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Mid-infrared supercontinuum generation in the fingerprint region

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Opening of the
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Abstracts for poster presentations

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Atomic, molecular and optical physics (AMO)

1 All-optical switching and feedback improved parity measurement in cavity QED systems

By A. E. B. Nielsen¹ and J. Kerckhoff²

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We propose an all-optical switch constructed from a two-mode optical resonator containing a strongly coupled, three-level system [1]. The coupling allows a weak, continuous wave laser drive to incoherently control the transmission of a much stronger, continuous wave signal laser into and through the resonator. The switch operates at low energies, and such optical devices provide an interesting alternative to silicon logic. We also consider an approach to measure the parity of two qubits located in separate cavities, and we demonstrate how coherent feedback can be used to conditionally decrease the total photon loss and decoherence during the measurement [2].

[1] A. E. B. Nielsen and J. Kerckhoff, Phys. Rev. A 84, 043821 (2011).

[2] A. E. B. Nielsen, Phys. Rev. A 81, 012307 (2010).

2 Elimination of information leakage in lossy quantum communication channels

By Christian S. Jacobsen¹ and Lars S. Madsen¹, Vladyslav Usenko^{2,3}, Ulrik L. Andersen¹, Radim Filip²

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Quantum key distribution is the most welldeveloped and most widely applied technologywithin the field of quantum information. Whileconceptually simpler, quantum key distributionusing discrete variables, such as thepolarization of single photons in the BB84protocol, face certain technologicaldisadvantages compared to continuous-variabletechnologies. There is a certain difficultyin sufficiently sensitive detection, which isnot an issue for continuous-variabletechnologies, as they have several decadesof advances in telecommunication research anddevelopment to draw upon. Further, sincecontinuous-variable telecommunicationtechnology is well developed and widelydistributed, in-field implementations ofcontinuous variable quantum key distributionschemes are considerably easier than thediscrete variable counterparts, disregardingthat optical parametric amplifiers are notreadily available at telecommunicationwavelengths. The first quantum key distributionprotocol in the regime of continuous variablesby Cerf et al. relied only on squeezing,which is usually considered a cheaper quantumresource than single photon states. Morerecently, protocols which only make use ofcoherent or even thermal states have beendeveloped employing various detection schemes.While some protocols rely on entanglementto provide the correlations and the randomnessin the measurements, prepare-and-measureprotocols use optical modulations with noise.The previously mentioned protocols which relyon coherent states are examples of this.We propose a continuous-variable quantum keydistribution protocol for complete eliminationof the correlations between a receiver and anavesdropper in the case of a purely lossychannel. The protocol uses the relatively cheapquantum resource of squeezing as its mainingredient. We further present an experimentalimplementation of this protocol and show thatthe correlations can be eliminated under thepredicted conditions. At the same time wedemonstrate that the protocol only requiresmoderate levels of squeezing, making a re-allife implementation feasible.We theoretically and experimentallydemonstrate that optically modulated squeezedstates can be used to completely eliminatecorrelations between Bob and Eve in the caseof reverse reconciliation, assuming a purelylossy channel. While there is entanglementbetween the sidebands of the squeezed state,the protocol can still be classified asprepare-and-measure. Additionally, it seemsthat this effect has no counterpart in thediscrete variable regime.

3 Preparation of quantum ground states of mechanical motion

By H. Kerdoncuff¹ and U.B. Hoff¹, H. Fu¹, G.I. Harris², W.P. Bowen², U.L. Andersen¹

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Observing and controlling the behavior of a massive mechanical oscillator at the quantum level has gathered a wide interest from tests of fundamental physics theories to applications in new information technologies. One initial challenge is the preparation of a micron-sized mechanical oscillator in its quantum ground state of motion. To achieve this goal we look at two different approaches. The first consists in continuously feeding back high-sensitivity measurements of the oscillator's position to damp the oscillator's motion via dielectric gradient forces. The second consists in conditional back-action evading pulsed measurements to reduce the uncertainties in the oscillator's position and momentum.

4 Non-destructive imaging and feedback stabilized production of cold atomic clouds

By Jan Arlt and Miroslav Gajdacz, Poul L. Pedersen, Troels Mørch, Andrew Hilliard, Jacob F. Sherson
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Reliable production of cold atomic clouds with well-defined properties is a notoriously difficult task. Variations in the final atom number and temperature arise mainly due to unpredictable fluctuations in the experimental sequence. Non-destructive measurements of the ensemble properties within the sequence allow for an adjustment of the cooling procedure to obtain the desired outcome. Our scheme utilizes an imaging technique based on Faraday rotation combined with on-line digital image evaluation and feedback to the evaporation sequence. We demonstrate sub-percent run to run stability of the final atom number obtained by a single point feedback. A weak gain many point feedback can be applied to counteract repeated external disturbances. In addition, it is investigated if the formation of a Bose-Einstein condensate can be stabilized by this feedback mechanism.

5 Sub-picosecond tracking of structural dynamics in photo-excited platinum complexes

By M.G. Laursen¹ and M. Christensen¹, K. Haldrup¹, M.M. Nielsen¹

¹Department of Physics, Technical University of Denmark.

In an upcoming study we aim to investigate the electronic and structural dynamics of the photo-active platinum complex, $[\text{Pt}_2-(\text{P}_2\text{O}_5\text{H}_2)_4]^{4-}$ (Abbreviated, PtPOP). Transient absorption studies of PtPOP reveal coherent vibrational Pt-Pt oscillations on a femtosecond timescale. Using time-resolved X-ray scattering the ultrafast structural dynamics of PtPOP will be studied. This study is made possible by the ultrafast and ultra brilliant Linac Coherent Light Source.

6 Next Generation Airport Security – From Stressed to Calm

By U.L. Olsen¹ and Y. Gu¹, J. Kehres¹, E. B. Knudsen¹, I. Kazantsev², M. Lyksborg², H.F. Poulsen¹

¹Institut for Fysik, Technical University of Denmark. ²Institut for Matematik og Computer Science, Technical University of Denmark.

The security check in airports still has the same base as was used at the first x-ray screening in 1973. Especially since 9/11 additional procedures have been implemented without changing the practice. A much needed fundamental redesign of the process will be provided now through this work. The improvement of the service will include development of new screening instrument with trolley entrance and a trolley with personal guide from check-in to gate.

Bio- and medical physics

7 miRNA Conjugated Spherical Gold Nanoparticles

By Ann-Katrine Vransø West and Chano Birkelind, Kamilla Nørregaard, Poul Martin Bendix, Lene B. Oddershede

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We study a possible gene silencing assay with miRNA coated gold nanoparticles. The loading of the miRNA is characterized in vitro according to nanoparticle size, as is the controlled laser-induced release due to localized heating. In cells, the laser induced heating also allows us to control the release of the gold nanoparticles and miRNA from the endosomes into the cytoplasm. A luciferase reporter plasmid will allow us to verify the intact miRNA in the cytoplasm.

8 Optical coherence microscopy with extended depth of focus

By Felix Fleischhauer^{1,2} and Hinnerk Schulz-Hildebrand¹, Dr. Gereon Hüttmann¹

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Introduction: Optical coherence tomography (OCT) is a non-contact imaging modality for reconstructing depth information of scattering samples. Conventional OCT systems have a lateral resolution of $\sim 10\text{-}15\ \mu\text{m}$ by an axial resolution of $5\text{-}10\ \mu\text{m}$. One main advantage of OCT is decoupling lateral and axial resolution. The useful imaging depth depends on the Rayleigh length and therefore on the numerical aperture (NA) used to focus the scanned beam [1]. To increase the imaging depth in OCT Leitgeb et al. [2] and Zappe et al. [3] successfully used an axicon lens. After passing the axicon, the intensity distribution of a planar wave front can be described by a first order Bessel function. This leads to a constant lateral width of the intensity distribution along the direction of propagation. Tearney et al. [4] demonstrated an increased imaging depth for OCT by removing the central part of a collimated Gaussian beam in order to produce a ring illumination. After focusing the ring into the sample, an increased imaging depth is generated.

Measurements: The light of a Superlum BLM-S-840-B-I-20 was split evenly into reference and sample arm. The reference arm consisted of dispersion compensation and Schäfter and Kirchhoff collimator optics. In the sample arm we used separate illumination and detection pathways. In the illumination path, light from a Schäfter and Kirchhoff collimator passed a 5° Axicon (removable), a mirror (with a central hole 5 mm diameter), a lens ($f = 100\text{ mm}$), scanning optics (two lenses $f = 25$, Thorlabs galvo scanners GVS102), a lens ($f = 50$) and a Zeiss-microscopy objective (part # 440639) with a NA of 0,45. The objective was moved over a range of $400\ \mu\text{m}$ in z-direction by means of piezo actuator. The detection path used the central hole in the mirror to detect light scattered by the sample, which was then directed into a spectrometer of a modified Hyperion OCT device from Thorlabs.

A sample with randomly distributed molecules (smaller than $1\ \mu\text{m}$) in a polymer was measured in $0,5\ \mu\text{m}$ steps over a range of $400\ \mu\text{m}$. In lateral direction the full width at half maximum (FWHM) of the PSF measured at one scattering particle positioned in different depths was compared.

Results: Using a ring illumination the DOF was increased from $10\ \mu\text{m}$ to $100\ \mu\text{m}$. By inserting the axicon a further increase to $200\text{-}300\ \mu\text{m}$ was possible.

Conclusion: The increase of lateral resolution leads to a decreased imaging depth, which destroys the benefit of Spectral domain OCT of measuring all depth information at once compared to Time-domain OCT. By using an axicon lens or a ring illumination the imaging depth can be increased by obtaining high lateral resolution.

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[4] Tearney et al., Method for Quantitative Study of Airway Functional Microanatomy Using Micro-Optical Coherence Tomography, *PLOS ONE* 8(1), 2013

9 Seeing Through Food - New X-ray Imaging Modalities in Food Science

By M.S. Nielsen¹ and H. Einarsdóttir², R. Miklos³, K. Dalby⁴, R. Lametsch³, R. Feidenhans'l¹

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Application of X-ray imaging within food science has so far been limited due to the poor contrast in food products using the conventional X-ray absorption modality. However, with the advent of phase-contrast and dark-field imaging, this has changed.

Due to the increased sensitivity towards small variations in electron density in soft matter materials, phase-contrast imaging have demonstrated improved signal-to-noise ratios (SNR) as well as contrast-to-noise ratios (CNR) for various food products such as meat [1] whereas dark-field imaging provides a sensitivity to ordered micro-structures through the recording of the USAXS signal, and has been succesfully applied e.g. to detect foreign bodies in food products [2].

Here we present examples of using X-ray phase-contrast imaging to study changes in electron density in protein structures in meat upon heating and applying X-ray dark-field imaging to distinguish between raw, frozen and defrosted food products [3].

When techniques giving several modalities simultaneously are applied, multivariational data analysis becomes possible which can give e.g. an improved segmentation [4].

References

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[3] MS Nielsen, LB Christensen & R Feidenhans'l. *Food Control*, 39, 222-226 (2014).

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Condensed matter physics

10 Electrokinetics and concentration polarization in microchannels

By Christoffer P. Nielsen and Henrik Bruus

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We present a comprehensive analysis of salt transport in microchannels during concentration polarization. We have carried out full numerical simulations of the coupled Poisson–Nernst–Planck–Stokes problem governing the transport and rationalized the behaviour of the system. A surprising discovery is that bulk advection relies heavily on the surface currents, even when these surface currents do not contribute much to the overlimiting current themselves. The numerical simulations are supplemented by analytical results valid in the long channel limit as well as in the limit of negligible surface charge. Notably, by including the effects of diffusion and advection in the diffuse double layers we extend a recently published analytical model of overlimiting current due to surface conduction.

11 New features of the McXtrace X-ray simulation package

By Erik B Knudsen¹ and Peter K Willendrup¹, Martin M Nielsen¹, Kristoffer Haldrup¹, Kim Lefmann², Martin Cramer Pedersen², Søren Schmidt¹

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We present the latest developments in the new release of McXtrace (1.2). McXtrace is a general versatile tool for simulating any and every X-ray scattering experiment, It runs on most computer hardware including netbooks and high performance clusters. The latest release of McXtrace includes many improvements, some of which are presented here. FEL-source models through integration with GENESIS 1.3 or Simplex-Accurate synchrotron source modelling via SPECTRANumerous new Beamline examplesPerformance enhancements Zone plate componentStreamlined installation proceduresROOT interface

12 Acoustic streaming in microchannels including thermoviscous effects

By H. Bruus and P.B. Muller

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We present a numerical study of the thermoviscous effects on the acoustic streaming flow generated by an ultrasound standing wave resonance in a long straight microfluidic channel. These effects enter through the temperature and density dependence of the fluid viscosity. The resulting magnitude of the streaming flow is calculated and characterized numerically, and remarkably, we find that even for thin acoustic boundary layers, the channel height affects the magnitude of the streaming flow. For the special case of a sufficiently large channel height we have successfully validated our numerics with analytical results from 2011 by Rednikov and Sadhal for a planar wall. Furthermore, the time-averaged energy transport in the system is analyzed, and the time-averaged second-order temperature perturbation of the fluid is calculated.

13 Electron Holography studies of maghemite ($\gamma\text{-Fe}_2\text{O}_3$) nanoflower particles

By J. Larsen¹ and M. Varón¹, T. Kasama², M. Beleggia², C. Frandsen¹

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Magnetic exchange-coupled maghemite ($\gamma\text{-Fe}_2\text{O}_3$) nanoparticles assembled into flowerlike structures, the so-called nanoflowers, show a high potential for localized magnetic hyperthermia – believed to be a

very promising alternative for human cancer treatment in the future [1]. The efficiency of magnetic hyperthermia is measured by the specific loss power (SLP), which expresses the nanoparticle ability to dissipate heat into the surrounding tissue/liquid [2,3]. The SLP of nanoflowers composed of several 11 nm maghemite particles outperform single core 11 nm maghemite particles by an order of magnitude [1].

Not much is known about the magnetic structure within individual nanoflowers, but averaged over a large ensemble of nanoflowers, the static magnetization curves at room temperature show almost no hysteresis [1,4], indicating a superparamagnetic-like state [4] or a magnetic flux-closure state in zero applied field

We have performed transmission electron microscopy and electron holography on individual nanoflowers. The phase image obtained from an electron hologram contains in principle the components of the magnetic field in the sample plane [5]. Hereby we obtain a magnetic field map (B_x,B_y) which, combined with micro-magnetic modelling, hints at the magnetic structure.

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14 Investigating Time-of-Flight Spin Echo Modulation for Small Angle Neutron Scattering through experiments and simulation

By Morten Sales^{1,2} and Jeroen Plomp³, Klaus Habicht¹, Markus Strobl⁴

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⁴European Spallation Source ESS-AB, Science Division, Sweden..

A Spin-Echo Modulated Small Angle Neutron Scattering (SEMSANS) instrument in a time-of-flight (TOF) mode has been investigated by comparing experimental data from a TOF SEMSANS set-up, where a spatial beam modulation of a white beam is obtained using triangular field coils, with Monte Carlo ray tracing simulations. Our experiments and simulations in accordance demonstrate that a good contrast can be achieved, using a constant field in the triangular coils. In our set-up only neutrons with certain wavelengths rotate by a Larmor precession angle that spatially modulates their polarisation to be coinciding with the period of a grating installed at the detector position. This is shown by measuring with a broad wavelength range while scanning the echo condition. The demonstrated SEMSANS technique can e.g. be used for investigating structures in the nano- to micrometer range without having to worry about depolarisation caused by sample and/or sample environment, and will be able to excel at pulsed neutron sources such as the European Spallation Source (ESS) currently under construction.

15 The McStas neutron scattering instrument simulation project

By Peter Willendrup^{1,2} and Emmanuel Farhi³, Erik Knudsen¹, Esben Klinkby⁴, Emmanouela Rantsiou⁵, Kim Lefmann⁶

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⁶NBI, Copenhagen.

The McStas neutron ray-tracing simulation package is a versatile tool for producing accurate simulations of neutron scattering instruments at reactors, short- and long-pulsed spallation sources such as the European Spallation Source. McStas is extensively used for design and optimization of instruments, virtual experiments, data analysis and user training. McStas was founded as an scientific, open-source collaborative code in 1997.

This contribution presents the project at its current state and gives an overview of lessons learned in areas of design process, development strategies, user contributions, quality assurance, documentation, interoperability and synergies with the McXtrace project.

Further, main new developments in McStas 2.0 (December 2012) and McStas 2.1 (September 2014) are discussed, including many new components, component parameter uniformisation, partial loss of backward compatibility, updated source brilliance descriptions, developments toward new tools and user

interfaces, web interfaces and a new method for estimating beam losses and background from neutron optics.

16 Going grainspotting and beyond with Dark field x-ray microscopy

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Polycrystalline materials are abundant, from rocks, ice and bone to metals, functional ceramics and drug tablets. Since their mechanical and physical properties are largely governed by their internal 3D structure, the availability of suitable structural characterization techniques is crucial.

Here we present the recently developed technique of dark field x-ray microscopy [1] that utilizes the diffraction of hard x-rays (15 – 50 keV) from individual grains or subdomains at the (sub)micron-scale embedded within mm-sized samples. By magnifying the diffracted signal 3D mapping of orientation and stresses inside the grain is performed with a remarkable angular resolution of 0.002° and spatial resolution of 200 nm and improving. Furthermore, the speed of the measurements at high-intensity synchrotron facilities allows for fast non-destructive in situ determination of structural changes induced by annealing or other external influences.

The capabilities of dark field x-ray microscopy are illustrated by examples from an ongoing study of the shape and internal structure of recrystallized micrometer-sized grains inside deformed aluminum.

[1] H. Simons et al., Nature Comm. 2015, in print

Nanophysics and nanomaterials

17 Nanoscale Aluminium dimples for light-trapping in organic thin-films

By A.J. Goszczak and J. Adam, P. Cielecki, J. Fiutowski, H.-G. Rubahn, M. Madsen
Mads Clausen Institute, University of Southern Denmark.

Integration of nanostructures in organic solar cells (OSCs) has been investigated intensively in the past few years as an alternative way for enhancing the power conversion efficiency of the devices. Incorporating structured electrodes in the solar cell architecture holds potential for light absorption improvement in the active layer of the devices. A prospective, cheap and large-scale compatible method for structuring the electrodes in OSCs arises by the use of anodic aluminum oxide (AAO) membranes. In the present work, aluminum films of high purity and low roughness are formed via e-beam evaporation of a few nanometers of aluminum followed by a micrometer layer of aluminum formed via sputter deposition. The samples are then anodized to form nano-scale pores of controlled sizes. The anodization of the prepared samples occurs in an electrochemical cell in H₂SO₄, H₂C₂O₄ and H₃PO₄ solutions. Electrolyte solution variation and anodization parameters (sample temperature, voltage) control, allows for AAO pore diameter and interpore distance tuning. The fabricated AAO is selectively etched in H₂CrO₄/H₃PO₄ mixtures, in order to reveal the underlying aluminum nanoscale dimples, which are present at the bottom of the pores. For the characterization of their light-trapping properties, the dimples are covered with a thin layer of PMMA, and the impact from different dimple dimensions is investigated experimentally via laser ablation based measurements of the field enhancement, which is compared to FDTD calculations to further explain the mechanisms of light-trapping in these structures. These dimples can potentially serve as nanostructured electrodes in P3HT/PCBM bulk heterojunction organic solar cells.

18 Ultrafast Photo-Induced Solid-Solid Phase Transition in Cobalt Nanoparticles

By P. Vester and M. Christensen, K. Haldrup, M.M. Nielsen
NEXMAP Group, DTU Physics, Technical University of Denmark.

Measurements of laser induced Solid-Solid Phase Transitions in Cobalt Nanoparticles, using Time-Resolved X-ray Scattering. Further, the necessary software to simulate the scattering signal for phase transitions and lattice expansions in the nanoparticles was made and used to analyze the obtained data

19 Local field enhanced second-harmonic response of organic nanofibers

By T. Leissner^{1,2} and O. Kostiučenko¹, J. Fiutowski¹, J. R. Brewer², H.-G. Rubahn¹

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Organic CNHP4 nanofibers showing a strong second-harmonic (SH) response have been successfully implemented as active components in a metal-organic hybrid system. Using nondestructive roll-on transfer technique nanofibers were transferred from the growing mica substrates onto electron-beam lithography-defined regular arrays of gold, titanium and silicon oxide. As shown in a femtosecond laser scanning microscopy study the fiber-substrate interplay leads (only) on gold to a significantly enhanced SH signal. We suggest that this effect is driven by the local field enhancement i.e. the excitation of surface plasmon polaritons (SPP) and lightning rod effects, since in case of Ti and SiO₂ no SPPs are excited at a laser wavelength of 790 nm and the used array dimensions. Furthermore, we observe a considerably reduced fluorescence lifetime for the fibers deposited on gold arrays supporting the assumption of strong interaction between gold substrate and fibers. In summary we show that by adjusting substrate and fiber properties the SH response can be locally controlled.

20 Applications of anodized aluminum substrates for silicon thin-film solar cells

By Yao-Chung Tsao¹ and Christian Fisker¹, Thomas Søndergaard¹, Kjeld Pedersen¹, Thomas Garm Pedersen¹

¹Department of Physics and Nanotechnology, Aalborg University, Denmark.

For silicon thin-film solar cells, the question of enhancing the photon capture within the absorption layer is crucial because thickness reduction without sacrificing too much efficiency is the trend followed for developing low-cost solar cells for the future. In the THINC project, we focus on the development of nanostructured backside reflectors (BSRs). Anodic aluminum oxidation (AAO) is used for fabricating nanostructures on aluminum surfaces for enhancing the optical absorption in thin-film silicon solar cells. In this report, three different BSR samples with various pore sizes of 320 nm, 430 nm and 700 nm are fabricated and investigated experimentally and theoretically. The results show that a 430 nm pore size with a 200 nm silicon coating is the best choice for actual cell production.

Nuclear and elementary particle physics

21 Gamma-ray light from stellar explosions

By Oliver Kirsebom

Aarhus University, Denmark.

The radioactive isotope ^{22}Na , a product of explosive hydrogen burning in novae, emits a characteristic gamma ray which carries important clues about nucleosynthesis in novae. Precise calculation of the expected gamma-ray flux requires precise knowledge of the rates of the nuclear reactions that create and destroy ^{22}Na . Unfortunately, one of the most important rates, namely, that of radiative proton capture on ^{22}Na , is uncertain by a factor of 2-3. In an attempt to reduce this uncertainty, we have measured the lifetime of a resonance in the compound nucleus, ^{23}Mg , that is known to dominate the rate. In my contribution I will describe the experiment and present preliminary results.

Photonics

22 Hybrid III-V-on-Si laser with ultra-low energy consumption

By A. Taghizadeh¹ and J. Mørk¹, I.-S. Chung¹

¹Department of Photonics Engineering, Technical University of Denmark.

We are working on investigation of novel micro-lasers with a diffraction-limited small modal volume. These laser structures consist of high-index-contrast gratings and aim for an emission to an in-plane waveguide which will be very important for future optical interconnects. For these structures, high-speed direct modulation and very low energy consumption are expected due to their small modal volume. Our group research on these laser structures involves theoretical/numerical investigation, device fabrication, and characterization. My project will cover mostly theoretical/numerical investigation part. In this part, an advanced optical simulator is developed based on Fourier modal method (FMM) which can solve Maxwell equations in 3D vectorial manner. Also rate equations are solved spatially and temporally and are integrated with the optical solver to make a comprehensive laser simulator. Using the laser simulator, physics of the micro-lasers with a diffraction-limited optical cavity are investigated.

23 Earth abundant materials for solar cells: thin films of chalcogenide material

$\text{Cu}_2\text{ZnSnS}_4$

By Andrea Cazzaniga¹ and Rebecca Bolt Ettliger¹, Andrea Crovetto², Jørgen Schou¹

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Pulsed Laser Deposition technique is applied to the production of thin films of earth abundant material $\text{Cu}_2\text{ZnSnS}_4$, which is a semiconductor to be used as absorber layer in solar cells. This vacuum technique has proven to be particularly successful in the production of films with a complex stoichiometry, as in the case of high temperature superconductors. The material ablated by the laser pulse is transferred to the substrate at very high kinetic energy (\sim keV), thus resulting in high mobility of the adsorbed atoms yet at low substrate temperatures. We investigate the optical and structural properties of thin films produced in high vacuum ($p < 10 - 6$ mbar) with a single target made with sintered powder with stoichiometry: $\text{Cu}_2\text{ZnSnS}_4$. The films are deposited on Mo coated SLG in the temperature range from 200 C to 350 C and subsequently annealed at 500 C in sulfurized atmosphere. X-ray diffraction patterns show an increase in the intensity of main peak associated to kesterite CZTS up to a substrate temperature of 300 C, then secondary phases start to show up and the main peak associated to kesterite drops down in intensity. Optical measurements (direct and diffuse reflectance) and ellipsometry analysis are used to investigate the optical properties of the films produced and to estimate the bandgap. The films produced are in the thickness range 400 – 600 nm, the excimer laser used is a Lambda Physik filled with KrF working at 248 nm, with pulse length of 20 ns. Pulse repetition rate was set at 10 Hz, the deposition process was lasting 1 hour.

24 Special Hollow Core Fibers for Fiber-based Optical Frequency Standard Technology

By M. Michieletto^{1,2} and M.Triches^{1,3}, J.K.Lyngsø², J. Hald³, J.Lægsgaard¹, O.Bang¹

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The aim of this project is to realize a versatile and compact optical frequency standard. The technology involves the realization of non-conventional cell based on gas-filled hollow core photonic crystal fibers. All the aspects have been considered, from fiber design to the cell assembly. Results from a first

prototype are presented. This project is part of an ITN European Marie-Curie project called “QTea”, which involves several university/companies from all over Europe, with the aim to exploit the quantum technology beyond the state-of-art, from the gravitational sensing to the optical clock/meter standard development. The project itself is involving two PhD students and two different industries coordinated by DTU Fotonik department. NKT Photonics is providing the infrastructure to design and draw the hollow-core fibers, as well as the knowledge and skills for the performance evaluation of the fibers behavior. Dansk Fundamental Metrologiinstitut (DFM) is providing the facilities and knowledge related to the spectroscopy in hollow core fibers. In order to achieve the wanted results, the unique property of hollow core fiber to propagate the light in diffraction-less fashion over several meters is exploited to realize laser frequency-locking using saturated absorption spectroscopy techniques. After an accurate evaluation of the performance of different fibers, using both experimental testing and simulations, a first prototype has been assembled using acetylene molecules. The acetylene gas has been chosen because of a well-known absorption line in the IR region (1542nm) close to the telecommunication wavelength (1550nm). The portable system has been compared with a conventional gas cell filled with acetylene and the results show an accuracy of the frequency within 5kHz and an average frequency instability of $5E-11$ in the 1-1000s sampling time. The fiber characterization in correlation with the frequency response is also presented as part of the performance evaluation study.

25 Advanced optical design for multicolored LED systems for lighting applications

By Maumita Chakrabarti and Carsten Dam-Hansen, DTU Fotonik LED team, Brother, Brother & Sons ApS

LED illumination of the Danish Royal Treasures at Rosenborg Castle:

We have optimized and optically modeled the Rosenborg LED system to discover angular distribution in terms of intensity and measured the tristimulus value for colour mixing. We have also experimentally proved the system by colour correlated temperature (CCT) tuning from 2000 K to 2400 K. Rosenborg system is a high light quality, energy efficient (≈ 30 lm /W) LED system and has been implemented at Rosenborg Castle with three coloured LEDs. By colour mixing of the LEDs, 2200 K CCT was achieved with colour rendering index (CRI) above 90 and rendering the blue background perfectly.

Multicolour high power LED engine:

We are developing a new LED-based light engine that will take the LED technology into the future of professional lighting. By meeting the entertainment industry’s critical demands for colour gamut, colour rendering of white light and intensity, the light engine will finally enable a revolutionary replacement of the energy consuming halogen based light sources in professional lighting.

26 High energy supercontinuum sources for photoacoustic imaging and multimodal applications

By Magalie BONDU¹

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Supercontinuum sources are very suitable for many biophotonics imaging systems such as photoacoustic imaging. Combining different wavelength simultaneously allows us to have a higher panel of information on a sample. However the lack of pulse energy delivered by the supercontinuum source is an important limit to improve the system resolution. At the moment, what most people do is using a Q-switch Nd:YAG laser to pump the nonlinear fiber in order to generate a supercontinuum spectrum. Nevertheless, this pump has no tunability in terms of pulse length and pulse repetition rate. To achieve this, we use a directly modulated diode. This improvement should be really useful in the future since this technology evolves very well and with such a tunable supercontinuum source we could achieve multimodal applications.

27 Fast single photons

By Nika Akopian

DTU Fotonik.

Can single-photons travel faster than c (the speed of light in vacuum)? So far there have been only a few attempts to answer this question experimentally [1,2]. Here we develop a hybrid semiconductor-atomic

[3] system and demonstrate that the group velocity of a single-photon can exceed the speed of light in vacuum. We use a single GaAs quantum dot (semiconductor part of our hybrid system) as frequency-tunable source of single-photons. We use Rb-87 vapour as a fast-light medium (atomic part of the hybrid system) through which single-photons are propagating.

[1] A. M. Steinberg, P. G. Kwiat & R. Y. Chiao, "Measurement of the single-photon tunneling time", *Phys. Rev. Lett.* 71, 708 (1993)

[2] S. Zhang, J. F. Chen, C. Liu, M. M. T. Loy, G. K. L. Wong & S. Du, "Optical Precursor of a Single Photon", *Phys. Rev. Lett.* 106, 243602 (2011)

[3] N. Akopian, L. Wang, A. Rastelli, O. G. Schmidt & V. Zwiller, "Hybrid semiconductor-atomic interface: slowing down single photons from a quantum dot", *Nature Photonics* 5, 230 (2011)

28 The PV LED Engine – a new generation of intelligent solar powered LED lighting

By Peter Behrendorff Poulsen and Sune Thorsteinsson

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Digging down cables for small electrical applications in the urban environment is extremely expensive due to the high labour cost associated with it. Small stand-alone PV applications powered by 0.5-50 Wp can become very attractive since e.g. in Copenhagen in Denmark the cost of digging down cables in the city is about 1000 \$ pr. meter so the cost savings on the cable digging can easily pay for the solar cells. The requirements to the products from the municipalities are high so if e.g. the products are for lighting purpose the reliability of the product meeting some specified amount of light is very important. The willingness to pay for such high-end stand-alone PV applications is though high but it is essential to be able to evaluate if the product will work in a given environment in both the development and dimension phase of the product and as a credible proof tool towards consumer/buyer/decision makers.

The barrier for exploiting this potential seems to be the lack of knowledge and tools for dimensioning and designing PV applications for the urban environments. The authors investigated the many PV dimensioning tools on the market and found none addressing exactly this issue and in the present project at design and simulation tool for small PV applications for the urban environment is developed.

The tool is advanced in its calculations on the solar irradiation parameters being very different in the urban environment compared to roof top applications both spectrally and in intensity variations. Weather parameters based on Typical Meteorological Year (TMY) for a given position on the globe is used for the solar irradiation calculations dissolved spectrally by the models proposed by D. R. Myers[1] and simple assumptions about the geometrical and optical properties of the environment of use. The irradiation parameters are filtered mathematically by the optical properties of the materials in front of the solar panel and assumptions about the soiling parameters. Lab measurements of solar cells/panels under different lighting conditions (spectrally and intensity) makes it possible to simulate performance of real solar panels of different technologies in the addressed environment since detailed electrical characteristics is known by the measurements. Optical parameters for the protection layer (in front of the solar panel) are put into a material library so the optimal choice can be made for a given application. Relevant light emitting diodes and batteries are characterized electrically to have detailed knowledge of the whole energy system. The consumption side of the model is quite advanced making it possible to create different lighting scenarios depending on the purpose of the lighting product and its ability to dispose intelligently over the energy.

To validate the model high-end PV products on the market has been bought, simulated and the whole electrical system been characterized electrically (battery, LED, electrical circuit, PV) and optical properties of the optical system in front of the solar panel and installed in an optical characterized urban test environment.

The simulation tool has already shown weak spots in the energy chain of a larger amount of stand-alone PV applications for the environment the vendors promised them to work in. It is possible to evaluate if different PV technology is better suited for the environment and if e.g. the battery technology is suited for the temperature challenges the product also meets. Since the products are meeting a large amount of low light conditions compared to roof-top PV installation it also seems relevant to develop an electrical circuit for a PV harvester module with more "gears" where one is optimized for low light conditions. The market for electrical harvester modules seems to meet those requirements far from optimally to the present project group's knowledge.

[1] D.R. Myers, *Solar Energy* 86 (2012) 2771-2782

29 Pulsed laser deposition of Cu-Sn-S for thin film solar cells

By Rebecca Bolt Ettliger¹ and Andrea Crovetto², Edoardo Bosco², Philip Rasmussen², Jørgen Schou¹

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Cubic-phase Cu_2SnS_3 is both a secondary phase of $\text{Cu}_2\text{ZnSnS}_4$ and a potential solar cell absorber in its own right. Using pulsed laser deposition, thin films of copper tin sulfide were deposited from a target enriched with Sn and S relative to the stoichiometry of Cu_2SnS_3 . During deposition and annealing, Sn and S were lost from the film. Annealing with S powder resulted in films close to the desired Cu_2SnS_3 stoichiometry, although the films remained Sn rich. X-ray diffraction showed that the final films contained both cubic-phase Cu_2SnS_3 and orthorhombic-phase SnS.

30 Grain Growth of CZTS Nanoparticles for Solar Cells

By S. Engberg¹ and J. Schou¹

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The kesterite material, $\text{Cu}_2\text{ZnSn}(\text{S}_x\text{Se}_{1-x})_4$ (CZTS), is very promising as absorber material in future thin film solar cells. The elements are abundant, the material has a high absorption coefficient, and the pure sulfide CZTS is non-toxic. These properties make CZTS a potential candidate also for large-scale applications. Here, solution processing allows for comparatively fast and inexpensive fabrication and solution processing also holds the record efficiency in the kesterite family, however for the selenized compound. The current challenges are, (1) that the high carbon content in nanoparticle thin films is one of the main limitations for this approach, and (2) that grain boundaries and defects are believed to be a site for recombination that limits the efficiency. Annealing in vacuum and/or a nitrogen atmosphere facilitates grain growth and improves the electronic properties. Conventionally selenization (annealing in selenium) shows the best results, however sulfurization (annealing in sulfur) has the advantage of leading to a non-toxic material.

In this work, nanocrystals of CZTS with a targeted Cu-poor/Zn-rich composition are synthesized through a hot-injection method with oleylamine as the solvent. The nanocrystal inks are deposited through doctor blading in octanethiol, and annealed in a vacuum furnace using a graphite box with selenium or sulfur. The surface morphology and thus grain growth are studied for various annealing conditions in a 10-mbar nitrogen atmosphere with a varying amount of sulfur and for different annealing times.

The films are characterized with scanning electron microscopy (SEM). Compositional changes are monitored by energy dispersive X-ray spectroscopy (EDX) and the crystallinity by X-ray diffraction (XRD).

A photovoltaic device of the structure soda lime glass (SLG)/Mo/CZTSSe/CdS/ZnO:Al/Ag has been built, and our preliminary results show a power conversion efficiency of 1.41% for the nanoparticles annealed in selenium.

31 Building up a Thermal Light Source for Spectral Domain Optical Coherence Tomography

By Sophie Caujolle¹ and Professor Leo Schmetterer²

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With the use of computers in everyday life, the number of patients affected by a dry eye syndrome increases. The conventional method of diagnosis is invasive that's why the idea to image the tear film structure which is directly in relation to this disease with an OCT system could be enticing. For this reason, we need to improve the resolution and the solution mentioned here is to use a light source with a large bandwidth as a thermal bulb.

We have two principal goals in this thesis. One, the most challenging is to find a compromise between the coherence length and the power. Indeed, to have a correct spatial coherence, we must reduce the size of the filament but the power greatly decreases. For that, we compare three bulbs and some optical layouts to optimize. The second is to build the interferometer in a large range (700-1000 nm) and to

get components which could be well suited without too many optical problems such as aberrations or dispersion.

32 Nonlinear interferometer for shaping the properties of bright squeezed vacuum

By T. Sh. Iskhakov¹, and A. Pérez², S. Lemieux³, R. W. Boyd³, P. Sharapova⁴, O. V. Tikhonova⁴, M. V. Chekhova^{2,4,5}, G. Leuchs^{4,5}

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Spurred by possible applications of nonclassical light in metrology, communication, microscopy, and interferometry we developed a new source of bright squeezed vacuum radiation with tunable properties in spatial and frequency domain. Using two-crystal configuration of the traveling-wave optical parametric amplifier operating at the high-gain regime we demonstrate a reduction of the number of transverse modes down to 1.1. with the distance between the crystals. We experimentally show that the insertion of a group velocity dispersion medium between the crystals, separated by a distance, is leading to the narrowing of the output spectrum.

33 Mid-infrared supercontinuum generation in the fingerprint region

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The mid-infrared spectral region is of great technical and scientific interest because most molecules display fundamental vibrational absorptions in this region, leaving distinctive spectral fingerprints. Here, we demonstrate experimentally that launching intense ultra-short pulses with a central wavelength of either 4.5 μm or 6.3 μm into short pieces of ultra-high numerical-aperture step-index chalcogenide glass optical fibre generates a mid-infrared supercontinuum spanning 1.5 μm to 11.7 μm and 1.4 μm to 13.3 μm , respectively [1]. This is the first experimental demonstration to truly reveal the potential of fibres to emit across the mid-infrared molecular fingerprint region, which is of key importance for applications such as early cancer diagnostics, gas sensing and food quality control.

[1] C. R. Petersen et al., “Mid-infrared supercontinuum covering the 1.4–13.3 μm molecular fingerprint region using ultra-high NA chalcogenide step-index fibre”, *Nature Photonics* 8, 830-834 (2014).

Plasma physics

34 Collective Thomson scattering measurements in fusion plasmas

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Collective Thomson scattering (CTS) diagnostics provide information about the composition and velocity distribution of confined ion populations in fusion plasmas. Such measurements are based on scattering of mm-waves from microscopic collective fluctuations, principally in the electron density. We will here give an overview of the CTS system operated by DTU Physics at the ASDEX Upgrade tokamak and show examples of recent results for the fast-ion velocity distribution, the ion temperature and plasma flow velocity.