CURRENT DEPENDENCE OF THE RESISTANCE IN SMALL GALLIUM SINGLE CRYSTALS*

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During an investigation of the size effect on the electrical conductivity of highly pure Ga single crystals at 4.2°K, we noticed[1] that a small increase in the measuring current caused an abnormally high increase in their resistance, which could not be explained as a simple heating effect. A more detailed investigation of the resistance as a function of current revealed that these crystals do not obey Ohm's law. The resistance, defined as $R = V/I$, where V is the potential across the specimen and I the current through it, was found to depend in a complicated way on the current, for current flow along each of the three principal directions of the orthorhombic Ga lattice. The single crystals, made from 99.9999% pure Ga, were in the form of wires of square cross section, and their size was such that at 4.2°K the mean free path of the electrons in the bulk metal (determined by comparing its resistance ratio between room temperature and 4.2°K with that of Weisberg and Josephs[2]) was much larger than the side of the square. The potential leads in every specimen were grown as an integral part of the single crystal. The value of $R_{273°\text{K}}/R_{4.2°\text{K}}$ for the bulk material from which these crystals were prepared was 60 000. The same ratio, for vanishingly small current, varied in these specimens from about 14 000 to 20 000, according to their size and orientation. This confirmed that the low-temperature resistance was being dominated by the scattering of the charge carriers at the walls.

The results obtained are shown in Figs. 1 and 2. Although there is a basic similarity between all these curves, they differ considerably in detail, not only for different orientations but also for different temperatures. Examination of these curves, particularly those in which the current flows along the c axis, suggests that each consists of a damped oscillation superimposed on a monotonically increasing function. We believe that both these phenomena are caused by the magnetic field produced by the measuring current in the crystals. The damped oscillations are due to "magnetoresistive size effects," which manifest themselves in small specimens where boundary scattering is predominant, whereas the steadily increasing component is due to the bulk magnetoresistance, which for small fields always increases the resistance. The magnetic field due to the current in a wire is essentially a transverse field and has the property of forcing the electrons away from the surface towards the axis of the wire, thereby lessening the influence of the boundary scattering. The initial fall in resistance is presumably due to this cause. Let us suppose that the first minimum in resistance occurs when the cyclotron radius of the charge carriers is just equal to the radius of the wire, so that they are able to avoid colliding with the surface. The field required for this to happen is given by

$$H = mv/er. \tag{1}$$

Now the magnetic field at the surface of the wire

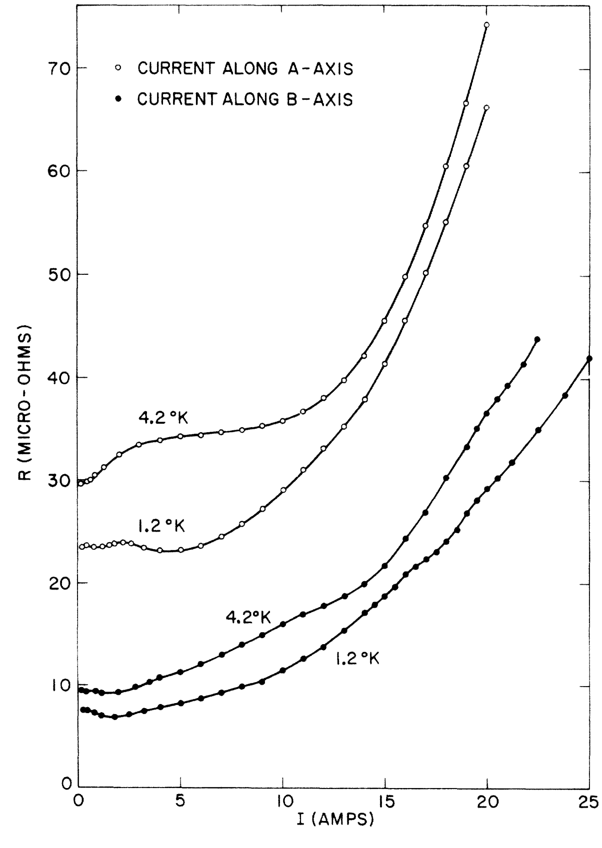

FIG. 1. Resistance versus current for current along the a and the b axes at 4.2°K and 1.2°K.

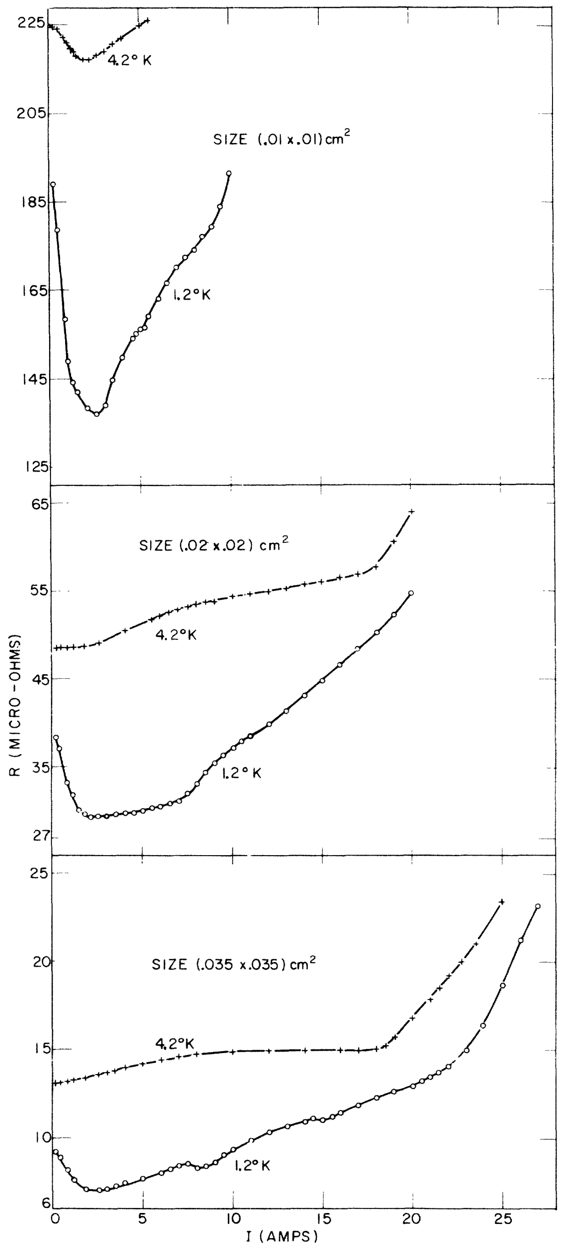

FIG. 2. Resistance versus current for current along the c axis for three different sizes at 4.2°K and 1.2°K.

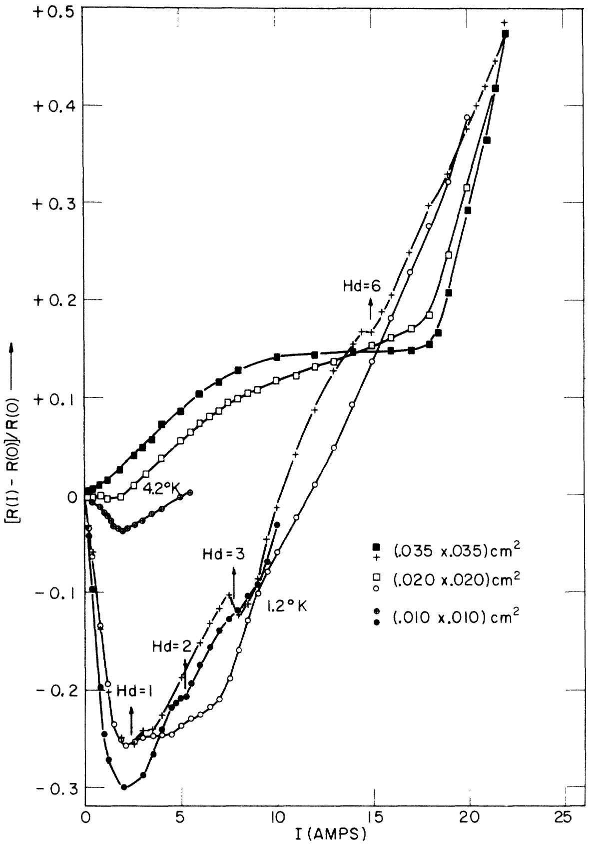

FIG. 3. $[R(I)-R(0)]/R(0)$ against current for the three c-axis crystals at 4.2°K and 1.2°K.

due to the current I is $2I/r$. Replacing H by $2I/r$ in Eq. (1), we find that r cancels, which shows that the position of the minimum should be independent of the size and should occur at the same value of the current for all specimens. From Fig. 3, which is a plot of $\Delta R/R(0)$ against I, it is clear that this indeed is the case. It need hardly be mentioned that the actual situation is much more complicated and would require a solution of the Boltzmann transport equation with appropriate boundary conditions.

Oscillations in resistance as a function of the field, somewhat analogous to the ones we have observed, can also be obtained in thin films when the current is parallel and an external magnetic field is perpendicular to the surface of the film. A theoretical discussion of such oscillations has been given by Sondheimer[3] and by Chambers,[4] and they have been experimentally observed by Babiskin and Siebenmann[5] in thin wires of Na in an external transverse field and by Førsvoll and Holwech[6] in Al films.

The current I in thin wires is proportional to Hd, where H is the field and d the diameter; on account of the small size, d is also their effective mean free path. Figure 3 is therefore equivalent to the well-known Kohler diagram, and has been plotted in order to test the validity of the magnetoresistive hypothesis. In view of the complexity of the phenomena involved, the divergence between the curves in the oscillating region is less significant than their convergence for high values of the current, where bulk magnetoresistance is the dominating factor.

The differences in detail between curves of different orientations are presumably due to changes both in the bulk magnetoresistance and in the mean free path: These variations are to be expected in a strongly anisotropic metal such as Ga. The fact that a change in the mean free path alone can affect the pattern considerably is clear from the curves for 4.2°K and 1.2°K for the same crystals.

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DOUBLE ACCEPTOR FLUORESCENCE IN II-VI COMPOUNDS*

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We wish to show that the unique characteristics of a radiative recombination process, which has been observed to be prominent in the low-temperature emission of five II-VI semiconducting compounds, can be explained in terms of the properties of a native double acceptor defect recently identified in electrical transport measurements. We believe that this type of defect, with its characteristic fluorescent emission, will be found to occur more generally in compound semiconductors.

The most familiar example of this process is the "green edge emission" of CdS.[1-5] Analogs have been recognized in CdTe,[6] ZnSe,[7] ZnS,[8] and ZnO.[9,2] In simplest form these fluorescent emission spectra are characterized by a temperature-dependent doublet structure, as illustrated in Fig. 1 for CdTe. This results from two closely spaced sets of emission lines, each set formed by the simultaneous emission of photons and 0, 1, 2, ⋯ longitudinal optical phonons. The high-energy set becomes dominant with increasing temperature. Additional structure and polarization effects appear in wurtzite (hexagonal) crystals due to valence-band splitting.

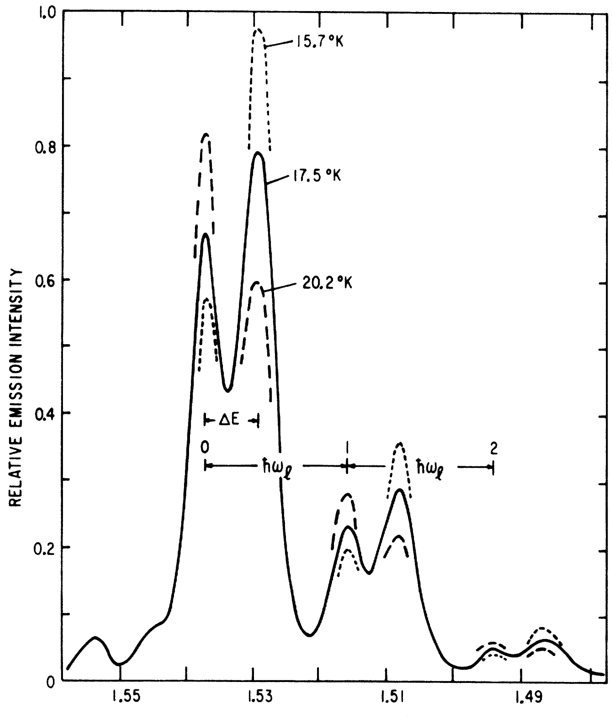

FIG. 1. Temperature-dependent doublet structure in fluorescent emission spectrum of CdTe attributed to transitions involving a native acceptor with a doubly ionized level near the conduction band.

We wish to explain this emission process in terms of a native double acceptor, A_2, which has a doubly ionized level, $A_2^=$, close to the conduction band. The existence of $A_2^=$ levels 0.056 and 0.09 eV below the conduction bands of CdTe and CdS, respectively, has recently been established by the electrical transport measurements of Lorenz and Woodbury[10]; and more recently at a depth of ~0.1 eV in ZnSe by Aven.[11] That the observed $A_2^=$ levels in these materials are close