20. Quantum Optics and Photonics

Academic and Research Staff

Prof. S. Ezekiel, Dr. B. Kleinmann, Dr. P.R. Hemmer, J. Kierstead

Graduate Students

H. Chou, D. DiFillipo, S.H. Jain, F. Long, R.E. Meyer, V. Natoli, C. O'Connor, G. Ontai, B.W. Peuse, D.R. Ponikvar, M.G. Prentiss, G.A. Sanders, S. Shu, R.E. Tench, E. Young, F. Zarinetchi

20.1 Precision Studies of Doppler–Free Lineshapes Generated by Pump–Probe Interactions in a Vapor

National Science Foundation (Grant PHY82-10369)
Joint Services Electronics Program (Contract DAAG29-83-K-0003)
Robert E. Tench, Shaoul Ezekiel

The interaction of monochromatic radiation with two and three level quantum systems is of much interest because it involves basic physical processes which can be described by relatively simple theoretical models. As part of our continuing investigations of basic atom–field interaction, we have performed a precision experimental study of the interaction of two monochromatic laser fields with a folded. Doppler–broadened three level system in I_2 vapor. Studies were performed both for copropagating fields (forward scattering) and counterpropagating fields (backward scattering); in both cases, the measured quantity was the gain induced at the frequency of a weak probe field in the presence of a pump field of arbitrary strength.

The experimental setup consisted of a CW argon ion laser operating at 5145 A (the pump), a CW dye laser operating near 5830 A (the probe), a single mode fiber and a cell containing I_2 vapor. Fast frequency stabilization techniques were used to reduce the short–term linewidths of the lasers to a few kHz rms. Long–term frequency stability was achieved by locking the argon laser to a molecular reference and transferring the long–term stability of the argon laser to the dye laser via a transfer Fabry-Perot cavity. Precision laser tuning was then accomplished by using an acousto–optic frequency shifter which operated at frequencies between 100 and 200 MHz. Collinear pump and probe fields were generated by coupling both lasers into a single model fiber,[1] and lineshapes are recorded by holding the pump frequency fixed and scanning the probe frequency.

Experimental studies of forward and backward scattered lineshapes were carried out in the weak and strong pump field limits. The forward and backward lineshapes obtained with weak pump fields were found to be Lorentzians of different widths; the forward scattered line had a width of 40 kHz. The experimental weak field lineshapes and linewidths were in excellent agreement with the predictions of a steady state theoretical model of the pump-probe interaction.[1] For intense pump fields, however, an apparent splitting was observed in the backward scattered case which is not predicted by the steady state theory and which cannot be attributed to the AC Stark effect. Careful tests of both the experimental measurements and the theoretical model showed that it is necessary to include the effects of velocity selective optical pumping[2] in the calculations. When these effects were included by using a rate equation approach, the theoretical strong field lineshapes were found to be in excellent agreement with experiment.[3]

References

1. R.E. Tench and S. Ezekiel, Chem. Phys. Lett. 96, 253 (1983).
2. J.E. Bjorkholm, P.F. Liao, and A. Wokaun, "Distortion of On-Resonance Two-Photon Spectroscopic Line Shapes Caused by Velocity-Selective Optical Pumping," Phys. Rev. A 26, 2643 (1982).
3. R.E. Tench and S. Ezekiel, to be published.

20.2 Precision Experimental Studies of Collisionally Broadened Lineshapes Using a Pump-Probe Technique

National Science Foundation (Grant PHY82-10369)

Robert E. Tench, Shaoul Ezekiel

We have performed preliminary experimental studies of the effects of collisions on pump-probe interactions in I_2 vapor. These studies were carried out for $I_2 - I_2$, $I_2 - H_e$, I_2 - Ar and I_2 - Xe collisions in both weak and strong pump field limits. In the weak pump field case, strong nonlinear behavior was observed in pressure broadening curves for both the forward and the backward scattered lineshapes. In the strong pump field case, an increase in height and a decrease in linewidth were observed for the backward scattered line when buffer gases were admitted to the I_2 cell. Such lineshapes are expected to be very sensitive, high resolution probes of velocity and phase changing collisions in a vapor, and these studies are being pursued both experimentally and theoretically.

20.3 Atom-Field Interaction in Atomic Beams

National Science Foundation (Grant PHY82-10369)

Mara Prentiss, Shaoul Ezekiel

We have previously studied atom-field interaction using a traveling wave excitation field and a sodium atomic beam[1-5] prepared as a two-level system. Our data showed that atomic recoil strongly influenced the symmetry of the fluorescent lineshapes as the intensity of the excitation field is increased. In order to reduce atomic recoil effects we have recently begun to investigate the use of a standing wave rather than a traveling wave excitation.

In this case, the fluorescence lineshapes also exhibited an asymmetry at strong fields which cannot be explained by residual recoil effects. We attribute the observed symmetries in a strong standing wave field to the atomic motion along the standing wave direction caused by the force on the induced atomic dipoles in the field gradient of the standing wave. This effect is being carefully studied both theoretically and experimentally.

References

1. P.R. Hemmer, B.W. Peuse, F.Y. Wu, J.E. Thomas, and S. Ezekiel, "Precision Atomic-Beam Studies of Atom-Field Interactions," Opt. Lett. 6, 531 (1981).
2. B.W. Peuse, R.E. Tench, P.R. Hemmer, J.E. Thomas, and S. Ezekiel, "Precision Studies in 3-Level Systems," in A.R.W. McKellar, T. Oka, and B.P. Stoicheff (Eds.), Laser Spectroscopy V (Springer-Verlag 1981) p. 251.
3. B.W. Peuse, M.G. Prentiss, and S. Ezekiel, "Distortion in Atomic Beam Absorption Lineshapes," Journal de Physique, Colloque C8, Supplement au n° 12, Tome 42, C8-53, December 1981.
4. B.W. Peuse, M.G. Prentiss, and S. Ezekiel, "Observation of Resonant Light Diffraction by an Atomic Beam," Phys. Rev. Lett. 49, 269 (1982).
5. B.W. Peuse, M.G. Prentiss, and S. Ezekiel, "Elimination of Lineshape Distortion in Laser Absorption Spectroscopy in Atomic Beams," Opt. Lett. 8, 154 (1983).

20.4 Laser Raman Microwave Clock

National Science Foundation (Grant PHY82-10369)
Joint Services Electronics Program (Contract DAAG29-83-K-0003)
Philip H. Hemmer, Guy Ontai, Shaoul Ezekiel

Recently, we have been investigating the possibility of developing an atomic clock based on a laser-induced resonance Raman transition.[1-4] The potential advantages of such a clock arise from the use of an all optical excitation, which eliminates the need for bulky and expensive microwave cavities and state selection magnets used in conventional atomic clocks. This should lead, for example, to the development of more accurate and more compact, portable cesium beam clocks.

In earlier work, it was demonstrated that transit time limited Raman linewidths as narrow as 1.3 kHz (FWHM) could be observed using a 1772 MHz resonance Raman transition in a sodium atomic beam. These narrow transit time limited linewidths were obtained using Ramsey's method of separated field excitation, in analogy with microwave techniques. To reduce laser jitter effects, an acousto-optic frequency shifter was used to generate one laser frequency directly from the other, thereby insuring a highly stable laser difference frequency.

To demonstrate clock applications, a microwave oscillator was stabilized to a 2.6 kHz wide Raman transition, obtained using a 15 cm Ramsey zone separation. The fractional frequency deviation of the stabilized oscillator was as small as 1.5×10^{-11} for a 1000 sec averaging time. This stability, which is close to the shot noise limit of the present setup, compares favorably with commercial cesium clocks when differences in transit time and transition frequency are taken into consideration.

For longer averaging times, the stability is not as good, due to the presence of long-term frequency errors. Potential sources of long-term frequency error studied recently include: (1) the effects of relative misalignments of the two laser fields away from copropagating, (2) the effects of birefringence related optical phase shifts produced when the relative phases of the two laser fields are different at the two Ramsey interaction zones, (3) phase shifts produced by path length changes on the scale of the effective microwave wavelength, (4) laser detuning effects, (5) the effects of external magnetic fields, including the earth's field, (6) changes in atomic beam alignment, (7) laser beam misalignments (both frequencies together), (8) laser power, both relative and absolute and (9) the effects of other atomic levels near the intermediate state. While these potential frequency error sources are still under study, much progress has already been made in order to achieve such stabilities at 1000 sec averaging times.

Future plans include a more detailed study of potential long-term frequency error sources. Efforts are also in progress to improve the (shot noise limited) short term stability by increasing sodium beam throughout and to improve overall stability by extending the Ramsey zone separation out to 1 meter. Finally, we are preparing to construct an experimental Raman cesium clock using a very simple atomic beam and employing semiconductor laser and fiber optic technology. With such an experimental Raman cesium clock we hope to demonstrate potential advantages over conventional microwave cesium clocks.

References

1. J.E. Thomas, S. Ezekiel, C.C. Leiby, Jr., R.H. Picard, and C.R. Willis, Opt. Lett. 6, 298 (1981).
2. J.E. Thomas, P.R. Hemmer, S. Ezekiel, C.C. Leiby, Jr., R.H. Picard, and C.R. Willis, "Observation of Ramsey Fringes Using a Stimulated Resonance Raman Transition in a Sodium Atomic Beam," Phys. Rev. Lett. 4, 867 (1982).
3. P.R. Hemmer, S. Ezekiel, and C.C. Leiby, Jr., "Stabilization of a Microwave Oscillator Using a Resonance Raman Transition in a Sodium Beam," in W.D. Phillips (Ed.), Laser-Cooled and Trapped Atoms, Nat. Bur. Stand. (U.S.), Special Publication 653, June 1983, p. 47.
4. P.R. Hemmer, S. Ezekiel, and C.C. Leiby, Jr., "Stabilization of a Microwave Oscillation Using a Resonance Raman Transition in a Sodium Beam," Opt. Lett. 8, 440 (1983).
5. P.R. Hemmer, S. Ezekiel, and C.C. Leiby, "Performance of a Microwave Clock Based on a Laser Induced Stimulated Raman Interaction," Technical Digest XIII, International Quantum Electronics Conference, June 18, 1984, p. 114.

20.5 Passive Resonator "Gyroscope"

U.S. Air Force - Office of Scientific Research (Contract F49620-82-C-0091)
Joint Services Electronics Program (Contract DAAG29-83-K-0003)
Farhad Zarinetchi, Shaoul Ezekiel

Precision measurement of inertial rotation is of much interest in a number of areas, such as navigation, geophysics, and relativity. The geophysical applications include the measurement of the various effects that cause fluctuations in the earth's rotation rate Ω_E, ranging from 10^{-7} to $10^{-9}\Omega_E$, for example, nutation, precession, wobble, and tidal-friction effects. The relativistic effects range in sensitivity from 10^{-9} to $10^{-11}\Omega_E$ and include measurements of the preferred frame and the drag parameters.

The advent of the laser in 1960 rekindled the interest in the use of the Sagnac effect for sensing inertial rotation by optical means. Several approaches of implementing the Sagnac effect have been under investigation. These include active techniques, such as the ring laser gyro, and passive techniques employing passive ring resonators[1-5] or multiturn fiber-optic interferometers. In all these approaches, the measurement sensitivity scales with the area enclosed by the light path. Typically, to reach the sensitivity needed to measure the geophysical and relativistic effects mentioned previously, it is necessary to consider areas between 10^2 and $10^4 m^2$.

Our research effort at present centers around a passive 10 cm square resonator with a Finesse of 12000 (kindly made available to us by Litton). The differences between the resonance frequencies of the cavity for clockwise and counterclockwise propagation that is induced by inertial rotation is measured by a low power He-Ne laser mounted external to the cavity. So far we have demonstrated excellent short term drift of 0.01°/hr for averaging times of 100 seconds which is consistent with the photon shot noise noise limit applicable to our set-up. In addition we have demonstrated the cross-coupling between the counter propagating beams due to back scatter and showed how to eliminate such an effect. We are also studying various configurations for probing such a resonator, in particular, the relative merits of observing the transmitted light versus the reflected light.

References

1. G.A. Sanders, M.G. Prentiss, and S. Ezekiel, "Passive Ring Resonator Method for Sensitive Inertial Rotation Measurements in Geophysics and Relativity," Opt. Lett. 6, 569 (1981).
2. R.E. Meyer, G.A. Sanders, and S. Ezekiel, "Observation of Spatial Variations in the Resonance Frequency of an Optical Resonator," J. Opt. Soc. Am. 73, 939 (1983).
3. G. Sanders and S. Ezekiel, "Measurement of Fresnel Drag in Moving Media Using a Ring Resonator Technique," Technical Digest XIII, International Quantum Electronics Conference, June 18-21, 1984, p. 114.
4. F. Zarinetchi, R.E. Meyer, G.A. Sanders, and S. Ezekiel, "Passive Resonator Gyro," Fiberoptic and Laser Sensors, SPIE publication No. 478 (1984).

5. S. Ezekiel, "An Overview of Passive Optical Gyros," Proceedings of the Snowbird Conference on Optical Ring Gyros, SPIE publication No. 487 (1984).

20.6 Fiberoptic Ring Resonator "Gyroscope"

U.S. Air Force - Office of Scientific Research (Contract F49620-82-C-0091)

Roberto Shu, John Kierstead, Shaoul Ezekiel

We are investigating the use of an all-fiber ring resonator as a sensor of absolute rotation.[1-4] The principle here is similar to that of the discrete mirror resonator method that has been under development in our laboratory for several years. In brief the mirror resonator is simply replaced with a single mode fiber resonator and the input-output coupling is accomplished by means of evanescent wave fiber couplers. The presence of rotation perpendicular to the plane of the resonator causes a difference in the frequencies of the resonator when observed along counter propagating directions.

To achieve high performance consistent with shot noise prediction a number of problems must be studied and solved. In particular we are studying the effects of cross coupling between the counter propagating beams, fiber birefringence and non-linear phenomena such as the optical Kerr effect and stimulated Brilloun scattering.

References

1. R.E. Meyer and S. Ezekiel, "Fiberoptic Resonator Gyroscope," presented at the First International Conference on Optical Fiber Sensors, IEE, London, England, April 1983.
2. R.E. Meyer, S. Ezekiel, D.W. Stowe, and V.J. Tekippe, "Passive Fiberoptic Ring Resonator for Rotation Sensing," Opt. Lett. 8, 644 (1983).
3. S. Ezekiel, "An Overview of Passive Optical "Gyros", Proceedings of the Snowbird Conference on Optical Ring Gyros, SPIE No. 478 (1984).
4. R.E. Meyer and S. Ezekiel, "High Finesse Fiber Ring Resonator for Rotation Sensing," Technical Digest, Conference on Fiberoptic Communication, OFC '84, January 23–25, p. 42.

20.7 Long-Term Wavelength Stabilization of Broadband Semiconductor Light Sources

Litton Guidance and Control System

Harry Chou, Shaoul Ezekiel

Work is under way to develop techniques for long-term stabilization of the average wavelength of broadband semiconductor sources, for example, super luminescent diodes, in the 0.8 μm wavelength range. These sources are important for minimizing coherent back-scattering and non-linear index effects in fiber-optical interferometric rotation sensors that make use of the

Sagnac effect. We are currently pursuing an indirect stabilization scheme in which a Michelson interferometer is first stabilized with respect to a HeNe laser of known wavelength, and the interferometer is then used to stabilize the semiconductor light source. The HeNe laser may be replaced by a stabilized single frequency semiconductor laser for compactness and ruggedness. We are also considering the use of an integrated optic Mach-Zender interferometer with unequal arms as a reference with or without a stable secondary light source.

In addition, a number of characteristics of broadband semiconductor sources are being investigated. These include the optical spectrum, the noise spectrum, and the shift of the average wavelength with temperatures and injection current.

20.8 Linewidth Reduction and Stabilization of Single Frequency Semiconductor Lasers

Joint Services Electronics Program (Contract DAAG29-83-K-0003)

Sudhanshu Jain, John Kierstead, Shaoul Ezekiel

Single frequency semiconductor lasers have inherently a broad linewidth as compared with gas lasers. Considerable effort has gone into the study of the properties of these lasers and the development of methods for the reduction of the laser linewidth.[1,2]

At present we are exploiting the simple techniques of linewidth narrowing by optical feedback from an external mirror. The magnitude of linewidth reduction depends on both the magnitude and phase of the light feedback into the laser. In addition to linewidth narrowing, we are also evaluating various schemes for the stabilization of the phase of the optical feedback so as to maintain narrow linewidth operations.

References

1. R. Lang and K. Kobayashi, "External Optical Feedback Effects on Semiconductor Injection Laser Properties," IEEE. J. Quant. Electron. QE-16, 3, March 1980.
2. G.A. Acket, D. Lenstra, A.J. denBoef, and B.H. Verbeek, "The Influence of Feedback Intensity on Longitudinal Mode Properties and Optical Noise in Index-Guided Semiconductor Lasers," IEEE J. Quant. Electron. QE-20, 10, October 1984.

20.9 Optical Phase Conjugation in a Ring Resonator

National Science Foundation (Grant PHY82-10369)

Bertrand Kleinmann, Shaoul Ezekiel

Used in a four-wave mixing configuration, a non-linear medium may have a reflection and a transmission coefficient higher than one.[1] Therefore, we should be able to observe a coherent oscillation in a ring resonator containing such a medium. We plan to study the various characteristics of the emitted light as a function of the direction of propagation and of any kind of reciprocal or non-reciprocal phase shifts that could be experienced by the light in the resonator.

Aside from fundamental interest, such research may be of use in the development of very sensitive optical rotation sensors based on the Sagnac effect[2] and in the generation and observation of "squeezed states".

References

1. B. Kleinmann, Ph.D. Thesis, École Normale Superieure, Paris, France, June 1984.
2. M.M. Tehrani, "The Phase Conjugate Ring Laser Gyro (Φ *RLG)," SPIE No. 412 (1983).