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Anisotropy of Electrical Conductivity in Si_2Te_3

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Silicon telluride Si_2Te_3 is a p-type semiconductor with hexagonal layer structure and space group p$\bar{3}$m1 /1, 2/. The crystallographic c-axis is perpendicular to the layers. The crystals are strongly hygroscopic and even traces of water vapour cause a chemical reaction. As a result SiO_2 and free tellurium are deposited on the sample surface /3, 4/. For electrical measurements on high resistivity Si_2Te_3 it is necessary to avoid this reaction or to restore the original low conductivity of the surface.

In a previous investigation /5, 6/ the samples were cleaved in high vacuum before the evaporation of gold contacts. During the transfer to the measurement apparatus, however, the samples were exposed to the laboratory atmosphere. Therefore the surface reaction produced a tellurium film, which was removed by a vacuum heat treatment at 520 K. The reproducibility of the experimental results was not satisfactory.

In this note we used an ultra-high vacuum equipment to avoid chemical surface reactions. In this apparatus it was possible to clean the samples, to apply gold contacts by evaporation, and to perform measurements of the electrical conductivity under permanent vacuum conditions. To obtain clean sample surfaces we cleaved the samples with the help of an adhesive tape or sputtered the crystal surfaces with an argon ion beam. With the first method, however, it was not possible to obtain two parallel sample surfaces perpendicular to the c-axis as good cleavage planes. Therefore the measurement of the electrical conductivity parallel to the c-axis was only feasible with sputtered samples.

The crystals were grown by transport in the vapour phase /2, 7/. The samples were platelets of 70 to 100 μm thickness and 40 to 50 mm^2 area. The sputtering was performed at an argon pressure of 10^{-4} mbar, the typical

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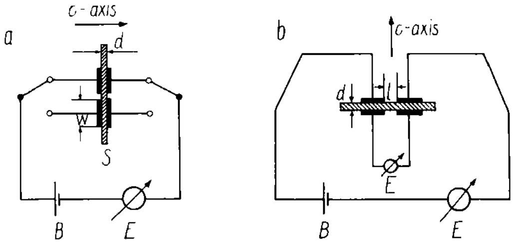

Fig. 1. Experimental arrangement for conductivity measurements; a) parallel to the c-axis, b) perpendicular to the c-axis; S sample, B battery, E electrometer, l = 1 mm, d = 70 to 100 μm, w = 2 mm

sputtering time was 2 h. After the sputtering two gold contacts were produced by evaporation on each sample surface perpendicular to the c-axis (Fig. 1). The measurement circuit for determination of the anisotropic electrical conductivity is shown in Fig. 1. After the sputtering the conductivity had increased by three orders of magnitude. Therefore the samples were annealed at 570 K for 30 h; after this procedure the samples showed the original low conductivity (Fig. 2). The measurements were performed in the linear range of the current-voltage characteristic at a pressure of 10^{-10} to 10^{-9} hPa.

The temperature dependence of the electrical conductivity $\sigma_{\perp\vec{c}}$ perpendicular to the c-axis for cleaved samples and also for a sputtered and subsequently annealed sample is presented in Fig. 3 (curve 1). The dark conductivity at room temperature is $10^{-13}\ \Omega^{-1}\ cm^{-1}$, the activation energy is 1.05 eV. The good agreement of the results for both samples indicates that the ion etching completely removed the tellurium and SiO_2 films. The arrangement of Fig. 1b was used to check if the samples were sufficiently thin to calculate the conductivity $\sigma_{\perp\vec{c}}$ from the geometric dimensions. For this purpose the applied voltage at the upper contacts was compared with the potential difference between the lower contacts.

The temperature dependence of the electrical conductivity $\sigma_{\parallel\vec{c}}$ parallel to the c-axis of a sputtered and subsequently annealed sample is presented by curve 2 in Fig. 3. The dark conductivity at room temperature is $10^{-15}\ \Omega^{-1} cm^{-1}$, the activation energy is 1.24 eV. For a comparison we present

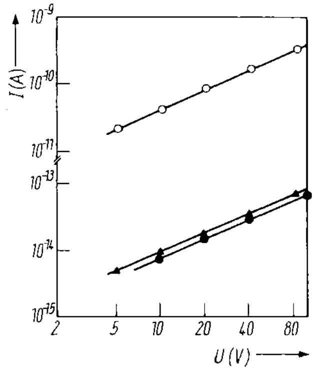

Fig. 2. Current-voltage characteristic of Si_2Te_3 at 300 K perpendicular to the c-axis; ▲ cleaved sample (UHV), ○ sputtered sample, ● sputtered and subsequently annealed sample

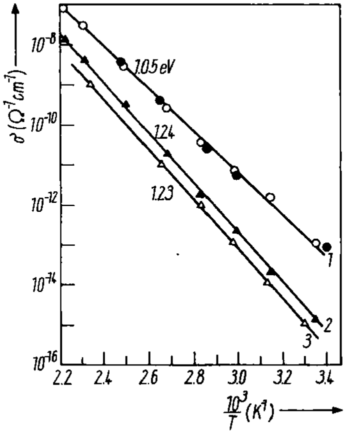

Fig. 3. Temperature dependence of the electrical conductivity σ ; (1)○ $\sigma_{\perp\vec{c}}$ sputtered and subsequently annealed sample,● $\sigma_{\perp\vec{c}}$ cleaved sample (UHV); (2)▲$\sigma_{\parallel\vec{c}}$ sputtered and subsequently annealed sample; (3)△$\sigma_{\parallel\vec{c}}$ results obtained by Bauer /6/

also in this figure (curve 3) the results obtained by Bauer /6/. From the data of Fig. 3 the anisotropy of the electrical conductivity $\sigma_{\perp\vec{c}}/\sigma_{\parallel\vec{c}}$ can be obtained (Fig. 4). At room temperature we have $\sigma_{\perp\vec{c}}/\sigma_{\parallel\vec{c}} \approx 100$. With increasing temperature up to 450 K the anisotropy decreases by one order of magnitude. These results cannot be explained by an effective mass anisotropy, which is usually substantially lower and temperature independent /8/.

The lattice of Si_2Te_3 is strongly disordered. The unit cell contains two Te atoms and on the average (4/3)Si atoms which are statistically distributed over eight possible positions between two tellurium layers /1, 2/. Therefore the translation symmetry is disturbed parallel as well as perpendicular to the layers. Moreover, stacking faults can occur in the hexagonal tellurium sublattice. The hole mobilities measured by Bauer and Birkholz /5, 6/ and Ziegler and Ziegler and Birkholz /2, 7/ are below 10^{-1} cm^2/Vs parallel and perpendicular to the c-axis. This means, that charge carrier transport in both directions is due to hopping. The activation energies of the conductivity exceed 1 eV, therefore the transport mechanism is caused by holes in localized states near the valence band. We assume the disturbance of the lattice parallel to the c-axis to be more pronounced than perpendicular to it. This could be due to weak van der Waals binding forces between the tellurium layers and to stacking faults along the c-axis. According to this model the temperature dependent anisotropy is determined by the difference of the hole mobility activation energies parallel and perpendicular to the layers.

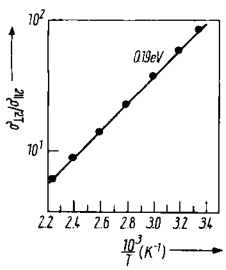

Fig. 4. Temperature dependence of the anisotropy of the electrical conductivity

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