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14. ABSTRACT

Many research papers of the major ONR grant were published dealing with quantum optics and laser physics as per our yearly reports. The main student supported result of this project is the Ph.D. thesis of Chris J. Bednar, to be defended Spring 2001. Thus, the final report will essentially consist of a description of the research conducted for that thesis, including the basic education necessary to enable the research.

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FINAL TECHNICAL REPORT

"Novel Linear and Nonlinear Optical Effects Due to Atomic Coherence and Interference"

Texas Engineering Experiment Station
Grant Number: N00014-96-1-0874
PR Number: 96PR06217-00
PI: Marlan O. Scully
AASERT Reporting Period: June 1, 1996 – May 31, 1999

Many research papers of the major ONR grant were published dealing with quantum optics and laser physics as per our yearly reports. The main student supported result of this project is the PhD thesis of Chris J. Bednar, to be defended Spring 2001. Thus, the final report will essentially consist of a description of the research conducted for that thesis, including the basic education necessary to enable the research.

The work is fairly broad in scope, covering the following topics:

PRACTICAL APPLICATIONS OF QUANTUM MECHANICS

including:

1. Basic research in atomic coherence, concentrating on the study of the interaction of lasers with gases of multilevel hyperfine-split (alkali) atomic systems, including the effects of the magnetic substructure, mostly in systems in which a steady-state treatment may be used.

2. Specific research and development of mathematical and numerical techniques for solving such problems, including parallel/distributed computing techniques, and applications of some specialized linear-algebraic tricks to speed up calculation of sparsely-changing matrix equations. The code was also used in support of several other projects.

3. Participation in experiments in LWI (for which this theoretical work was used to explain results) and in nonlinear Faraday-rotation Magnetometry (for which the theoretical work was part of the basis, and also used to explain and support the results). From the Faraday paper [5]:

   > We utilize the generation of large atomic coherence in optically dense media to enhance the resonant nonlinear magneto-optic effect by several orders of magnitude, thereby eliminating power broadening and improving the fundamental signal-to-noise ratio. A proof-of-principle experiment is carried out in a dense vapor of Rb atoms. Applications such as optical magnetometry, the search for violations of parity and time reversal symmetry and nonlinear optics at low light levels are feasible.

4. Basic research into the free-electron laser, leading to a proposal to enhance the gain in an "inversionless" FEL; from the paper in progress: A new gain regime of the free electron laser without inversion is considered. Using numerical simulation of the coupled pendulum equation for electrons and Maxwell's equations for the laser field, we investigate the dependence of gain on the electron momentum spread as well as on saturation effects. It is shown that gain in the free electron laser without inversion is less dependent on the electronic momentum spread in the large-gain regime and a higher saturation intensity than an ordinary free electron laser. A new regime with an ultra high gain, due to extraordinarily large bunching of electrons, is found. Design of the drift region necessary for the realization of the above effects is studied.

FUNDAMENTALS OF QUANTUM MECHANICS

including:

1. Basic research into the micromaser, an electromagnetic chamber used to enhance and tune the interaction of the vacuum radiation field with atoms.

2. Work to support and clarify previous theoretical work employing micromasers in a quantum Young's-double-slit experiment; specifically, a detailed calculation of the effect of the micromasers on the space wavefunction of the atoms passing through, demonstrating the feasibility of the "Quantum Eraser"'. This was published in [1].

3. Work making use of much of the understanding gained in the "practical" section above to propose a Bell-basis preparation/detection scheme based on alkali atoms. Bell states are the basis of existing quantum teleportation and quantum dense coding experiments, and this work proposed another method of implementing them.

PUBLICATIONS of C. Bednar:

[1] S. F. Yelin, C. J. Bednar, and C.-R. Hu. The role of atomic recoil micromaser welcher-weg detection. Optics Communications, 136:171-184, 1996.

[2] C. J. Bednar, M. Löffler, M. O. Scully, and H. Walther. Tunneling and the mazer. In Quantum Interferometry, Proc. of an Adriatico Workshop, Trieste, Weinheim, 1996. VCH.

[3] M. O. Scully, C. J. Bednar, Yu. V. Rostovtsev, and S.-Y. Zhu. Counter-counterintuitive quantum coherence effects. Proceedings of the Royal Society, 1997.

[4] M. O. Scully, B.-G. Englert, and C. J. Bednar. Two-photón scheme for detecting the Bell basis using atomic coherence. Physical Review Letters, 83(21):4433-4436, 1999.

[5] V. A. Sautenkov, M. D. Lukin, C. J. Bednar, I. Novikova, E. Mikhailov, M. Fleischhauer, V. L. Velichansky, G. R. Welch, and M. O. Scully. Enhancement of magneto-optic effects via large atomic coherence in optically dense media. Physical Review A, 62, 2000.