

Polarization spectra of optical transitions at a clean GaAs (110) surface

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(Submitted 20 March 1985)

Pis'ma Zh. Eksp. Teor. Fiz. **41**, No. 11, 453–455 (10 June 1985)

The polarization of optical transitions at a clean GaAs (110) surface has been measured at 300 and 1.8 K for the first time. Two transitions, with energies of 2.62 and 2.83 eV, involving surface states occur. Lines at 3.04 and 3.27 eV correspond to E_1 and $E_1 + \Delta_1$ volume transitions.

A detailed spectrum of optical transitions on a clean cleaved GaAs (110) surface has been obtained through the use of a modulation technique at low temperatures. Two transitions with a predominant polarization along the $[\bar{1}10]$ direction are interpreted as involving surface states. The spectrum of the surface also has evidence of E_1 and $E_1 + \Delta_1$ volume transitions, whose intensity, polarization, and lineshape depend very strongly on the surface state.

Surface optical transitions have previously been detected almost exclusively by the method of differential reflection, which involves comparing the reflection spectra obtained from a clean surface and then from an oxidized surface. This method was used in the original observation¹ of optical transitions at the GaAs (110) surface. In the present experiments we use a polarization method which involves studying the polarization dependence of the optical reflection from the surface. This method has the advantage that the spectrum can be recorded without resorting to oxidation, and the spectrum is recorded directly from a clean surface.

The (110) cleaved surface of gallium arsenide retains the symmetry of the corresponding volume plane² and consists of rows of atoms along the $[\bar{1}10]$ direction (Fig. 1). Surface states are formed from ruptured bonds of Ga and As atoms. Optical transitions can be expected to correspond to charge transfer predominantly along a row and will thus be polarized along the $[\bar{1}10]$ direction at the surface. Optical transitions in the interior, of cubic symmetry, should not exhibit a polarization.

In our experiments the GaAs crystal samples are cleaved in high vacuum ($\sim 10^{-8}$ Pa) at room temperature or in liquid helium. The linear polarization of a light beam

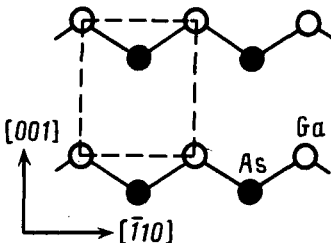


FIG. 1. Arrangement of atoms at the (110) surface of gallium arsenide. The dashed lines show the unit cell.

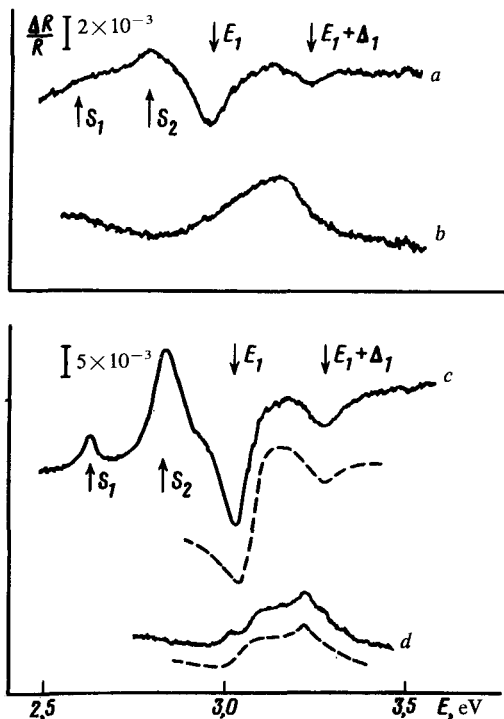


FIG. 2. Polarized reflection spectra of a cleaved GaAs (110) surface. *a, b*—Room temperature; *c, d*—1.8 K. *a, c*—Clean surface; *b, d*—oxidized surface. The dashed lines are the results of a calculation under the assumption of a splitting of E_1 and $E_1 + \Delta_1$ volume transitions.

incident normally on the cleaved plane is modulated between two mutually perpendicular directions that coincide with the $[\bar{1}10]$ and $[001]$ axes of the crystal. The reflected light is measured by a photomultiplier and then subjected to an ordinary synchronous detection. The polarization signal found is normalized by dividing by the total light flux; the measured quantity is the ratio

$$\frac{\Delta R}{R} = \frac{R_{\parallel} - R_{\perp}}{R_{\parallel}},$$

where R_{\parallel} and R_{\perp} are the reflection coefficients for light with a linear polarization along the $[\bar{1}10]$ and $[001]$ axes, respectively.

Figure 2 shows the polarized reflection spectra obtained in this manner for clean and oxidized cleaved GaAs (110) surfaces at room temperature and liquid-helium temperature. In general, the spectra have the same shape at these two temperatures. At the lower temperature the lines are narrowed, intensified, and shifted slightly toward higher energies. The short-wave line pair is present in the spectra of both the clean and oxidized surfaces. The spectral positions of the lines agree very well with the known energies of the E_1 and $E_1 + \Delta_1$ volume transitions along the Λ direction of the three-dimensional Brillouin zone.³

The pair of lines S_1 and S_2 , positioned at 2.62 and 2.83 (± 0.01) eV, with half-widths of 0.05 and 0.08 eV, respectively, lies in an energy region in which there are no other structural features of any sort associated with transitions in the volume. Both of

these lines disappear when the surface is oxidized, so that these lines can confidently be attributed to transitions involving surface states. For the S_1 and S_2 lines the ratio $\Delta R/R$ is positive, so that the transitions involving the surface states have a predominant polarization along the $[\bar{1}10]$ twofold axis.

The GaAs (110) surface spectrum published in Ref. 1 was obtained at room temperature by a differential reflection method and contained three peaks, with energies of about 2.8, 3.1, and 3.6 eV, all of which were attributed to transitions between surface states. In our spectra we observe no structural features of any sort near 3.6 eV. The peak at 2.8 eV coincides roughly with the line S_2 that we observe. At 3.1 eV, on the other hand, our spectra clearly reveal short-wave lines, which we attribute to volume E_1 and $E_1 + \Delta_1$ transitions. Further evidence for this interpretation of the short-wave lines comes from the circumstance that their shapes (on both the clean and oxidized surfaces) can be reproduced through simple transformations of the absolute reflection curve. The theoretical curves in Fig. 2 were calculated in the model of parallel bands along the Λ direction. It was assumed that the volume transitions are split in two in accordance with the two sets of Λ directions which are nonequivalent with respect to the (110) surface. For the cases of the clean and oxidized surfaces, we selected transition splittings differing in magnitude and sign. These results will be reported in detail in a separate paper.

The manifestation of volume transitions in the polarized spectra of the surface of a cubic crystal is a fact that requires special study. It may be that the explanation lies in an effect which the clean or oxidized surface has on the closest layers of the interior. At any rate, the existence of volume transitions must be taken into account in analyzing surface spectra in the region above the fundamental absorption edge of the crystal.

¹P. Chiaradia, G. Chiarotti, F. Ciccacci, R. Memeo, S. Nannarone, P. Sassaroli, and S. Selci, *J. Phys. Soc. Jpn.* **49**, Suppl. A, 1109 (1980).

²A. Kahn, *Surf. Sci. Rep.* **3**, 240 (1983).

³M. Cardona, K. L. Schaklee, and F. H. Pollak, *Phys. Rev.* **154**, 69, 696 (1967); D. E. Aspnes and A. A. Atudna, *Phys. Rev. B* **7**, 4605 (1973).

Translated by Dave Parsons