X. INFRARED NONLINEAR OPTICS

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1. INFRARED NONLINEAR PROCESSES IN SEMICONDUCTORS

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Studies of resonant, impurity-induced, four-photon mixing in n-Ge are continuing. During the past year, this technique has been used to study the magnetic field dependence of the valley-orbit splitting in Ge:P and Ge:As. The experiment is similar to an ESR measurement – employing fixed-frequency sources and a magnetic field to tune the energy levels. As anticipated, the valley-orbit splitting varies with magnetic field (B) according to the relation:

$$\Delta(B) = \Delta(0) + \alpha B^2.$$

Our measurements of α lead to the following conclusions:

1. Observed values of α disagree with those predicted by the Lee, Larsen, Lax theory, but agree with a recent calculation by Dr. Larsen. His results show that α is more sensitive to the form of the donor wave function than we had originally expected.
2. α increases with increasing donor concentration (in the 10^{15}-10^{16}/cc range), indicating the onset of electron delocalization for $n \simeq 10^{16}$/cc.
3. Splittings due to off-diagonal matrix elements of the Zeeman interaction are observed in Ge:As.

Semiconductor lasers oscillate at a frequency $h\omega = E_G$; to date, however, laser action has not been achieved for wavelengths greater than about 30 μ, despite the fact that in a variety of semiconductor alloys the gap can be continuously varied to zero. It is believed that laser action is precluded (for $\lambda > 30\ \mu$) by an exceedingly rapid recombination process, in which electron-hole pairs recombine via plasmon emission. This process can be controlled by a magnetic field, which modifies both the electron-state density and the plasmon dispersion relation. Detailed calculations suggest that, in large fields, the recombination rate can be reduced enough to permit lasing. Two modes of laser action seem possible — one in which plasma modes are excited, then radiate via a finite geometry; and another in which a mixed EM-plasma mode directly emits. Experiments to test these ideas are planned.

A theory of Cardona predicts that $\chi^{(3)}$ of small gap semiconductors varies as $E_G^{-9/2}$. Experiments to test this variation and to explore the resonance enhancement of $\chi^{(3)}$ as $h\omega \rightarrow E_G$, are in progress. This work will also study the behavior of $\chi^{(3)}$ when the difference frequency, $\omega_1 - \omega_2$, is matched to a collective mode of the medium. Previous theoretical work indicated strong mixing when $\omega_1 - \omega_2 = \omega_p$; similar effects are anticipated when the difference frequency is matched to a phonon frequency. Both of these processes can serve, in finite geometries, as sources of far infrared radiation.

References

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