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EFFECT OF DOPING ON THE RESONANCE RAMAN
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EFFECT OF DOPING ON THE RESONANCE RAMAN SCATTERING IN InSb NEAR THE E_1 TRANSITION

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Resonant Raman Scattering (RRS) of highly doped InSb at the E_1 transition has been measured. Increase in impurity concentration broadens and shifts the RRS peaks towards lower energies and changes the peak height of the surface-field-induced (SFI) LO phonon and 2LO phonon curves. Our results suggest an alternate explanation for the donor concentration dependence of $I(\text{LO})/I(\text{TO})$ ($I(\text{LO})$ and $I(\text{TO})$ are Raman intensities of the SFI LO phonon and TO phonon respectively) observed by Pinczuk and Burstein.

There has been considerable interest in the RRS at the E_1 transition of InSb after some pioneering work by Pinczuk and Burstein [1, 2]. In this paper we report the RRS of highly doped InSb at the E_1 transition.

Our measurements have been performed on two n-type samples (referred to as NL and NH) with bulk carrier concentration $2 \times 10^{14} \text{ cm}^{-3}$ and $1 \times 10^{18} \text{ cm}^{-3}$ respectively, and two p-type samples (PL and PH) with concentrations $1.6 \times 10^{16} \text{ cm}^{-3}$ and $4.8 \times 10^{18} \text{ cm}^{-3}$. The samples cooled to $\sim 10^\circ \text{K}$ were excited by a CW dye laser tunable between 1.98 eV and 2.20 eV. In sample NH the LO mode appeared at its unscreened frequency due to presence of a depletion layer [1] while in sample PH the frequency is slightly shifted towards lower energy.

In Figures 1 and 2 we show the RRS of the TO phonon, SFI LO phonon and 2LO phonon for all four samples. We notice the linewidth of all three RRS curves are much broader in the impure samples. In the n-type samples the halfwidth of the TO phonon curve increases from 50 meV to 150 meV while that of the

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FIG. 1: Raman cross-section of two n-type InSb samples with carrier concentrations (a) $2 \times 10^{14} \text{ cm}^{-3}$ and (b) $1 \times 10^{18} \text{ cm}^{-3}$ as a function of incident photon energy. The incident radiation is parallel to the $[111]$ axis in both cases. TOX2 means the cross-section of the TO mode has been multiplied by a factor of 2.

SFI LO phonon and 2LO phonon curves increases from 30 meV to 60 meV.

The corresponding broadening is smaller in the p-type samples. In both cases the broadening is asymmetric, being larger on the high energy side. In addition to broadening the RRS peaks also tend to shift towards lower energies with increase in doping. This is most obvious in the sharper LO phonon peaks where the shift is more than 10 meV. The TO phonon curve for sample NH seems to show a blue shift. This is probably caused by its large asymmetric broadening.

The observed shift and broadening of the RRS curves in InSb with increased doping can be attributed to the corresponding shift and broadening of the E_1 transition. Wavelength modulated reflectivity on the sample NH has been measured by Petroff et al. [3]. The shift and broadening of the E_1 peak they observed are in good agreement with our RRS results. We have also

FIG. 2: Raman cross-section of two p-type InSb samples with carrier concentrations (a) $1.6 \times 10^{16} \text{ cm}^{-3}$ and (b) $4.8 \times 10^{18} \text{ cm}^{-3}$ as a function of incident photon energy. The incident radiation is parallel to the $[110]$ axis in both cases. Notations are same as in Fig. 1.

studied RRS in InSb at different temperatures. Our results support the contention that the effect of impurities in broadening structures in optical spectra by decreasing carrier lifetime and by breaking down momentum conservation is comparable to raising the sample temperature [4].

Increased doping changes the peak heights of the the three Raman modes in InSb differently (note that the same unit for Raman cross-section is used in both figures). With increase in doping the peak height of the TO phonon curves decreases by less than a factor of 2 while the 2LO phonon curves decreases by an order of magnitude for both n- and p-type samples. The height of the SFI LO phonon curve, however, depends on the sign of the free carrier. It increases in the n-type sample and decreases in the p-type sample.

The drop in the height of the TO phonon and the 2LO phonon RRS curves is due to broadening of the peaks. The different behaviour of the SFI LO phonon

curves suggest that they are induced by surface electric field and not due to wave vector dependence [5].

It has been shown [6] that at the surface of InSb the Fermi level is pinned within the forbidden energy gap E_g at $\sim 1/3 E_g$ above the valence band edge independent of the doping and of temperature between 77°K and 300°K. This pinning effect produces a depletion layer at the surface with potential height given by [1]:

$$V_n \simeq V_{Fn} - 1/3 E_g \quad \text{n-type} \quad (1)$$

$$V_p \simeq V_{Fp} - 1/3 E_g \quad \text{p-type} \quad (2)$$

where V_{Fn} and V_{Fp} are respectively the bulk Fermi level of the n- and p-type crystal measured from the top of the valence band. It is obvious from Eq. 1 that increase in ionised donor concentration will increase the surface potential. This should enhance the SFI LO phonon as we have observed in the n-type samples. For p-type samples the change in V_p with increase in carrier concentration will be much less than in n-type samples because the hole mass of InSb is much heavier than the electron mass [1]. As a result the SFI LO phonon curve decreases in height due to broadening by impurities. It should be pointed out that the enhancement of the SFI LO phonon RRS curve we observed in the highly doped n-type sample is much less than what Pinczuk and Burstein [1] observed at an incident photon energy of 1.96 eV. Our results show that, due to broadening and shifting of the RRS curves, change in $I(\text{LO})/I(\text{TO})$ with doping is strongly photon energy dependent. It is conceivable that the dependence of $I(\text{LO})/I(\text{TO})$ on donor concentration observed by these authors can be explained mainly by the larger shift towards low energy of the SFI LO phonon curve relative to the TO phonon curve. It is also clear that to determine the dependence of the LO phonon on surface field it is desirable to apply an external electric field rather than to vary the dopant concentration.

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