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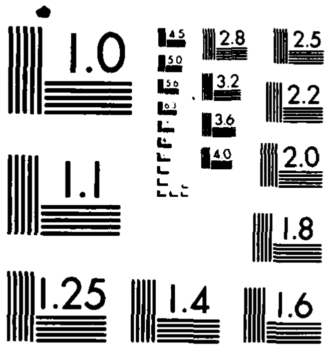

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Observation of exceedingly narrow spin flip lines in n-InSb suggests the existence of spin waves in this crystal. Si:P has been shown to have a large nonlinear optic coefficient at the metal-insulator transition; the effect is believed to be due to electron promotion from localized to delocalized states. Preliminary nonlinear optic experiments imply that hole kinetics in p-type InGaAs/GaAs strained layer superlattices are different from those of bulk p-GaAs.

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I. Summary of Research Goals

The following research topics are planned. Most of them involve nonlinear optical processes, that are used to probe electron and hole dynamics in semiconductors.

a.) Continuing study of donor levels in germanium via four-wave magnetospectroscopy and uniaxial strain experiments.

b.) Study of the spin-flip Raman lineshape in n-type InSb via four-wave mixing of CO_2 lasers.

c.) Detection of magnetoacoustic waves in n-InSb by Raman gain experiments.

d.) Attempt stimulated plasma wave emission in n-type $Hg_{1-x}Cd_xTe$.

e.) Study optical nonlinearities near the metal-insulator transition in n-Si:P.

f.) Investigate free carrier nonlinear optic processes in superlattices and strained layer superlattices.

g.) Study the third-order nonlinear susceptibility of uniaxially stressed semiconductors such as n-Si, n-Ge, p-Si, p-Ge, p-GaAs and p-$Hg_{1-x}Cd_xTe$.

II. Current Status of the Research Effort

The research program uses nonlinear optical processes to study carrier dynamics in semiconductors. Recent work includes the following accomplishments:

(i) Four-Wave Spectroscopy of Donors in Semiconductors (Item a. above)

Nonlinear optic studies of donors are continuing. In previous work, this technique was used to study the Raman-allowed 1s (A_1) → 1s (T_2) transition of As donors in Ge.

A predicted anti-crossing, of a spin down state with high diamagnetism and a spin up state with low diamagnetism, was observed at 10T. Magnetic field-induced valley repopulation was also seen. This research will form the basis for a Ph.D. thesis, and has been accepted for publication in Phys. Rev. The experiments are now being extended to include uniaxial stress; the combination of stress and magnetic field will provide a searching test of donor theory.

(ii) Study of the Spin-Flip Raman Lineshape in n-InSb (Item b. above)

Four-wave mixing studies of the spin-flip lineshape in n-InSb are continuing. Recent work has demonstrated pronounced line splittings; theory suggests that they are caused by saturation of the spin resonance. Individual spin flip lines are exceedingly sharp--far narrower than the single-particle non-parabolicity model would imply. Tentatively, we ascribe these sharp features to collective, spin wave modes. Experiments to test this idea are planned.

(iii) Study of Optical Nonlinearities near the Metal-Insulator Transition in n-Si (Item e. Above)

At low temperatures, n-Si exhibits a metal-insulator transition at electron concentration $n = 3.7 \times 10^{18}$/cc. We have observed large nonlinear susceptibilities, $\chi^{(3)} \approx 10^{-7}$ esu, in such samples; $\chi^{(3)}$ per carrier peaks when $n \approx 3 \times 10^{18}$/cc. Previously, n-Si had been thought to be a quite linear material. To explain these data, we postulate that the laser beams modulate the temperature of the carriers. In samples near the metal-insulator transition, temperature modulation promotes carriers from localized to delocalized states, giving rise to a sizable nonlinear effect. This model explains the observed $\chi^{(3)}$, and suggests that four-wave mixing will be a useful tool for studying the metal-insulator transition. Measurements are continuing, and will be extended to other materials.

(iv) Free Carrier Nonlinear Processes in Superlattices (Item f. above)

Four-wave mixing by holes has been detected in a p-type InGaAs/GaAs strained layer superlattice 1μ thick. The nonlinear susceptibility [$\chi^{(3)} \approx 5 \times 10^{-8}$ esu] is comparable to that of an unstrained, p-type GaAs LPE layer of comparable hole concentration. However, the frequency dependence of $\chi^{(3)}$ $(\Delta\omega)$ is quite different in the two cases. Our preliminary results imply that the carrier relaxation time in the p-type SLS is about 10x longer than that of bulk p-GaAs; this effect is believed to result from alterations in the valence band structure caused by uniaxial stress in the SLS. The experiments will continue with a view to exploiting the technique to study hole kinetics.

III. Publications

1. C. Jagannath and R.L. Aggarwal, "Stress-Induced Electric-Dipole-Allowed Far Infrared Generation at the Spin Resonance Frequency in InSb," (in press).

2. S.Y. Yuen, P.A. Wolff, L.R. Ram-Mohan, and R.A. Logan, "Hole Induced Four-Wave Mixing and Intervalence Band Relaxation Times in p-GaAs and p-Ge," submitted to Solid State Comms.

3. E.R. Youngdale, D.M. Larsen, and R.L. Aggarwal "Observation of Anti-Crossing between Zeeman-Split 1s (T_2) States of Opposite Spin for As Donors in Germanium," Bull. Am. Phys. Soc. 29 (1984) and Phys. Rev. B (in press).

4. C. Jagannath, R.L. Aggarwal, and D.M. Larsen, "Four-Wave Magneto-Piezo Spectroscopy of Shallow Donors in Germanium and Silicon," Solid State Comms. 53, 1089 (1985).

5. P.A. Wolff, S.Y. Yuen, and G.A. Thomas, "Nonlinear Optics at the Metal-Insulator Transition in Si:P (to be published).

IV. Professional Personnel

Professor P.A. Wolff, Principal Investigator

Dr. R.L. Aggarwal, Co-Principal Investigator

Dr. D.M. Larsen, Research Scientist

Professor L.R. Ram-Mohan, Consultant

Dr. S.Y. Yuen, Research Scientist

E. Isaacs, Physics Graduate Student

J. Warnock, Physics Graduate Student

S. Wong, Physics Graduate Student

E.R. Youngdale, Physics Graduate Student

V. Interactions

We are continuing our interaction with Dr. Marion Reine of the Honeywell Electro-Optics Division. Dr. Donald Nelson of that group will provide us high homogeneity n-type samples of $Hg_{1-x}Cd_xTe$ (with $x = 0.24$ and $n = 3 \times 10^{15}/cm^3$) for stimulated plasma wave emission experiments.

We have a long-established collaboration with AT&T Bell Laboratories through Professor Wolff's consultancy. Dr. R.A. Logan provided heavily doped p-type GaAs LPE layers for measurements of picosecond intervalence times, Dr. G.A. Thomas provided a range of n-Si:P samples for nonlinear optic studies of the metal-insulator transition and will be a co-author in that work, and Dr. W. Tsang is growing InSb superlattices for us.

p-type InGaAs/GaAs strained layer superlattices were provided by Dr. J. Schirber of Sandia Laboratories. He and/or other members of the Sandia group will be collaborators in our nonlinear optic studies of SLS.

Drs. Aggarwal and Yuen often meet with Dr. C. Jagannath of GTE Laboratories. They may collaborate in nonlinear optic studies of uniaxially stressed semiconductors (Item g. above).

At MIT we regularly interact with Dr. P. Becla and Professor A. Witt concerning crystal growth and characterization problems.

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