21. Quantum Optics and Photonics

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21.1 Precision Studies of Stimulated Resonance Raman Interactions in an Atomic Beam

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

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

Philip H. Hemmer, Guy P. Ontai, Vincent Natoli, Shaoul Ezekiel

Precision studies of stimulated resonance Raman interactions in a sodium atomic beam have been performed with emphasis on Ramsey's separated field excitation. Ramsey fringes were obtained for a field separation of up to 30 cm, and the data were consistent with theoretical predictions. Possible applications of this Raman interaction to clock development have also been studied by stabilizing a microwave oscillator to a Raman/Ramsey fringe. The resulting oscillator stability of 1.5×10^{-11} for a 1000 second averaging time compares favorably with commercial cesium clocks when differences in atom transit time and transition frequency are taken into consideration. Finally, potential sources of long term frequency error which are important for clock applications have also been partially investigated.

Publications

Hemmer, P.R., G.P. Ontai, and S. Ezekiel, "Precision Studies of Stimulated Resonance Raman Interactions in an Atomic Beam," J. Opt. Soc. Am. B, March 1986, to be published.

21.2 Observation of Lineshape Asymmetry for a Two-Level Atom in a Standing Wave Field

National Science Foundation (Grant PHY82-10369)

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

Mara G. Prentiss, Shaoul Ezekiel

We have observed intensity dependent asymmetries in the fluorescence lineshape of a two level sodium atomic beam in the presence of either a travelling or a standing wave excitation field. The asymmetry in the travelling wave case has been noted previously and is due predominantly to the recoil that the atoms experience in traversing the excitation field. We attribute the observed asymmetries in the standing wave field to the force experienced by the induced atomic dipoles in the field gradient of the standing wave. Our calculations agree well with our data.

Such lineshape studies are of much interest because of the important information they convey about basic atom field interactions and also because such lineshape asymmetries can influence the accuracy of frequency/wavelength standards as well as the ultimate precision of spectroscopic measurements.

Publications

Prentiss M.G., and S. Ezekiel, "Observation of Intensity Dependent Fluorescence Lineshape Asymmetry for Two-Level Atoms in a Standing Wave Field," Phys. Rev. Lett. 56, 46 (1986).

21.3 Observation of Lock-in Behavior in a Passive Resonator Gyroscope

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

Farhad Zarinetchi, Shaoul Ezekiel

A passive resonator rotation sensor or "gyroscope" is a ring resonator in which counter propagating light beams within the resonator experience a nonreciprocal phase shift due to an applied rotation rate. Because of this nonreciprocal phase shift the resonance frequencies of the resonator for counter propagating fields are not identical. This difference in resonance frequency, Δ f, is measured by means external to the resonator, e.g., by locking the frequencies of external laser beams to corresponding resonances of the cavity.

Our research demonstrated that because of backscattering within the cavity, the difference in resonance frequency Δ f cannot be determined as long as Δ f is below a certain value which is set by the degree of backscattering. This behavior which is called "lock-in" has long been observed in ring laser gyros where a laser amplifier is placed within the resonator. In our passive approach lock-in occurs if all the information about backscattering is fed faithfully to the servo loops which hold the external laser frequencies to the cavity resonance.

Lock-in was observed using mechanical rotation and also nonmechanical rotation, e.g., by sweeping the frequency of one of the external lasers. The theory of lock-in relative to our passive resonator set-up was developed and used to understand the observed behavior in the neighborhood of lock-in. Finally, we demonstrated several nonmechanical schemes of eliminating lock-in in a passive resonator gyro.

Publications

Zarenetchi F., and S. Ezekiel, "Observation of Lock-in Behavior in a Passive Resonator Gyroscope," Opt. Lett., June 1986, to be published.

21.4 Fiber Ring Resonator "Gyroscope"

Joint Services Electronics Program (Contract DAAG29-83-K-0003)
Litton Guidance and Control System
Chris O'Connor, M. Selim Shahriar, Lisa Rockoff, John Kierstead, Shaoul Ezekiel

We are continuing our investigation of an all-fiber ring resonator as a sensor of absolute rotation. 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 replaced with a single mode fiber resonator and the input-output coupling is accomplished by 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 counterpropagating directions.

We have studied a number of problem areas such as back-scattering, fiber birefringence and nonlinear phenomena such as the optical Kerr effect. In addition, we have constructed a homemade polarization holding resonator to eliminate birefringence effects but the finesse of this resonator has been low, so far, around 10, due to coupler losses.

21.5 Fiber Interferometer Gyroscope

Joint Services Electronics Program (Contract DAAG29-83-K-0003)
Litton Guidance and Control System
Leo Hergenroeder, Stephen Smith, John Kierstead, Shaoul Ezekiel

In a multiturn fiber interferometer gyroscope a broadband light source, e.g., a superluminescent diode (SLD), is used to reduce any undesirable backscatter and also the optical Kerr effect. However, SLDs do not produce a lot of power and their lifetime is limited because they operate at a much higher current density than semiconductor lasers.

We are investigating the use of a chirped frequency semiconductor laser to produce an effectively broad width so as to replace the SLD. The frequency of a semiconductor laser may be chirped by varying the injection current. A number of techniques for chirping the laser are being studied with emphasis on the effect of mode hopping and on any broadband noise created by the chirping.

21.6 Wavelength Stabilization of Broadband Semiconductor Light Sources

Litton Guidance and Control System

Harry Chou, Shaoul Ezekiel

Broadband semiconductor light sources, e.g., superluminescent diodes (SLDs) have been suggested for use in fiberoptic rotation sensor to reduce the noise arising from backscattering in the fiber and from the optical Kerr effect. For precision rotation sensing, the wavelength of such a source must be stabilized to about 1 part in 10^6 since the scale factor of the sensor involves the source wavelength.

Since the spectral width of SLDs is extremely wide in the neighborhood of 10 nm and also asymmetric, conventional stabilization schemes based on molecular absorption are not very useful. The scheme we developed is based on the use of a 2-beam interferometer technique in which the average wavelength of the broadband source is stabilized to a short path difference in a Michelson interferometer. This path difference is held fixed by stabilizing it to the wavelength of a stable laser. Using such a technique we demonstrated a stability of the SLD wavelength to better than one part in 10^6 in an averaging time of 1 second. If the Michelson interferometer were constructed on an integrated optic chip the reference laser could be dispensed with. This scheme has the merit of being easily extendible to any wavelength regime.

Publications

Chen H., and S. Ezekiel, "Wavelength Stabilization of Broadband Semiconductor Light Sources," Opt. Lett. 10, 612 (1985).

21.7 Stabilization of External Optical Feedback Phase in a Semiconductor Laser

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

Litton Guidance and Control System

Sudhanshu H. Jain, Shaoul Ezekiel

Narrow spectral output semiconductor lasers are important for heterodyne optical communication systems, optical sensors and spectroscopy. The laser linewidth is typically 30 MHz depending on the output power.

One method of reducing the laser linewidth is by applying optical feedback from an external mirror. The degree of linewidth reduction depends strongly on both the magnitude and phase of the optical feedback. Therefore both these quantities must be controlled to achieve and maintain a narrow laser linewidth.

We have investigated a simple scheme of stabilizing the phase of optical feedback based on the asymmetric response to feedback phase at the two laser facets. Using such a scheme, we reduced the laser linewidth to much less than 1 MHz and held it at that value.

Publications

Jain, S.H., and S. Ezekiel, "Stabilization of External Optical Feedback Phase in a Semiconductor Laser," Electron. Lett. 21, 957 (1985).

21.8 Frequency Stabilization of a Semiconductor Laser

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

Litton Guidance and Control System

Veronique Pevtschin, Shaoul Ezekiel

Single frequency semiconductor lasers are now easily available and are being considered for a number of applications such as communication, wavelength multiplexing, sensors, spectroscopy, and so on. The long term stability of the frequency of the laser is important in a number of such applications.

We have performed a study of a simple scheme for the frequency stabilization of a simple semiconductor laser. The laser is a single frequency Hitachi HLP 1400 operating at 0.82 μm with a linewidth of about 30 MHz at a few mW of power. Long term stabilization was accomplished by locking the laser frequency to the center of a 1.2 GHz wide absorption line in H_2O vapor. A stability of about one part in 10^9 for an averaging time of one second was achieved which was close to the theoretical shot-noise limit. The scheme is straightforward and does not require precision alignment procedures. The performance was measured using an independent H_2O vapor cell. Intensity shifts were negligible but temperature dependent pressure shifts were measured as 3 MHz/° C at room temperature and 1 MHz/° C at 0° C. Since water vapor has many transitions in the near infrared, this simple stabilization system should be very useful.

Publications

Pevtschin V., and S. Ezekiel, "Performance of a H_2O Stabilized Semiconductor Laser," in preparation.

21.9 Observation of Bidirectional Emission in a Phase-Conjugate Ring Resonator

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

Bertrand Kleinmann, Shaoul Ezekiel

Optical Phase-Conjugate Ring Resonators have been proposed to develop a "squeezed states generator" as well as a new type of rotation sensor.[1,2]

Various experiments have been performed using atomic vapors as the non-linear medium but they require the use of tunable lasers and it is very difficult to achieve high phase-conjugate reflectivities.[3]

By using a $BaTiO_3$ crystal as the non-linear medium, it is very easy to obtain reflectivities higher than one (that is to say higher than 100%) when it is pumped by an Argon laser.[4] By placing the crystal in a ring cavity we were able, for the first time to our knowledge, to observe a bidirectional emission of light in the cavity. The previous reported results mentioned only unidirectional emissions of light that were due to two-beam coupling in the crystal.[5] In our case, one of the emitted beams was mainly due to that effect but the other one was generated by four-wave mixing and was therefore the phase-conjugate of the first one.

Unfortunately it was not possible to stabilize the set-up well enough to obtain a steady emission and a more detailed study of the crystal itself is necessary before it is possible to go forward in the cavity experiment. As a matter of fact, we observed that a single beam of light can be phase-conjugated by the crystal with no additional pump-beam. That "self-pumped phase-conjugate mirror" can reach reflectivities up to 30% depending on the angle of incidence of the light. We used such a "self-pumped phase-conjugate mirror" in a Michelson-like interferometer and we observed a beat note in the output showing that the phase-conjugate beam is frequency shifted with respect to the laser beam. That effect can be understood in terms of moving gratings[6] but it clearly shows that a better understanding of the photorefractive crystals themselves is necessary before it is possible for anyone to perform precise experiments using that material.

References

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2. M.M. Tehrani, "The Phase-Conjugate Ring Laser Gyro," SPIE no. 412, 1983.
3. B. Kleinmann, Ph.D. Thesis, Ecole Normale Superieure, Paris, France, June 1984.
4. J. Feinberg and R.W. Hellwarth, Opt. Lett. 5, 519 (1980).
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