An Attempt to Reproduce the SchwarzHora Effect

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trum, but the peak at 0.70 eV is greatly enhanced in intensity usually by a factor of 10 and the broad peak around 1.02 eV which invariably existed otherwise is absent in this case. The result is very similar to that obtained from photoluminescence of GaAs grown in oxygen where a level at 1.0 eV thought to be related to silicon was supressed.[2,13]

To summarize, the observation of all the energy levels under various conditions is tabulated in Table I. The last column indicates, from the pressure dependence at various temperatures, the association of the different energy levels to the vacancies, V_{Ga} and V_{As}, in the gallium and arsenic sublattice, respectively. The level at 1.02 eV is simply assigned to a divacancy because of its independence of the pressure. The elements in parentheses in the last column of the table are the possible impurities that may be associated with the vacancies. The assignments of silicon and oxygen, influenced by the knowledge of their residual existence in the materials, are reached through the above-mentioned evidence together with that reported in the literature. In this connection, the V_{As} level at 1.40 eV and the V_{Ga} level at 1.35 eV are in very good agreement with recent electrical measurements on liquid epitaxial GaAs,[3] and could conceivably be due to the vacancies themselves. From the table, it is clear that the spectra changed from the V_{As}-dominant case to the V_{Ga}-dominant case as the temperature is increased. Also, that the near gap emission is observed at low temperatures where arsenic vacancies are important is consistent with the known fact of its enhancement in Ga-rich crystals.

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An Attempt to Reproduce the Schwarz-Hora Effect*

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Several attempts were made to observe the modulation of an electron beam by a laser (the Schwarz-Hora effect). These were not successful and possible reasons are reported.

The Schwarz-Hora effect,[1,2] in which a beam of fast electrons is modulated in some fashion in a crystalline film by the electromagnetic field of a laser, then demodulated when the beam is stopped, has been attributed to several microscopic effects in a number of theoretical papers.[3-15] Many of these papers, however, do not try to explain how the modulation is converted to visible light when the electrons are stopped. Since the first report over a year ago, there has been *no* experimental confirmation of the effect. We report our attempts to reproduce this effect, giving possible reasons for our negative results.

The apparatus was a Siemens Elmiskop 1 electron microscope equipped with a universal diffraction attachment in place of the projector lens. Two to four μA of 60- or 80-keV electrons were incident on a spot 10—20 μm in diameter on our sample, which was the thin edge of a mica sheet, cleaved by peeling with cellophane tape. The regions used were too thin to give interference colors under a low-power

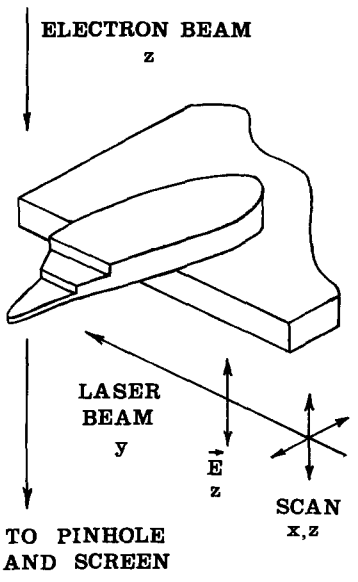

FIG. 1. Sample geometry: The sample was held with silicone vacuum grease to the holder in a plane perpendicular to the electron beam. The *c* axis of the irregularly shaped sample was parallel to the electron beam. The laser beam was incident in the plane of the sample, the *xy* plane being focused on the thin edge.

optical microscope, but they transmitted electrons easily, giving from 5 to 50 diffraction spots. Thickness estimates range from 500 to 3500 Å.[16] By alternately examining the diffraction pattern and an electron shadow of the sample, we could locate the electron beam position to within 1 mm along the edge of the sample (see Fig. 1). An auxiliary electron gun (300 V, 3 mA) mounted near the sample ionized residual gas molecules which allowed the sample to discharge. This was necessary, for the charge picked up by the sample from the principle electron beam caused the sample to move.

The 2-W Ar-ion laser (Carson Laboratories Model 101) was used primarily at 4880 Å, where the output power was about 1 W. The beam was focused, spatially filtered, expanded to 25 mm diameter, and then focused on the sample. (The loss of power due to beam manipulation was measured to be about 75%.) Half of the laser power was measured to pass through a cylindrical region about 50 μm in diameter and 800 μm long. The intensity on the sample was thus about 1.3×10^4 W/cm^2. The light was polarized parallel to the electron beam. The focus was placed on the region of the sample edge through which the electron beam passed, then slowly scanned in steps of about 15 μm by moving the focusing lens which was on a mount adjustable by micrometers (see Fig. 1). The focus diameter was so much larger than the sample thickness that focused light was present on both sides of the sample, as well as (presumably) in it. The longitudinal position of the focus was adjusted by another set of micrometers.

The normal luminescent viewing screen could be lifted to expose our nonluminescent detection screens to the diffracted electrons. These detectors were single-crystal Al_2O_3 with a frosted surface, powdered Al_2O_3, mica, a Schott OG-2 filter, and copper, the latter three being used only once. (The latter two were tried because they absorb 4880-Å light, hence can have 2.54-eV excitations.) None of these screens luminesced strongly in the electron beam; only the central diffraction spot was faintly visible. If such luminescence had been a problem, we planned to view the screen through a 4880-Å interference filter. (Other screen materials, crystals of Al_2O_3, CaF_2, and NaCl, luminesced too strongly to be used. Torr Seal, a resin used to bind the Al_2O_3 powder to the substrate, luminesced strongly if exposed to the electron beam.) At first there was considerable background light on the screen from scattered laser light. This was reduced by putting a sheet of aluminum foil with a pinhole a few mm below the sample, and some other baffles further along. (We also used a 400-Å-thick Al foil between the sample and the screen. Although transparent to electrons and opaque to light, it was abandoned for fear that it could, in some fashion, "demodulate" the electrons.) The remaining scattered light was sufficiently weak that the dark-adapted eye could see it, but not distinguish its color. It was uniform on the screen.

Enough scans were made with each sample-screen combination to ensure that the electron and laser beams had intersected, and no effect was seen. Several other laser lines were tried, and the sample-to-screen distance was varied from 30 to 34 cm in increments of a few mm. In addition, a 400-Å Al film was tried as a sample, since a metal produces a sharper field discontinuity. Diffraction rings were seen on the ZnS screen, but no effect due to the laser was observed on the nonluminescent target.

Our vacuum was only about $(1-5)\times10^{-5}$ Torr, but even after use of one sample for several hours, no diffraction rings from carbon were observed. This carbon, from pump oil cracked by the electron beam, could cause heating of the sample by absorption of the laser light and it could alter the electric field distribution at the sample surfaces. We believe the contamination rate was less than 50 Å of carbon per hour. The electron beam heated the sample to an orange heat when it was absorbed in the thick part of the sample. It did not cause the sample to glow when it passed through the thin part. The laser did not heat the samples to incandescence. Measurements using another Ar^+ laser and a power meter showed that damage to our samples (when in air) occurred only when the intensity exceeded about 1.5×10^4 W/cm^2.

We also tried electron diffraction by reflection from single crystals of NaCl and MgO with the laser incident normal to the surface and focused only to about 0.25 mm in diameter. The electrons were at grazing incidence. Only electron diffraction was observed.

Possible reasons for our failure to observe any modulation of the electron beam follow:

(i) There may be something subtle about the exact geometry of sample and both beams. For example, it might be necessary to have the electric field only on one side of the sample and within it, or on both sides but not within it, etc. We cannot describe our geometry any more precisely than we did above.

(ii) Our electron coherence length may not have been correct. We were unable to change it. The energy spread in our electron beam is estimated[17] to be about 0.7 eV.[18] Schwarz[2] originally suggested 0.1 eV as his energy spread, but no description of how it was estimated was given. We may have slightly compensated for our poorer energy spread by using a higher beam energy and current, using the model of Ref. 2.

(iii) Our laser power may be inadequate, However, we saw *nothing* and assume that the dark-adapted eye should be able to detect an effect about $\frac{1}{500}$ as intense as that observed by Schwarz, since he reported the color of the spots.[19,20]

(iv) The effect may be weaker in mica than in SiO_2, SrF_2, and Al_2O_3,[1,2] or perhaps our mica samples were not of an optimum thickness. Until the origin of this effect is clarified, we do not know how important the thickness and dielectric constant are. A particular range of electron velocities and sample thickness may be required

(v) The effect may be sufficiently weak that we did not see it for physiological reasons. Even our low laser beam scan rate may have been too rapid. This is difficult to assess when nothing was seen.

(vi) For unknown reasons, our target screens may not have been appropriate. The detection mechanism still seems to us to be completely unknown. We do not believe our poor vacuum accounts for this, however. We also believe that glow discharge cleaning of the screen should be necessary in all cases.

(vii) The effect is much weaker than reported or does not exist at all. This is difficult to explain since photoelectric as well as visual observations have been reported, and the photocurrent oscillated with sample-to-screen distance, exhibiting near nulls.[2]

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