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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Abstract Of Technical Progress -- In the first year, significant advances were made in realizing the goals of this proposal. The lowest single beam switching (<8 pj) and the fastest reported ON/OFF switching (<1 ns) bistable device with clearly resolved states was demonstrated using the nonlinearity associated with bound excitons in CdS. The role of thermal effects in transient measurements done on the nanosecond time scale near free excitons was investigated theoretically. Thermal effects on the millisecond and

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20. Abstract - (Continued)

microsecond time scales were experimentally studied. In particular, self-pulsation of the transmitted beam and intra-cavity optical bistability due to optically induced changes in absorption and refraction were investigated. Large degenerate four-wave mixing signals were observed near free and bound excitons in CdS at cryogenic temperatures. Four-wave mixing measurements at higher temperatures are now in progress.

Research Objectives:

Some of the largest optical nonlinearities in nature have been observed in direct-gap semiconductors exhibiting excitonic effects. Because these large nonlinearities open new possibilities in the field of all-optical signal processing, they have recently attracted much attention. So far, the main effort has been devoted to minimizing the switching energy of a semiconductor bistable optical device for low or room temperature operation. A good physical understanding of the role of phonons, impurities, carriers, and carrier-exciton interactions on the switching energy of bistable devices is still required. The study of the resonant nonlinearities associated with free and bound excitons in CdS promises to be a very fruitful area of research. For these reasons, we have proposed a comprehensive research program that has three major thrusts.

1. To characterize the optical nonlinear response of bound excitons in CdS and to demonstrate the fast and low power operation of an all-optical bistable device (p. 3 of our proposal);

2. to demonstrate novel electro-optical and all-optical signal processing functions (pp. 3-4 of our proposal);

3. to study the influence of electrically sweeping carriers on the switching energy and switching speed of a near room temperature direct gap semiconductor optical bistable device (p. 4 of our proposal).

Accomplishments and Progress

1) Demonstration of the lowest single beam switching energy and the fastest reported ON/OF switching bistable device with clearly resolved states (tasks 1.i and 1.ii of p. 29 of our proposal).

The nonlinearity associated with excitons bound to neutral donors is extremely interesting because of recent prediction that they have an enormous oscillator strength. Oscillator strengths of order 100, with a

consequent radioactive decay of ≈ 30 ps, have been theoretically predicted in CdS. This leads not only to interesting new physics, but also to practical applications like fast all-optical switches. Coupling of this strong radiator with the incident laser field is optimized by working at cryogenic temperatures. This minimizes the amount of dipole dephasing, due to acoustic and optical phonons. It then becomes possible to approach the fundamental limits on optical switching energies. Using triangular optical pulses of 80 ns rise and fall time as input, switch-up and switch-down times were measured to be less than 1 ns and 2 ns, respectively. The measured switching energy was less than 8 pJ, the lowest reported for an all-optical bistable semiconductor device. By optimizing the cavity parameters (mirror reflectivity and single thickness) and by focusing the incident laser beam more tightly, it should be possible to approach the fundamental limits on the switching energy. The nonlinearity due to bound excitons is so large that multiple hysteresis loops were observed in the output power versus input power characteristics. This is the first time such an observation has been made on the nanosecond time scale. A paper reporting the observations was published in Applied Physics Letters.

2) Investigation of Periodic Pulsations and Chaos (task 1.iii on p. 29 of our proposal).

The transmission characteristics of a CdS platelet immersed in liquid helium were investigated as the incident intensity was increased. At a certain threshold intensity, very regular pulsations of the transmitted intensity on the 10 μs. time scale were recorded. As the intensity was increased even more, new frequency components appeared and the temporal behavior became very complicated (non-periodic).. These pulsations are believed to be thermal in origin. Some of the experimental results were published in the Conference Proceedings of the Second Optical Bistability Conference held in Rochester.

3) Controlled Generation of New Bound Exciton Lines by Lithium Implantation of CdS.

In ongoing research conducted in parallel with the AFOSR sponsored work, sharp new bound exciton optical absorption lines were observed following very low fluence ($\phi < 5 \times 10^{12} cm^{-2}$) room temperature ^{11}Li implantation of high quality cadmium sulfide platelets. Using ion implantation and modern mask technology, complicated two-dimensional patterns can be written with good accuracy. This opens completely new possibilities in all-optical signal processing applications. Furthermore, the use of thinner samples with strong bound exciton absorption lines permits the operation of a Fabry-Perot bistable device in a sharp focusing geometry. This should make possible the demonstration of subpicojoule switching energy bistable devices. A substantial broadening of the free exciton resonance by the lithium neutral donor impurities was observed. A better understanding of the scattering of exciton polaritons by impurities was obtained. This work will appear in the Journal of Applied Physics.

4) Optical Hysteresis in Fast Transient Experiments Near the Band Gap of Cadmium Sulfide.

A theoretical calculation pointed out the possible role of laser heating effects in transient measurements, reported by a German group (Klingshirn et al.) who used relatively low power nanosecond pulses tuned near the band gap of CdS. The calculation is based on the assumption that most of the optical energy can be dissipated non-radiatively on a nanosecond time scale. This, of course, depends on the optical quality of the samples used in the study. The calculation was published in Applied Physics Letters. This theorectical investigation stresses the potential role of thermal effects on optical experiments done with too high optical energy pulses. The insight obtained from the study of thermal effects can lead to a better understanding of how to avoid them.

5) Intra-Cavity Optical Bistability Due to Optically Induced Changes in Absorption and Refraction

A theoretical and experimental study of optical bistability in a cavity in the presence of both an optically induced absorption and an optically induced index change generated by local heating of a CdS sample was done. The laser was tuned in the vicinity of the A-free exciton. Since thermal effects will ultimately impose a speed limitation on two-dimensional optical signal processing, it is important to study in more detail the importance and the role of thermal effects on the operating characteristics of bistable devices in general. Power levels of the order of 5 to 10 mW were sufficient to switch the bistable device on a submillisecond time scale. These results will appear in the IEEE Journal of Quantum Electronics.

6) Degenerate Four-Wave Mixing Near the Band Gap of CdS (task 3 of our proposal).

Forward degenerate four-wave mixing signals were recently obtained in the vicinity of the A-free and the I_2-bound exciton resonances in cryogenically cooled (2K) CdS. A scattering efficiency larger than 1% for peak input power levels of about 5 mW in each beam was measured. The beam diameter on the sample was about 40 μm. A four-wave mixing signal was observed on each side of the free exciton resonance. The four-wave mixing signal was resonantly enhanced on the bound exciton resonance. Thermal effects did not play any role in these measurements. Measurements at higher temperatures are now in progress. Will thermal effects become more important? This is an important question that needs to be answered. If thermal effects can be avoided, transient carrier dynamics, using degenerate four-wave mixing, will be investigated at room temperature. This would ensure completion of task 3 of the proposal. We are also hopeful to observe optical bistability at room temperature (task 2). We have been delayed in completing some of the tasks described in the proposal because of equipment failure. The laser tube has failed twice, causing a loss of three months laboratory utilization. We expect to get back on schedule shortly.

7) Future work (tasks 4, 5, and 6)

In the coming year, we expect to demonstrate the saturation of birefringence near bound excitons (task 4.ii). We will also deposit electrodes in the CdS platelets and will study the Stark shifting of bound excitons (task 4.i). If we are successful in depositing electrodes on a CdS platelet, we will study the dynamics of carrier sweeping on a nanosecond time scale (task 5). An important problem that we might be facing here is that the carrier lifetime in our samples may already be faster than 1 ns. Furthermore, thermal effects may play an important role at room temperature when the laser intensity is increased. For the demonstration of task 6, we still have to determine if thermal effects can be avoided at room temperature. We already know that these thermal effects play an important role in GaAs bistable devices.

Publications

"Generation of New Bound Exciton Films by Lithium Implantation of CdS," M. Dagenais, B.S. Elman, and W.F. Sharfin, Jnl. of Appl. Phys, in press.

"Very Fast, Picojoule Optical Switching in a CdS Etalon," W.F. Sharfin and M. Dagenais, to appear in Proc. 7th Int. Conf. Lasers and Applications.

"Nonlinear Optical Materials, Devices and Applications," M. Dagenais and R.J. Seymour, Opt. Eng., in press.

"Intra-Cavity Optical Bistability Due to Thermally Induced Changes in Absorption and Refraction," M. Dagenais, Alisa Surkis, W.F. Sharfin, and H.G. Winful, IEEE J. Quant. Elect., in press.

"Linear and Nonlinear Optical Properties of Free and Bound Excitons in CdS and Applications in Bistable Devices," (invited paper) M. Dagenais and W.F. Sharfin, J. Opt. Soc. Amer. B2 (1985).

"Picojoule, Subnanosecond, All-Optical Switching Using Bound Excitons in CdS," M. Dagenais and W.F. Sharfin, Appl. Phys. Lett. 46, p. 230 (1985).

"Optical Hysteresis in Fast Transient Experiments Near the Band Gap of Cadmium Sulfide," M. Dagenais, Appl. Phys. Lett. 45, p. 1267 (1984).

"Giant Nonlinearities and Low Power Optical Bistability in Cadmium Sulfide Platelets," M. Dagenais, Phil. Trans. R. Soc. London A313, p. 265 (1984).

"Cavityless Optical Bistability Due to Light Induced Absorption in Cadmium Sulfide," M. Dagenais and W.F. Sharfin, Appl. Phys. Lett. 45, p. 210 (1984).

"Low Power Optical Bistability Near Bound Excitons in Cadmium Sulfide," M. Dagenais and H.G. Winful, in Optical Bistability 2, edited by C.M. Bowden, H.M. Gibbs, and S.L. McColl (Plenum, New York, 1984), p. 267.

Personnel

Dr. M. Dagenais (Principal Investigator)
Dr. W.F. Sharfin
Dr. H.G. Winful
Dr. R.J. Seymour (Project Manager)

Contributed and Invited Papers

"Giant Nonlinearities with Fast Response: Ion Implementation of Bound Excitons in CdS and Applications in Bistable Devices," M. Dagenais, W.F. Sharfin, and M. Prise, 1985 Materials Research Society Symposium, Boston, Dec. 1985.

"Forward Degenerate Four-Wave Mixing Near Bound Excitons in CdS," M. Dagenais, M. Prise, and W.F. Sharfin, 1985 Annual Meeting of the Optical Society of America, Washington, D.C. Oct. 1985.

"Intracavity Optical Bistability in the Presence of an Optically Induced Absorption," M. Dagenais, A. Surkis, W.F. Sharfin, and H.G. Winful, 1985 Annual Meeting of the Optical Society of America, Washington, D.C., Oct. 1985.

"Picojoule Subnanosecond Response, Optical Bistable Device Using Bound Excitons in CdS," (invited) M. Dagenais and W.F. Sharfin, 1985 Gordon Conference on Nonlinear Optics and Lasers, Wolfeboro, NH, July 1985.

"Picojoule, Subnanosecond All-Optical Switching in a CdS Etalon," M. Dagenais and W.F. Sharfin, CLEO'85, Baltimore, June 1985.

"Very Fast, Picojoule Optical Switching in a CdS Etalon," W.F. Sharfin and M. Dagenais, 7th Int. Conf. on Lasers and Applications, Los Angeles, CA, Dec. 1984.

"Low-Power Optical Bistability in Cadmium Sulfide Platelets," M. Dagenais and W.F. Sharfin, IQEC'84, Anaheim, CA, June 1984.