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Piezospectroscopy of the I Lines of Gallium in Germanium

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Abstract. Piezospectra have been obtained for the closely spaced I lines of Ga in Ge. Small, homogeneous stresses have been obtained by abrading the optical faces. The symmetries of the final states of some of these lines have been deduced.

In piezospectroscopic studies of the lines of the Lyman series of impurities in semiconductors, it is essential that the parent transitions of the stress-induced components be identified unambiguously. The more closely the parent lines are spaced, the smaller the stress required to meet the above needs. In the application of an external force, a large area is necessary to produce small stresses as there is a practical lower limit to the size of the force and, since the spectral features studied need the sample to be at cryogenic temperatures, there is a practical limit to the size of the area over which the external force can be applied.

It has been determined [1,2] that when the two opposing faces of samples of either Si or Ge are abraded, an uniaxial, compressive, homogeneous, effective force, F_{eff}, is established perpendicular to the two faces, with $F_{eff} = |F_{eff}| \propto t^{-1}$. (Here t is the mean spacing of the two faces, the samples being wedged to suppress interference fringes.) For this to be so, the same grit size of the abrasive is required to produce different values of t, with the latter ranging from ~ 0.5 to 4 mm. The nature of F_{eff} has been deduced [1] from the splittings, intensities and polarisations of the optical absorption lines characteristic of the Lyman series of the shallow acceptors and donors in the *bulk* of these two semiconductors; the quantitative behaviour of such lines under an externally applied F is well known. [3-6]. The problems involved in mounting a sample in a stress cryostat to ensure that F_{eff} is applied along the oriented length of the sample are obviated. Now only the crystallographic planes chosen for the optical faces of the sample need be of the desired type. The main limitation to the use of this technique is that only the stress-induced transitions allowed for $E \perp F$ can be readily observed since, for normal incidence, the exciting infrared beam is parallel to F_{eff}.

The piezospectroscopic behaviour of the more prominent of the closely spaced I lines of acceptors in Ge [7] has been studied here using the above surface treatment to produce small, homogeneous, compressive stresses. The lower spectrum of Fig.1 shows some of the unperturbed A and I features of B in Ge immersed in liquid He. Except for lines I_A and I_B, those labels near the other lines are from [7], where the short, 'horizontal' bold lines represent the errors in the energy values [7] given in the parentheses to each label. The vertical lines are at the energies calculated by Kurskii [8] for B in Ge. The lengths of these latter lines are not meant to indicate the intensities of the transitions except that those with an even parity final state are made shorter, it being noted that the ground states of all the group III impurities in Ge are also of even parity. The set of labels below these lines indicate the labels of the transitions as identified in [8] and their correlation with the observed lines in [7]; only the lines claimed to relate to the experimental features have been so labelled. It might be noted that [8] has a slightly different labeling scheme to that of [7]. The piezo-spectra studied were those of Ga in Ge because of sample availability. The upper perturbed spectrum in Fig. 1 is that of a Ga-doped sample of Ge moved down in energy by the relative chemical shift. The labels on the I lines omit the symbol I.
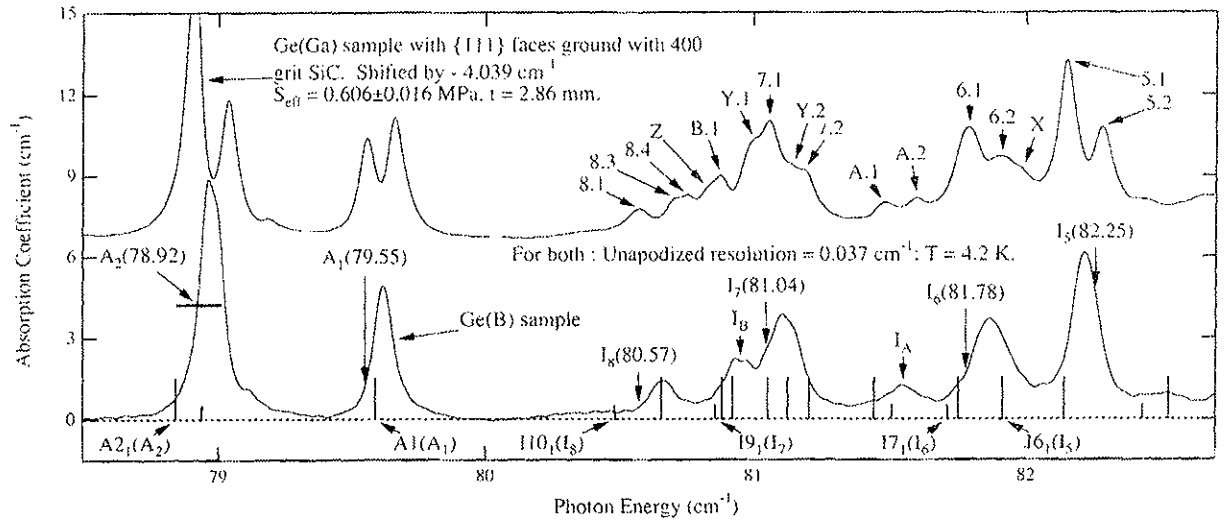
FIGURE 1. Lower spectrum is that of A and I lines of B in stress-free Ge while the upper spectrum is that of Ga in stressed Ge.

The stress has been determined from the splitting of the $2p_{\pm}^{(1)}$ line of P [6], a compensating group V impurity in the same sample[1]. The dependence on S_{eff} of the energies of the components of the lines I_5 – I_8 and I_A and I_B is shown in Fig. 2. The full curves are linear fits to the data, while the two dashed curves are quadratic fits. It has been shown that the splitting of A_2 is that of the ground state of Ga in Ge[1]. With this as gauge, it is found that this is also the splitting $I_{8.3}$ – $I_{8.1}$ and those of I_Y and I_6. The fact that there are three components for I_8, with a pattern that

FIGURE 2. Stress dependence of the I components of Ge.

is the same as that of the G line [1, 6], shows that the final state of I_8 is of Γ_8^- symmetry, possibly the $8\Gamma_8^-$ state of Kurskii [8], which also agrees with the calculated energy. The other two, I_Y and I_6, appear to have only two components indicating that their final states are of either Γ_6^- or Γ_7^- symmetry; that of I_6 could be the $5\Gamma_7^-$ state of [8] although neither the energy nor assignment agrees with this. The rest of the lines need to have Γ_8^- symmetry for their final states. The quadratic fits to the higher energy components of both I_5 and I_7 supports this. The features I_X, I_Y and I_Z have not been observed in the unperturbed spectrum. Further results and details will be presented elsewhere.
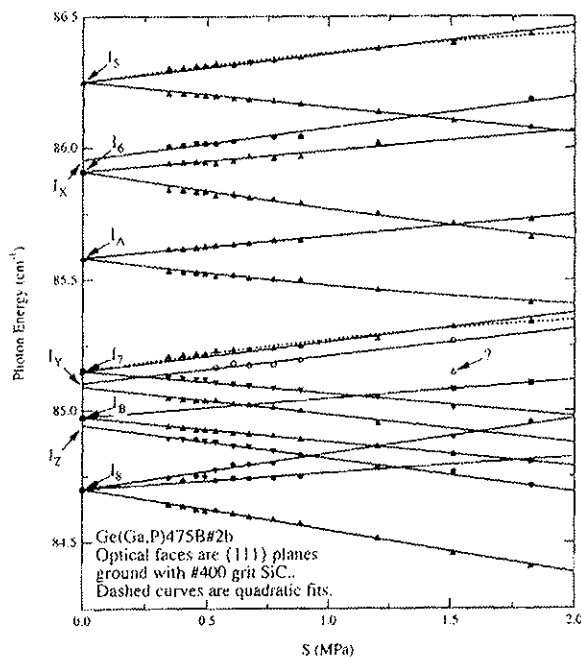
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