatur. Måling af temperatur og kalibrering af termometre. Bie & Berntsen A/S seminar, Rødovre (DK), 3 Dec 1998. Unpublished.

Lindvold, L., Polymer optics. What are the potentials in optical sensors?. In: 40 years of research at Risø: A platform for the future - interacting with industry and society. Summary of presentations. Symposium in celebration of Risø's 40. Anniversary, Risø (DK), 3 Jun 1998. Rosendahl, L.; Lading, L. (eds.), Risø-R-1062(EN,DA) (1998) p. 49.

Petersen, P.M.; Andersen, P.E., Optics for medical diagnostics. In: 40 years of research at Risø: A platform for the future - interacting with industry and society. Summary of presentations. Symposium in celebration of Risø's 40. Anniversary, Risø (DK), 3 Jun 1998. Rosendahl, L.; Lading, L. (eds.), Risø-R-1062(EN,DA) (1998) p. 54.

Thrane, L.; Yura, H.T.; Hanson, S.G.; Andersen, P.E., Optical coherence tomography of heterogeneous tissue: Calculation of the heterodyne signal. In: Annual meeting of the Danish Optical Society. (DOPS), Aalborg (DK), 19-20 Nov 1998. (Aalborg Universitet, Aalborg, 1998) p. 14.

5.2.6 Unpublished international lectures

Bak, J., FTIR low resolution spectroscopy. EU-projektmøde (AEROPROFILE), Risø (DK), 2-3 Jul 1998. Unpublished.

Bak, J.; Clausen, S., FTIR low resolution spectroscopy. Pittcon conference on analytical chemistry and applied spectroscopy, New Orleans, LA (US), 1-5 Mar 1998. Unpublished.

Glückstad, J., New phase contrast encoding methods. Seminar at Regional Centre for Electronics Technologies, University of Durham, Durham (GB), 30 Jun 1998. Unpublished. Abstract available.

Hanson, S., Compact optical sensors for mechanical measurements in industry (invited paper). In: Conference on lasers and electro-optics. Summaries of papers. CLEO '98, San Francisco, CA (US), 3-8 May 1998. (Optical Society of America, Washington, DC, 1998) (1998 OSA Technical Digest Series, 6) Paper CThB3.

Hanson, S.G., Free Pen Project. Meeting at UDT Sensors, Los Angeles, CA (US), 25 Feb 1998. Unpublished.

Limeres, J.; Carrascosa, M.; Andersen, P.E.; Petersen, P.M., Nonlinear cross talk between mutually incoherently recorded gratings in $BaTiO_3$. In: CLEO/Europe'98. Technical digest. Conference on lasers and electro-optics-Europe, Glasgow (GB), 14-18 Sep 1998. (IEEE, Piscataway, NJ, 1998) p. 224.

Lindvold, L.; Larsen, N.B.; Rasmussen, E., The use of elastomer micromoulding to create replicated diffractive optics from a UV-curable resin. Diffractive and holographic device technologies and applications 5. Photonics West 1998, San José, CA (US), 28-29 Jan 1998. Unpublished.

Linneberg, C.; Jørgensen, T.M., Cross-validation techniques for N-tuple based neural networks. VI-DYNN '98, Stockholm (SE), 22-26 Jun 1998. Unpublished.

Thrane, L.; Yura, H.T.; Hanson, S.G.; Andersen, P.E., Optical coherence tomography of heterogeneous tissue: Calculation of the heterodyne signal. In: Cleo/Europe'98. Technical digest. Conference on lasers and electro-optics-Europe, Glasgow (GB), 14-18 Sep 1998. (IEEE, Piscataway, NJ, 1998) 1 p.

Toyoda, H.; Hara, T.; Glückstad, J., Phase-contrast pattern projection system using a liquid crystal phase shifter. In: Japan Society of Applied Physics and Related Society. Extended abstracts. Vol. 3. 59. Autumn meeting, Hiroshima (JP), 15-18 Sep 1998. (JSAP, Hiroshima, 1998) (JSAP Catalog No: AP-981129-03) p. 898.

5.2.7 Internal reports

Andersen, P.E.; Hanson, S.G., Photoacoustic imaging of buried objects using an optical detection scheme. Risø-Dok-561 (1998) 5 p.

Andersen, P.E.; Lindvold, L., Lysspredning og lysudbredelse i homogent spredende medier. Risø-Dok-564 (1998) 19 p.

Andersen, P.E.; Thrane, L., Optical coherence tomography in skin tissue. Risø-Dok-560 (1998) 6 p.

Dannemand Andersen, P.; Idier, D.; Lading, L., Products, markets and technology for biomedicine, energy conversion and fluid dynamics/mechanics in relation to Dantec MT's core competencies. (Risø National Laboratory. Optics and Fluid Dynamics Department, Systems Analysis Department, Roskilde, 1998) 26 p.

Hanson, S.G., Blood perfusion measurements by speckle techniques. (Risø National Laboratory. Optics and Fluid Dynamics Department, Roskilde, 1998) 5 p.

Lading, L., Visco-elastic sensing. (Risø National Laboratory. Optics and Fluid Dynamics Department, Roskilde, 1998) 17 p.

Lindvold, L.R., Corneal and lens autofluorescence: A possible screening method for diabetes related conditions in the human body?. (Risø National Laboratory. Optics and Fluid Dynamics Department, Roskilde, 1998) 3 p.

5.3 Plasma and Fluid Dynamics

5.3.1 International publications

Bang, O.; Berge, L.; Juul Rasmussen, J., Wave collapse in bulk media with quadratic and cubic responses. Opt. Commun. (1998) v. 146 p. 231-235.

Bergé, L.; Juul Rasmussen, J.; Schmidt, M.R., Pulse splitting in nonlinear media with anisotropic dispersion properties. Phys. Scr. (1998) v. T75 p. 18-22.

Christiansen, P.L.; Gaididei, Y.B.; Johansson, M.; Rasmussen, K.O.; Mezentsev, V.K.; Juul Rasmussen, J., Solitary excitations in discrete two-dimensional nonlinear Schrödinger models with dispersive dipole-dipole interactions. Phys. Rev. B (1998) v. 57 p. 11303-11318.

Jensen, S.J.; Schwab, M.; Denz, C., Manipulation, stabilization, and control of pattern formation using Fourier space filtering. Phys. Rev. Lett. (1998) v. 81 p. 1614-1617.

Jovanovic, D.; Pegoraro, F.; Juul Rasmussen, J., Tripolar shear-Alfvén vortex structures. J. Plasma Phys. (1998) v. 60 p. 383-391.

Konijnenberg, J.A. van de; Flor, J.B.; Heijst, G.J.F. van, Decaying quasi-two-dimensional viscous flow on a square domain. Phys. Fluids (1998) v. 10 p. 595-606.

Królikowski, W.; Denz, C.; Stepken, A.; Saffman, M.; Luther-Davies, B., Interaction of spatial photorefractive solitons. Quantum Semiclass. Opt. (1998) v. 10 p. 823-837.

Krolikowski, W.; Saffman, M.; Luther-Davies, B.; Denz, C., Anomalous interaction of spatial solitons in photorefractive media. Phys. Rev. Lett. (1998) v. 80 p. 3240-3243.

Kuroda, K.; Saffman, M.; Zozulya, A.A., Introduction: JOSA B feature issue on Photorefractive materials, effects and devices. J. Opt. Soc. Am. B (1998) v. 15 p. 1968.

Lushnikov, P.M.; Lodahl, P.; Saffman, M., Transverse modulational instability of counterpropagating quasi-phase-matched beams in a quadratically nonlinear medium. Opt. Lett. (1998) v. 23 p. 1650-1652.

Mamaev, A.; Saffman, M.; Zozulya, A.A., Phase-dependent collisions of (2+1)-dimensional spatial solitons. J. Opt. Soc. Am. B (1998) v. 15 p. 2079-2082.

Mamaev, A.V.; Saffman, M., Selection of unstable patterns and control of optical turbulence by Fourier plane filtering. Phys. Rev. Lett. (1998) v. 80 p. 3499-3502.

Naulin, V., Turbulent transport by higher-order particle drifts. Europhys. Lett. (1998) v. 43 p. 533-538.

Naulin, V.; Nielsen, A.H.; Juul Rasmussen, J., Diffusion of ideal particles in a 2D-model of electrostatic turbulence. Physicalia Mag. (1998) v. 20 p. 123-130.

Naulin, V.; Nycander, J.; Juul Rasmussen, J., Equipartition and transport in two-dimensional electrostatic turbulence. Phys. Rev. Lett. (1998) v. 81 p. 4148-4151.

Saffman, M., Self-induced dipole force and filamentation instability of a matter wave. Phys. Rev. Lett. (1998) v. 81 p. 65-68.

Saffman, M.; Zozulya, A.A., Circular solitons do not exist in photorefractive media. Opt. Lett. (1998) v. 23 p. 1579-1581.

Schjødt-Eriksen, J.; Schmidt, M.R.; Rasmussen, J.J.; Christiansen, P.L.; Gaididei, Y.B.; Berge, L., Two-beam interaction in saturable media. Phys. Lett. A (1998) v. 246 p. 423-428 Schmidt, M.R.; Beckers, M.; Nielsen, A.H.; Juul Rasmussen, J.; Heijst, G.J.F. van, On the interaction between two oppositely signed, shielded, monopolar vortices. Phys. Fluids (1998) v. 10 p. 3099-3110.

Wyller, J.; Fla, T.; Juul Rasmussen, J., Classification of kink type solutions to the extended derivative nonlinear Schrödinger equation. Phys. Scr. (1998) v. 57 p. 427-435.

Zolotaryuk, Y.; Christiansen, P.L.; Juul Rasmussen, J., Polaron dynamics in a two-dimensional anharmonic Holstein model. Phys. Rev. B (1998) v. 58 p. 14305-14319.

Zozulya, A.A.; Anderson, D.Z.; Mamaev, A.V.; Saffman, M., Solitary attractors and low-order filamentation in anisotropic self-focusing media. Phys. Rev. A (1998) v. 57 p. 522-534.

5.3.2 Danish publications

Heinemeier, N.P., Flow speed measurement using two-point collective light scattering. Risø-R-1064(EN) (1998) 137 p. (M.Sc. thesis).

Lynov, J.P.; Singh, B.N (eds.), Association Euratom - Risø National Laboratory annual progress report for 1997. Risø-R-1070(EN) (1998) 60 p.

5.3.3 Conference lectures

Dinesen, P.G.; Lading, L.; Lynov, J.P.; Hesthaven, J.S., Waveguides and diffractive elements for non-contact sensors: Analysis. In: Diffractive optics and micro-optics. Conference edition. Technical digest, Kailua-Kona, HI (US), 8-11 Jun 1998. (Optical Society of America, Washington, DC, 1998) (1998 Technical Digest Series, 10) p. 209-211.

Heinemeier, N.; Saffman, M., Theoretical analysis of two-point collective scattering correlation functions using a drift wave model. In: 1998 International congress on plasma physics combined with the 25. European Physical Society conference on controlled fusion and plasma physics. Contributed papers. 1998 ICPP; 25. EPS conference, Prague (CZ), 29 Jun - 3 Jul 1998. Pavlo, P. (ed.), (European Physical Society, Prague, 1998) (Europhysics conference abstracts vol. 22C) p. 1474-1477.

Hesthaven, J.S.; Dinesen, P.G.; Lynov, J.P., Pseudospectral time-domain modeling of diffractive optical elements. In: 14th Annual review of progress in applied computational electromagnetics. Conference proceedings. Vol. 1, Monterey, CA (US), 16-20 Mar 1998. Jianming Jin (ed.), (Applied Computational Electromagnetics Society, Monterey, CA, 1998) p. 858-865.

Jessen, T.; Michelsen, P.K.; Saffman, M.; Svendsen, W., Analysis of collective light scattering in terms of drift wave turbulence models. In: Fusion theory. Proceedings. 7. European fusion theory conference, Jülich (DE), 8-10 Oct 1997. Rogister, A. (ed.), (Forschungszentrum Jülich, Jülich, 1998) (Schriften des Forschungszentrums Jülich Reihe Energietechnik, v. 1) p. 159-162.

Juul Rasmussen, J., Transport and coherent structures. In: Fusion theory. Proceedings. 7. European fusion theory conference, Jülich (DE), 8-10 Oct 1997. Rogister, A. (ed.), (Forschungszentrum Jülich, Jülich, 1998) (Schriften des Forschungszentrums Jülich Reihe Energietechnik, v. 1) p. 13-20.

Juul Rasmussen, J.; Naulin, V.; Nycander, J., Equipartition and transport in two-dimensional electrostatic turbulence. In: 1998 International congress on plasma physics combined with the 25. European Ohysical Society conference on controlled fusion and plasma physics. Contributed papers. 1998 ICPP; 25. EPS conference, Prague (CZ), 29 Jun - 3 Jul 1998. Pavlo, P. (ed.), (Europan Physical Society, Prague, 1998) (Europhysics conference abstracts vol. 22C) p. 2354-2357.

Korsholm, S.B.; Michelsen, P.K.; Naulin, V., Three dimensional study of the Hasegawa-Wakatani drift-wave model. In: 1998 International congress on plasma physics combined with the 25. European Physical Society conference on controlled fusion and plasma physics. Contributed papers. 1998 ICPP; 25. EPS conference, Prague (CZ), 29 Jun - 3 Jul 1998. Pavlo, P. (ed.), (European Physical Society, Prague, 1998) (Europhysics conference abstracts vol. 22C) p. 2378-2381.

Królikowski, W.; Saffman, M.; Luther-Davies, B.; Denz, C., Anomalous interaction of spatial solitons in photorefractive media. In: Nonlinear guided waves and their applications. Conference edition. Collocated with the workshop on novel solitons and nonlinear periodic structures; Integrated photonics research. Proceedings, Victoria (CA), 1-3 Apr 1998. (Optical Society of America, Washington, DC, 1998) (1998 OSA Technical Digest Series, 5) p. 170-172.

Lomholt, S.; Lynov, J.-P.; Telleman, P., Numerical simulation of magnetic separation of particles in a rectangular microchannel. In: Micro total analysis systems '98. Proceedings. µTAS '98 workshop, Banff (CA), 13-16 Oct 1998. Harrison, D.J.; Berg, A. van den (eds.), (Kluwer Academic Publishers, Dordrecht, 1998) p. 419-422.

Michelsen, P.K.; Juul Rasmussen, J.; Chakrabati, N., Ion temperature gradient vortices in shear flow. In: Fusion theory. Proceedings. 7. European fusion theory conference, Jülich (DE), 8-10 Oct 1997. Rogister, A. (ed.), (Forschungszentrum Jülich, Jülich, 1998) (Schriften des Forschungszentrums Jülich Reihe Energietechnik, v. 1) p. 143-146.

Michelsen, P.K.; Juul Rasmussen, J., Vortex dynamics in low-frequency electrostatic turbulence. In: Double layers. Potential formation and related nonlinear phenomena in plasmas. 5. Symposium on double layers, Sendai (JP), 17-19 Sep 1996. (World Scientific, Singapore, 1997) p. 309-314.

Naulin, V., Structures and transport in drift-wave turbulence. In: Fusion theory. Proceedings. 7. European fusion theory conference, Jülich (DE), 8-10 Oct 1997. Rogister, A. (ed.), (Forschungszentrum Jülich, Jülich, 1998) (Schriften des Forschungszentrums Jülich Reihe Energietechnik, v. 1) p. 83-86.

Naulin, V., Numerical simulation of drift and flute modes in cylindrical geometry. In: Fusion theory. Proceedings. 7. European fusion theory conference, Jülich (DE), 8-10 Oct 1997. Rogister, A. (ed.), (Forschungszentrum Jülich, Jülich, 1998) (Schriften des Forschungszentrums Jülich Reihe Energietechnik, v. 1) p. 147-150.

Naulin, V., Structures in driftwave turbulence and some comments on the related particle transport. In: Two-dimensional turbulence in plasmas and fluids. Research workshop, Canberra (AU), 16 Jun - 11 Jul 1997. Dewar, R.L.; Griffiths, R.W. (eds.), (American Institute of Physics, Woodbury, NY, 1997) (AIP conference proceedings, 414) p. 243-254.

Naulin, V.; Nielsen, A.H.; Juul Rasmussen, J., Density flux and diffusion of ideal particles in strong drift-wave turbulence containing vortical structures. In: 1998 International congress on plasma physics combined with the 25. European Physical Society conference on controlled fusion and plasma physics. Contributed papers. 1998 ICPP; 25. EPS conference, Prague (CZ), 29 Jun - 3 Jul 1998. Pavlo, P. (ed.), (European Physical Society, Prague, 1998) (Europhysics conference abstracts vol. 22C) p. 2395-2398.

Nielsen, A.H.; Lynov, J.P.; Juul Rasmussen, J., Particle transport across a circular shear layer with coherent structures. In: Fusion theory. Proceedings. 7. European fusion theory conference, Jülich (DE), 8-10 Oct 1997. Rogister, A. (ed.), (Forschungszentrum Jülich, Jülich, 1998) (Schriften des Forschungszentrums Jülich Reihe Energietechnik, v. 1) p. 211-214.

Nielsen, A.H.; Torres, D.J.; Coutsias, E.A., Decaying two-dimensional turbulence in bounded flows. In: 1998 International congress on plasma physics combined with the 25. European Physical Society conference on controlled fusion and plasma physics. Contributed papers. 1998 ICPP; 25. EPS conference, Prague (CZ), 29 Jun - 3 Jul 1998. Pavlo. P. (ed.), (European Physical Society, Prague, 1998) (Europhysics conference abstracts vol. 22C) p. 2346-2349.

Okkels, F.; Jensen, M.H., Dynamical organization around turbulent bursts. In: Advances in turbulence 7. Proceedings. 7. European turbulence conference, Saint-Jean Cap Ferrat (FR), 30 Jun - 3 Jul 1998. Frisch, U. (ed.), (Kluwer Academic Publishers, Dordrecht (NL), 1998) (Fluid Mechanics and its Applications, v. 46) p. 235-238.

5.3.4 Unpublished Danish lectures

Basse, N.P., Trace tritium transport at JET. Workshop on coherent structures, turbulence and anomalous transport in plasmas and fluids, Risø (DK), 21-23 Oct 1998. Unpublished.

Heinemeier, N.; Saffman, M., Theoretical analysis of two-point collective scattering correlation functions. In: Danish Physical Society annual meeting 1998. Book of abstracts. Annual meeting of the Danish Physical Society, Nyborg (DK), 3-4 Jun 1998. (HCØ Tryk, København, 1998) p. FF29P.

Jensen, V.O., Fusionsforskningen - status og udsigter. Dansk naturvidenskabsfestival arrangeret af Experimentarium i København, Tølløse (DK), 28 Sep 1998. Unpublished.

Jensen, V.O., Fusionsforskningen - status og udsigter. Dansk naturvidenskabsfestival arrangeret af Experimentarium i København, Fredericia (DK), 29 Sep 1998. Unpublished.

Jensen, V.O., Fusionsforskningen - status og udsigter. Dansk naturvidenskabsfestival arrangeret af Experimentarium i København, Farum (DK), 30 Sep 1998. Unpublished.

Jensen, V.O., Status of fusion research. Workshop on coherent structures, turbulence and anomalous transport in plasmas and fluids, Risø (DK), 21-23 Oct 1998. Unpublished.

Jensen, V.O., Plasmafysik 1. 5 forelæsninger på Danmarks Tekniske Universitet, Lyngby (DK), Aug - Sep 1998. Unpublished.

Jensen, V.O., Elementær plasmafysik. Fusionsenergi. Fusionsenergi. Kursus for gymnasielærere i fagene fysik og naturfag, Elmuseet, Bjerringbro (DK), 2-4 Sep 1998. Unpublished.

Jensen, V.O., Elementær plasmafysik. Plasmafysik. Fusioneenergi. Kursus for gymnasielærere i fagene fysik og naturfag, Elmuseet, Bjerringbro (DK), 2-4 Sep 1998. Unpublished.

Juul Rasmussen, J., Overview of coherent structures, solitons, and theoretical models. Graduate school in nonlinear science. Minicourse on spatial nonlinear optics, Risø (DK), 27-28 May 1998. Unpublished.

Juul Rasmussen, J., Vortices. Nordic Graduate Physics program, visit to Risø, Risø (DK), 11 Sep 1998. Unpublished.

Juul Rasmussen, J., General overview, motivation, turbulent equipartition. Workshop on coherent structures, turbulence and anomalous transport in plasmas and fluids, Risø (DK), 21-23 Oct 1998. Unpublished.

Konijnenberg, J. van de, 2D-vortices in rotating fluids. Workshop on coherent structures, turbulence and anomalous transport in plasmas and fluids, Risø (DK), 21-23 Oct 1998. Unpublished.

Korsholm, S.B., 3D simulations of drift-wave turbulence. Workshop on coherent structures, turbulence and anomalous transport in plasmas and fluids, Risø (DK), 21-23 Oct 1998. Unpublished.

Korsholm, S.B.; Michelsen, P.K., Three dimensional numerical investigations of drift wave turbulence in plasmas. In: Danish Physical Society annual meeting 1998. Book of abstracts. Annual meeting of the Danish Physical Society, Nyborg (DK), 3-4 Jun 1998. (HCØ Tryk, København, 1998) p. AF18P.

Mamaev, A.V.; Saffman, M., Laboratory demonstrations: Self-focusing, self-defocusing, modulational instabilities. Graduate school in nonlinear science. Minicourse on spatial nonlinear optics, Risø (DK), 27-28 May 1998. Unpublished.

Mamaev, A.V.; Saffman, M., Laboratory demonstrations: Optical patterns, pattern selection by Fourier filtering. Graduate school in nonlinear science. Minicourse on spatial nonlinear optics, Risø (DK), 27-28 May 1998. Unpublished.

Michelsen, P.K., Vortex dynamics in drift wave models: Effects on shear flows. Workshop on coherent structures, turbulence and anomalous transport in plasmas and fluids, Risø (DK), 21-23 Oct 1998. Unpublished.

Naulin, V., Drift-waves: 2D and 3D modelling. Workshop on coherent structures, turbulence and anomalous transport in plasmas and fluids, Risø (DK), 21-23 Oct 1998. Unpublished.

Nielsen, A.H., Vortex dynamics in 2D flows. Workshop on coherent structures, turbulence and anomalous transport in plasmas and fluids, Risø (DK), 21-23 Oct 1998. Unpublished.

Okkels, F., Vortex dynamics in periodically forced shear flow. Workshop on coherent structures, turbulence and anomalous transport in plasmas and fluids, Risø (DK), 21-23 Oct 1998. Unpublished.

Saffman, M., Optical pattern formation. Graduate school in nonlinear science. Minicourse on spatial nonlinear optics, Risø (DK), 27-28 May 1998. Unpublished.

Saffman, M., Introduction to laboratory demonstrations. Graduate school in nonlinear science. Minicourse on spatial nonlinear optics, Risø (DK), 27-28 May 1998. Unpublished.

Saffman, M., Spatial solitons and modulational instabilities in nonlinear atom-optics. Seminar University of Aarhus, Aarhus (DK), 23 Apr 1998. Unpublished.

5.3.5 Unpublished international lectures

Denz, C.; Juul Jensen, S.; Schwab, M.; Tschudi, T., Manipulation and control of transverse optical patterns in a photorefractive feedback system using Fourier space filtering. In: Patterns in nonlinear optical systems. PINOS. 1. Euroconference on trends in optical nonlinear dynamics: Physical problems and applications, Pueblo Acantilado (ES), 21-23 May 1998. (European Union, TMR Programme, Alicante, 1998) p. P1-38.

Denz, C.; Krolikowski, W.; Saffman, M.; Luther-Davies, B., Interaction of photorefractive spatial solitons. In: EQEC 1998. Technical digest. European quantum electronics conference, Glasgow (GB), 14-18 Sep 1998. (IEEE, Piscataway, NJ, 1998) p. 231 (QThJ7).

Denz, C.; Schwab, M.; Juul Jensen, S., Manipulation, selection and control of pattern formation using Fourier space filtering. In: EQEC 1998. Technical digest. European quantum electronics conference, Glasgow (GB), 14-18 Sep 1998. (IEEE, Piscataway, NJ, 1998) p. 48 (QTuF2).

Dinesen, P.G.; Hesthaven, J.S.; Lynov, J.P., A spectral collocation time-domain method for diffractive optics. In: International conference on spectral and high order methods. ICOSAHOM '98. Book of abstracts, Herzliya (IL), 22-26 Jun 1998. (Tel Aviv University, Tel Aviv, 1998) ICO98-80.

Jensen, V.O., News from the fusion research. 33. Nordic plasma and gas discharge symposium, Geilo (NO), 25-28 Jan 1998. Unpublished.

Jensen, V.O., How does a plasma move in a magnetic field?. 33. Nordic plasma and gas discharge symposium, Geilo (NO), 25-28 Jan 1998. Unpublished.

Juul Rasmusen, J.; Nielsen, A.H.; Naulin, V., Particle diffusion and density flux in strong drift-wave turbulence containing vortical structures. In: Transport in fusion plasmas. Programme and abstracts. EU - US transport task force workshop, Göteborg (SE), 7-10 Sep 1998. (Chalmers University of Technology. Center for Fusion Science, Göteborg, 1998) 1 p.

Juul Rasmussen, J., Formation of dipolar vortices in two-dimensional flows. CECAM workshop on nonlinear processes in nonneutral plasmas and in fluids, Lyon (FR), 15-18 Jul 1998. Unpublished.

Juul Rasmussen, J., Collapse dynamics in discrete nonlinear Schrödinger equations. Progrès récents autour des équations de Schrödinger non linéaires, Orsay (FR), 3-5 Nov 1998. Unpublished. Abstract available.

Juul Rasmussen, J., Experimental and numerical investigations of shear flow instabilities in rotating shallow water. 1998-9 Warwick symposium on computation and mathematics. Workshop 1: Cardiac arrhythmias, pattern formation, atmospheres and oceans, Warwick (GB), 14-25 Sep 1998. Unpublished.

Juul Rasmussen, J., Transport and mixing in two-dimensional turbulent flows dominated by vortex structures. 1998-9 Warwick symposium on computation and mathematics. Workshop 1: Cardiac arrhythmias, pattern formation, atmospheres and oceans, Warwick (GB), 14-25 Sep 1998. Unpublished.

Juul Rasmussen, J., Collapse and modulational instability in nonlinear media with anisotropic dispersion properties. Workshop: Nonlinear MHD waves and turbulence, Nice (FR), 1-4 Dec 1998. Unpublished. Abstract available.

Juul Rasmussen, J.; Naulin, V.; Nycander, J., Turbulent equipartition and plasma transport. 33. Nordic plasma and gas discharge symposium, Geilo (NO), 25-28 Jan 1998. Unpublished.

Juul Rasmussen, J.; Nielsen, A.H., Vortex interactions and spectral cascade in two-dimensional flows. CECAM workshop on nonlinear processes in nonneutral plasmas and in fluids, Lyon (FR), 15-18 Jul 1998. Unpublished. Abstract available.

Juul Rasmussen, J.; Naulin, V.; Nycander, J., Flux-driven turbulence exhibiting large scale flows. 6. European fusion physics workshop, Cadarache (FR), 9-11 Dec 1998. Unpublished.

Konijnenberg, J.A. van de; Nielsen, A.H.; Juul Rasmussen, J.; Stenum, B., Particle tracing in a cirkular shear layer. 23. General assembly of the European Geophysical Society, Nice (FR), 20-24 Apr 1998. Ann. Geophys. Suppl. 4 (1998) v. 16 p. C1137.

Konijnenberg, J.A. van de; Nielsen, A.H.; Juul Rasmussen, J.; Stenum, B., Influence of the beta effect on shear-flow instability. 23. General assembly of the European Geophysical Society, Nice (FR), 20-24 Apr 1998. Ann. Geophys. Suppl. 4 (1998) v. 16 p. C1137.

Korsholm, S.B.; Michelsen, P.K.; Naulin, V., Three-dimensional study of the Hasegawa-Wakatani drift wave model. In: Transport in fusion plasmas. Programme and abstracts. EU - US transport task force workshop, Göteborg (SE), 7-10 Sep 1998. (Chalmers University of Technology. Center for Fusion Science, Göteborg, 1998) 1 p.

Korsholm, S.B.; Michelsen, P.K.; Naulin, V., Three dimensional study of the Hasegawa-Wakatani drift-wave model. 35. Culham plasma physics summer school, Culham (GB), 6-17 Jul 1998. Unpublished. Abstract available.

Krolikowski, W.; Luther-Davies, B.; Saffman, M.; Belic, M.; Stepken, A., Interaction of spatial photorefractive solitons. Workshop on novel solitons and nonlinear periodic structures, Victoria, CA (US), 28-29 Mar 1998. Unpublished.

Lodahl, P.; Saffman, M.; Bang, O., Instabilities and pattern formation in second harmonic generation. In: Patterns in nonlinear optical systems. PINOS. 1. Euroconference on trends in optical nonlinear dynamics: Physical problems and applications, Pueblo Acantilado (ES), 21-23 May 1998. (European Union, TMR Programme, Alicante, 1998) p. P2-9.

Lodahl, P.; Saffman, M., Modulational instabilities in a backward parametric interaction. In: Patterns in nonlinear optical systems. PINOS. 1. Euroconference on trends in optical nonlinear dynamics: Physical problems and applications, Pueblo Acantilado (ES), 21-23 May 1998. (European Union, TMR Programme, Alicante, 1998) p. P2-10.

Lodahl, P.; Saffman, M.; Bang, O., Spatial patterns in second harmonic generation. In: EQEC 1998. Technical digest. European quantum electronics conference, Glasgow (GB), 14-18 Sep 1998. (IEEE, Piscataway, NJ, 1998) p. 246 (QFA3).

Lynov, J.P.; Bergeron, K.; Coutsias, E.A.; Nielsen, A.H., An accurate and efficient spectral method for studies of the dynamical properties of forced, circular shear layers. In: International conference on spectral and high order methods. ICOSAHOM '98. Book of abstracts, Herzliya (IL), 22-26 Jun 1998. (Tel Aviv University, Tel Aviv, 1998) ICO98-23.

Lynov, J.-P., Research in fluid dynamics, plasma physics, and optics at Risø National Laboratory, Denmark. Meeting at Institute of Mechanics, Chinese Academy of Sciences, Beijing (CN), 26 Oct 1998. Unpublished.

Lynov, J.-P., Self-organization of vortical structures in circular shear flows. Meeting at Institute of Mechanics, Chinese Academy of Sciences, Beijing (CN), 28 Oct 1998. Unpublished.

Lynov, J.-P., Spectral methods for numerical simulations in fluid dynamics and optics. Meeting at Institute of Mechanics, Chinese Academy of Sciences, Beijing (CN), 29 Oct 1998. Unpublished.

Mamaev, A.V.; Saffman, M., Stabilizing optical turbulence by Fourier plane filtering. In: Patterns in nonlinear optical systems. PINOS. 1. Euroconference on trends in optical nonlinear dynamics: Physical problems and applications, Pueblo Acantilado (ES), 21-23 May 1998. (European Union, TMR Programme, Alicante, 1998) p. P1-36.

Mamaev, A.V.; Saffman, M., Suppressing the transition to turbulence in a strongly pumped pattern formation experiment. In: EQEC 1998. Technical digest. European quantum electronics conference, Glasgow (GB), 14-18 Sep 1998. (IEEE, Piscataway, NJ, 1998) p. 50 (QTuF5).

McCluskey, D.R.; Stenum, B., Flows in a large scale flow - with model-whole-field optical measurements of velocity and mixing. 8. International symposium on the applications of laser techniques to fluid mechanics, Lisbon (PT), 8-11 Jul 1998. Unpublished.

Naulin, V., Equipartition and transport in 2D electrostatic turbulence. Seminar at Institute of Plasma Physics, Garching (DE), 28 Apr 1998. Unpublished.

Naulin, V., Equipartition and transport in 2D electrostatic turbulence. Seminar at Christian-Albrechts Universität, Kiel (DE), 12 May 1998. Unpublished.

Naulin, V., Diffusion von Partikeln in zweidimensionalen Plasma und Fluidströmungen. Seminar at Eidgenössische Technische Hochschule ETH, Zürich (CH), 21 Sep 1998. Unpublished.

Naulin, V., Turbulent equipartition in plasma and fluid turbulense. Seminar at Heinrich Heine Universität, Düsseldorf (DE), 15 Nov 1998. Unpublished.

Naulin, V.; Juul Rasmussen, J.; Nielsen, A.H., Diffusion of particles in a 2D model of electrostatic turbulence. 33. Nordic plasma and gas discharge symposium, Geilo (NO), 25-28 Jan 1998. Unpublished.

Naulin, V.; Juul Rasmussen, J.; Nycander, J., Equipartition and transport in 2d electrostatic turbulence. In: Transport in fusion plasmas. Programme and abstracts. EU - US transport task force workshop, Göteborg (SE), 7-10 Sep 1998. (Chalmers University of Technology. Center for Fusion Science, Göteborg, 1998) 1 p.

Naulin, V.; Korsholm, S.B.; Michelsen, P.K., Three-dimensional simulations of drift-wave turbulence. Theory of fusion plasmas. Joint Varenna-Lausanne international workshop, Varenna (IT), 31 Aug - 4 Sep 1998. Unpublished. Abstract available.

Nielsen, A.H.; Juul Rasmussen, J.; Schmidt, M.R., Vortex merging in two-dimensional turbulence. International workshop on vortex dynamics in geophysical flows, Lecce (IT), 22-26 Jun 1998. Unpublished. Abstract available.

Nielsen, A.H.; Juul Rasmussen, J.; Schmidt, M.R., Formation and dynamics of dipolar vortices. International workshop on vortex dynamics in geophysical flows, Lecce (IT), 22-26 Jun 1998. Unpublished. Abstract available.

Saffman, M., Transverse instabilities in nonlinear optics and atomoptics (invited paper). In: Nonlinear guided waves and their applications. Conference edition. Collocated with the workshop on novel solitons and nonlinear periodic structures; Integrated photonics research. Workshop on novel solitons and nonlinear periodic structures, Victoria (CA), 29-30 Mar 1998. (Optical Society of America, Washington, DC, 1998) (1998 OSA Technical Digest Series, 5) Paper WMD2.

Saffman, M., Patterns and solitons in nonlinear optical resonators. Seminar ETH, Zurich (CH), 2 Nov 1998. Unpublished.

Saffman, M., Optical hydrodynamics: Instabilities and patterns in nonlinear optics and atom-optics. PGS celebration symposium, California Institute of Technology, CALTECH, Pasadena, CA (US), 15 Jun 1998. Unpublished.

Saffman, M., Filamentation instability of a matter wave. In: Patterns in nonlinear optical systems. PINOS. 1. Euroconference on trends in optical nonlinear dynamics: Physical problems and applications, Pueblo Acantilado (ES), 21-23 May 1998. (European Union, TMR Programme, Alicante, 1998) p. 4.

Saffman, M., Waveguide splitters induced by high order vortex decay. In: Patterns in nonlinear optical systems. PINOS. 1. Euroconference on trends in optical nonlinear dynamics: Physical problems and applications, Pueblo Acantilado (ES), 21-23 May 1998. (European Union, TMR Programme, Alicante, 1998) p. P1-35.

Saffman, M., Self-induced atomic dipole force. In: EQEC 1998. Technical digest. European quantum electronics conference, Glasgow (GB), 14-18 Sep 1998. (IEEE, Piscataway, NJ, 1998) p. 26 (QMF9).

Saffman, M., Spatial solitons in anisotropic media. In: EQEC 1998. Technical digest. European quantum electronics conference, Glasgow (GB), 14-18 Sep 1998. (IEEE, Piscataway, NJ, 1998) p. 185 (QThF1).

Saffman, M., Fluctuation measurements at W7-AS using CO_2 laser anemometry. Seminar at Max Planck Institut für Plasmaphysik, Garching (DE), 10 Feb 1998. Unpublished.

Stenum, B.; Konijnenberg, J.A. van de; Lynov, J.-P., Particle motion and magnetic separation in microflow. ERCOFTAC Nordic Pilot Center meeting, Narvik (NO), 26-28 Aug 1998. Unpublished.

Svendsen, W.; Saffman, M.; Endler, M., Small angle collective scattering correlation measurements at W7-AS. In: 1998 International congress on plasma physics combined with the 25th EPS conference on controlled fusion and plasma physics. Abstracts of invited and contributed papers. Part 1. 1998 ICPP; 25. EPS conference, Prague (CZ), 29 Jun - 3 Jul 1998. Badalec, J.; Stöckel, J.; Sunka, P.; Tendler, M. (eds.), (ICPP Local Organizing Committee, Prague, 1998) p. 71.

5.3.6 Internal reports

Korsholm, S.B., Resistive drift wave turbulence. Analytical and numerical investigations in a three dimensional geometry. Risø-I-1280(EN) (1998) 92 p. (M.Sc. thesis).

6. Personnel

Scientific Staff

Andersen, Peter E. (from 1 March)
Bak, Jimmy
Clausen, Sønnik
Hanson, Steen Grüner
Imam, Husian Gulam (from 14 August)
Jensen, Arne Skov (until 31 January)
Jensen, Vagn O.
Johansen, Per Michael
Jørgensen, Thomas Martini
Kaiser, N.E.
Kirkegaard, Mogens
Kristensen, Jesper Glückstad
Lading, Lars
Lindvold, Lars R.
Linneberg, Christian (until 31 March)
Lynov, Jens-Peter
Michelsen, Poul K.
Nielsen, Anders H.
Olsen, Aksel
Pedersen, Henrik Chresten (from 1 April)
Petersen, Paul Michael
Ramanujam, P.S.
Rasmussen, Jens Juul
Saffman, Mark
Schou, Jørgen
Stenum, Bjarne

Post Docs

Andersen, Peter E. (until 28 February)
Dinesen, Palle
Hansen, Rene Skov (from 1 March)
Holme, Niels Chr. Rømer (until 14 August)
Konijnenberg, Johan Antoon van de
Mogensen, Paul Christian (from 1 December)
Naulin, Volker
Svendsen, Winnie (until 31 August)

Industrial Post Docs

Dam-Hansen, Carsten (until 31 October)
Løbel, Martin (from 1 June)

PhD Students

Jensen, Sussie Juul
Jessen, Thomas

Korsholm, Søren Bang (from 1 May)
Lodahl, Peter
Lomholt, Sune
Løbel, Martin (until 31 May)
Nielsen, Birgitte Thestrup
Nikolajsen, Thomas
Okkels, Fridolin (from 1 April)
Schmidt, Michel R. (until 28 February)
Thrane, Lars

Industrial PhD Students

Linnebjerg, Christian (from 1 April)
Rose, Bjarne (until 31 January)

Technical Staff

Andersen, Finn
Bækmark, Lars (until 31 August)
Eilertsen, Erik
Hansen, Bengt Hurup
Nordskov, Arne
Jessen, Martin (from 15 September)
Petersen, Torben D.
Rasmussen, Erling
Sass, Bjarne
Stubager, Jørgen
Thorsen, Jess

Secretaries

Astradsson, Lone
Skaarup, Bitten
Carlsen, Heidi

Guest Scientists

Angelsky, Oleg, Chernivtsy University, Ukraine
Bergé, Luc, Commissariat á l'Energie Atomique, Centre d'Etudes de Limeil-Valenton, France
Clercx, Herman, Eindhoven University of Technology, The Netherlands
Fridkin, Vladimir, Institute of Crystallography, Moscow, Russia
Hesthaven, Jan, Brown University, Rhode Island, USA
Karpman, Vladimir I., Racah Institute of Physics, Hebrew University, Jerusalem, Israel
Limeres, Josefa, Universidad Autonoma de Madrid, Spain
Lushnikov, Pavel, Landau Institute, Moscow, Russia
Mamaev, Alexander, Russian Academy of Sciences, (Moscow), Russia
Mezentsev, V.K., Novosibirsk, Russia
Podivilov, E.V., Institute of Automation and Electrometry, Russian Academy of Sciences, Novosibirsk, Russia
Popov, Ivan, Vavilov Optical Institute, St. Petersburg, Russia
Shagalov, Arkadi G., Institute of Metal Physics, Ekaterinburg, Russia
Snezhkin, E.N., Institute Nuclear Fusion, Kurchatov Institute, Moscow, Russia

Sturman, Boris I., International Institute for Non-Linear Studies, Novosibirsk, Russia
Titishov, Kirill Borisovich, Institute Nuclear Fusion, Kurchatov Institute, Moscow, Russia
Wang, Peng-Ye, Chinese Academy of Sciences, Beijing, China
Yura, Harold T., The Aerospace Corporation, Los Angeles, USA
Zozulya, Alexei, Worcester Polytechnic Institute, Worcester, USA

Short-term Visitors

Bang, Ole, Optical Sciences Centre, Australian National University, Canberra, Australia
Block, Dietmar, University of Kiel, Germany
Coutsias, E.A., University of New Mexico, Albuquerque, USA
Fleck, B., Universität Jena, Germany
Garcia, Odd Erik, University of Tromsø, Norway
Hansen, Tue Normann, Trinity College, Dublin, Ireland
Klinger, Thomas, University of Kiel, Germany
Kuznetsov, E.A., Landau Institute for Theoretical Physics, Moscow, Russia
Lunney, James, Trinity College, Ireland
Montgomery, David C., Dartmouth College, Hanover, New Hampshire, USA
Paulsen, Jim Viktor, University of Tromsø, Norway
Pécseli, Hans, University of Oslo, Norway
Pogany, Peter, Technische Universität Berlin, Berlin, Germany
Ratynskaia, Svetlana, University of Tromsø, Norway
Rypdal, Kristoffer, University of Tromsø, Norway
Ter-Avetisyan, Sargis, Armenian Academy of Science, Ashtarak, Armenia
Torruellas, William, Washington State University, USA
Yaroshchuk, Oles, Institute of Physics, Kiev, Ukraine

Students Working for the Master's Degree

Christensen, Bo Toftmann (from 25 August)
Clausen, Thomas (from 28 April)
Hansen, Kasper (from 25 March - 30 May)
Heinemeyer, Nicholas (until 31 May)
Korsholm, Søren Bang (until 28 February)
Lindberg, Peter (from 25 March – 30 May)
Madsen, Magnus Hald (from 9-21 March)
Sundstrøm, Martin (until 30 June)
Tycho, Andreas (until 30 September)

Student Working for the Bachelor's Degree

Andersen, Alan Hauge

Student Assistants

Andersen, Ulrik Lund
Basse, Nils Plesner
Schwab, Michael

Bibliographic Data Sheet			**Risø-R-1100(EN)**
Title and author(s) Optics and Fluid Dynamics Department Annual Progress Report for 1998 Edited by S. G. Hanson, P. M. Johansen, L. Lading, J. P. Lynov and B. Skaarup			
ISBN 87-550-2511-0 (Internet)			ISSN 0106-2840 0906-1797
Dept. or group Optics and Fluid Dynamics Department			Date May 1999
Pages 100	Tables 1	Illustrations 56	References 259

Abstract (max. 2000 char.)

Research in the Optics and Fluid Dynamics Department has been performed within the following three programme areas: (1) optical materials, (2) optical diagnostics and information processing and (3) plasma and fluid dynamics. The work is concentrated on combinations of systems, structures and materials. The *systems* work is focused on sensors, information processing and storage; the *structures* work is concentrated on pattern formation and diffractive elements; the *materials* work is centred on the understanding and utilisation of novel materials and nonlinear phenomena for optical components, including lasers, and systems. Scientific computing is an integral part of the work. Biomedical optics and polymer optics are areas of enhanced activity. The research is supported by several EU programmes, including EURATOM, by research councils and by industry. A summary of the activities in 1998 is presented.

Descriptors INIS/EDB

DYNAMICS; FLUIDS; LASERS; NONLINEAR OPTICS; NONLINEAR PROBLEMS; NUMERICAL SOLUTION; PLASMA; PROGRESS REPORT; RESEARCH PROGRAMS; RISOE NATIONAL LABORATORY; THERMONUCLEAR REACTIONS

Risø National Laboratory performs research within science and technology. The laboratory is organised in the following seven research departments:

- Materials Research Department
- Condensed Matter Physics and Chemistry Department
- Optics and Fluid Dynamics Department
- Plant Biology and Biogeochemistry Department
- Systems Analysis Department
- Wind Energy and Atmospheric Physics Department
- Nuclear Safety Research and Facilities Department

Risø reports its activities in 1998 in the following publications: Risø Annual Report (available in Danish and English), Risø Business Statement (only available in Danish), Risø Publication Activities and the annual progress reports of the seven research departments. The publications and further information about Risø can be obtained from the web site www.risoe.dk. Printed copies of the reports are available from the Information Service Department, phone +45 4677 4004, email risoe@risoe.dk, fax +45 4677 4013.