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Publication Date

1972-11-01

Paper given at the International Conference
on Modulation Spectroscopy
Tucson, Arizona, November 23-26, 1972

LBL-1410
c.2

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Prepared for the U. S. Atomic Energy Commission
under Contract W-7405-ENG-48

LBL-1410
c.2

34

Tech Info

Paper to be given at the International
Conference on Modulation Spectroscopy,
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LBL-1410
Preprint

UNIVERSITY OF CALIFORNIA

Lawrence Berkeley Laboratory
Berkeley, California

AEC Contract No. W-7405-eng-48

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Effect of Carrier Concentration on the Reflectivity Spectrum of Ge and InSb

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ABSTRACT

We have measured at 5°K the derivative spectra 1/R dR/dE around the E_1 and $E_1 + \Delta_1$ structures, of Ge. and InSb with different impurity concentrations. In the more highly doped samples, the peaks are broadened and shifted slightly to lower frequencies. The change in the value of 1/R dR/dE is much larger than recently predicted by Seraphin and Aspnes, based on the surface field effect. Different possibilities for the effect are discussed.

Wavelength modulation measurements on samples with an applied surface electric field have shown no difference.

Introduction

The purpose of this paper is to report some preliminary data on the effect of the surface field on optical wavelength modulation spectra. This question has been recently raised by Seraphin and Aspnes,[1] who observed that this effect is usually completely neglected. In fact Welkowsky and Braustein[2] have investigated the possibility that surface field in semiconductors may perturb the resulting lineshape of the W.M.S. They used an electrolytic cell to apply an electric field on the surface of a sample of Ge with an applied dc voltage of 1 V across the cell's electrodes; this corresponds to 10^4 V/cm. They did not observe any difference with or without electric field within the sensitivity of the experimental setup.

Zucca and Shen[3] also studied the effect of the surface field on a sample of Si by using different carrier concentration varying between 10^{13} and 10^{17} cm^{-3}; they did not find any appreciable change.

We have repeated these experiments, extending the measurement to higher concentration. The experimental setup has been previously described.[3] Essentially, the spectrometer employs a two-beam system with two feedback loops in order to compensate the dispersion of the optical components. The samples are mounted in a liquid helium dewar; the liquid helium stored in a separate reservoir flows into the sample chamber where it is evaporated. This process avoids any pollution of the surface and even after a few days at low temperature , we have not noticed any change in the reflectivity.

Ge

We have represented in Fig. 1 the logarithmic derivative $1/R\ dR/dE$ for two samples having very different carrier concentrations; the first one is a very pure p-type sample ($60\ \Omega/\text{cm}$, 10^9 impurities/cm^3); the second is highly doped n-type ($0.0055\ \Omega/\text{cm}$).

The difference between the two curves are easily seen. We observe

a) A broadening of the peaks E_1 and $E_1 + \Delta_1$, and a decrease of the value of $1/R\ dR/dE \sim 50\%$.

b) A small shift of the position of the E_1 peak; 2.220 eV for the pure sample, 2.212 eV for the doped one.

We can now, using the Seraphin and Aspnes model, calculate the magnitude of the change due to the surface field; we suppose that the reflectivity can be represented as

$$R = R_o + \Delta R(\vec{\mathcal{E}}) \qquad (1)$$

where R_o is the intrinsic reflectivity and $\Delta R(\vec{\mathcal{E}})$ the change induced by the surface field $\vec{\mathcal{E}}$.

$$\frac{1}{R}\frac{dR}{dE} = \frac{1}{R_o+\Delta R}\frac{d}{dE}(R_o+\Delta R) = \frac{1}{R_o}\frac{dR_o}{dE} - \frac{\Delta R}{R_o^{\ 2}}\frac{dR_o}{dE} + \frac{1}{R_o}\frac{d}{dE}(\Delta R). \qquad (2)$$

The first term of Eq. (2) is the intrinsic spectrum, the second one is negligible, and the last one is:

$$\frac{1}{R_o}\frac{d}{dE}(\Delta R) \sim \frac{\Delta R}{R_o\Gamma} \qquad (3)$$

where Γ is the broadening parameter.

For the E_1 structure of Ge, $\Delta R/R_o \sim 0.002$ and $\Gamma \approx 60$ meV;[4] Seraphin and Aspnes using the value 1/R dR/dE = 0.6 eV^{-1} from Welkowski and Braustein[2] concluded that the error term (Eq. (3)) was about 5% of the amplitude of 1/R dR/dE.

We think that the value used for 1/R dR/dE is too low. Our result gives 2 eV^{-1} in good agreement with the previous result.[5] In this case the error term is of the order of 1.5% and we consider that it is too small to be observed.

What are the other possibilities able to produce this large a difference? The E_1 structure was primarily interpreted[6] like a critical point M_1 along the (111) symmetry direction in the Brillouin zone. More recently, Koeppen _et al._[4] suggested that, by electroreflectance measurements, the observed structure could be described by a two-dimensional critical point. In any case, an exciton is associated with this transition. The screening effect of carrier on excitons could explain the broadening, but in this case the shift would be expected towards the higher energy.[7]

We have also made some measurements with an electric field applied with an M-I-S structure; we used the liquid helium as an insulator and a transparent metallic electrode. The distance between the electrode and the sample was 40μ. One hundred volts were applied between the electrode and the sample. No appreciable difference in the logarithmic derivative was observed.

On the other hand experiments with a p-type sample of 0.5 Ω/cm does not show any difference with that of the 60 Ω/cm. It seems that the change occurs for crystals with more than 10^{17} cm^{-3}. In fact, what we observed is very similar to the measurements made some years ago by Cardona and Sommers.[8] We think that above a certain concentration of impurities, the defects and inhomogeneities in the sample reduce the scattering time of the electrons, giving a broadening of the energy levels.

InSb

To verify the results observed for Ge, we have performed measurements on two samples of InSb n-type with 2.10^{14} cm^{-3} and 10^{18} cm^{-3}.

The curves are represented in Fig. 2. It can be seen that the situation is not very different; a large change in the magnitude of 1/R dR/dE, a broadening of the peaks, and a small shift towards the low energy side are observed for doped samples. The value of the E_1 peak is 1.982 eV for the pure sample and 1.968 eV for the doped one.

The shift observed (14 meV) is in very good agreement with that obtained by resonant Raman scattering for the same concentration of carriers by P. Yu.[9]

We must also emphasize that, contrary to Ge, it seems that the surface is more sensitive to the etching process; some broadening has been observed in the optical spectra when the etching is not good enough.

In conclusion, we have not found that the surface field effect plays an important role in the wavelength modulation spectra. We hope to be able to test the Seraphin and Aspnes model by doing the electroreflectance and the wavelength modulation on a ferroelectric like SbSI where this effect must be very important and easy to measure.

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* Work supported by the U. S. Atomic Energy Commission.

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Figure Captions

Fig. 1. Logarithmic derivative 1/R dR/dE at T = 5°K for two samples of Ge. Full line p-type 60 Ω/cm; Dashed line, n-type 0.0055 Ω/cm.

Fig. 2. Logarithmic derivative 1/R dR/dE at T = 5°K for two samples of InSb. Full line n-type 2.10^{14} cm^{-3}; Dashed line n-type 10^{18}cm^{-3}.

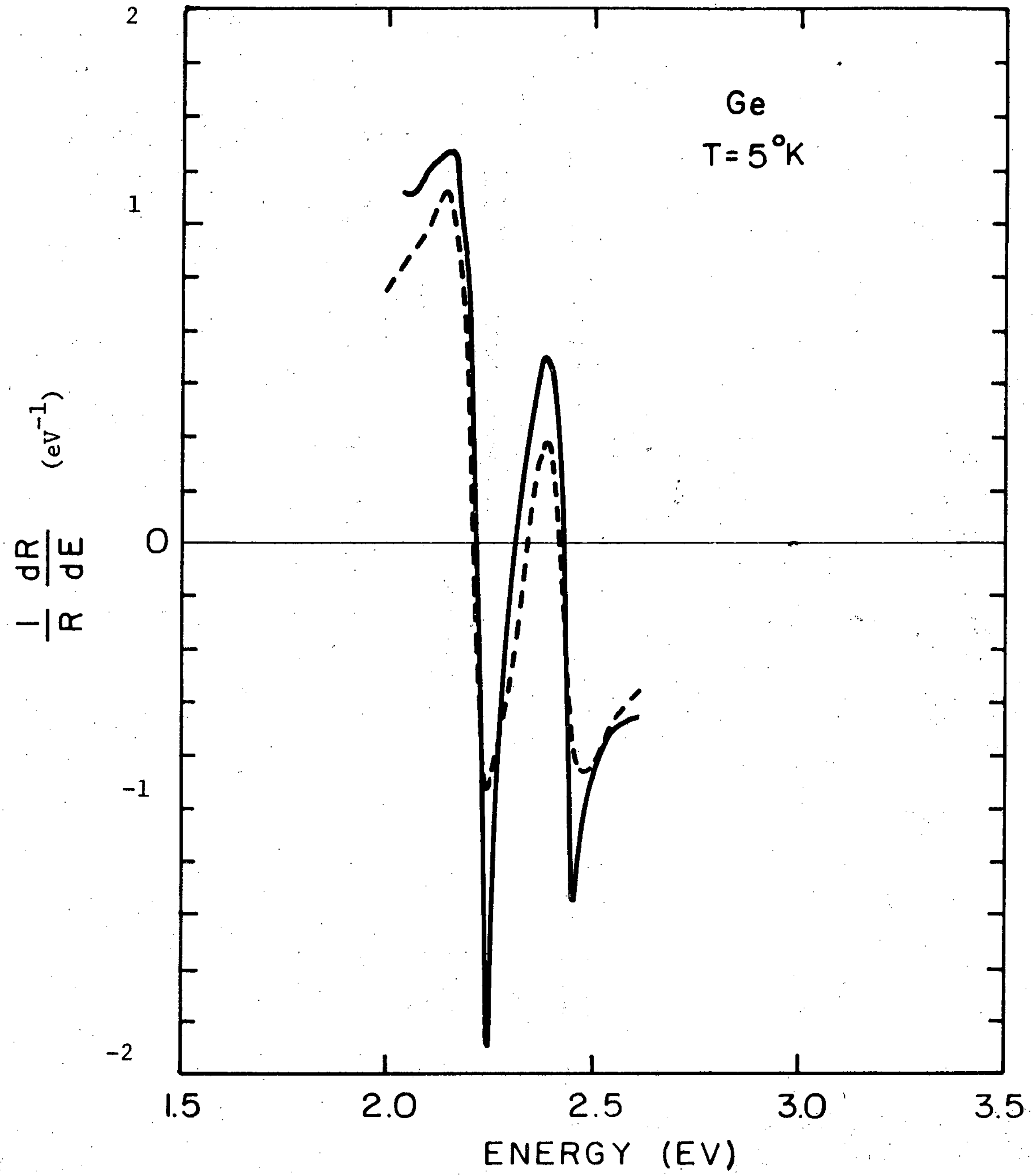

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Fig. 1

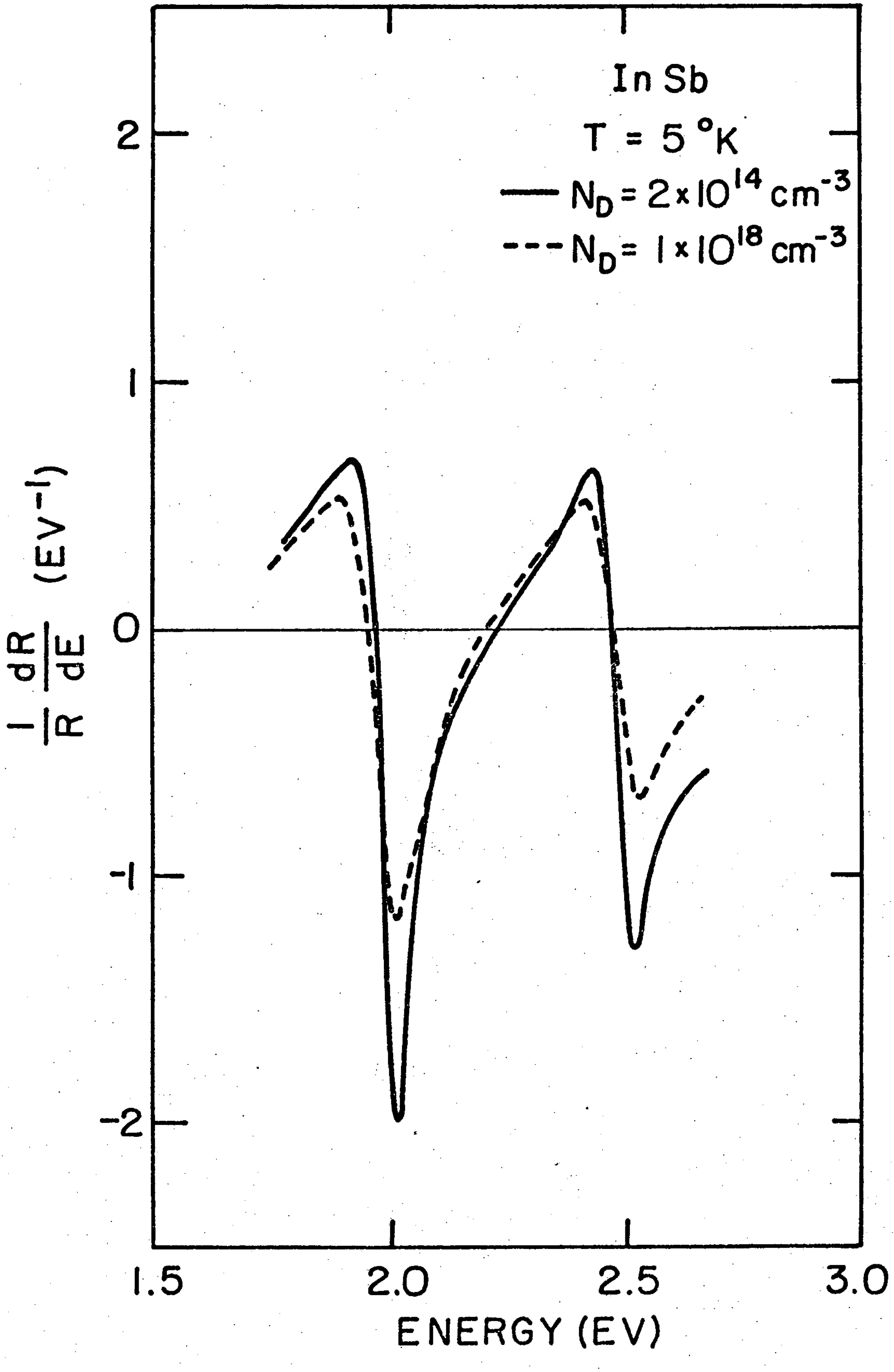

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Fig 2

Fig. 2

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