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TEMPERATURE-DEPENDENCE OF ELECTRIC AND PHOTOVOLTAIC PROPERTIES OF HgTe THIN FILM

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The I–V characteristics of an illuminated thin film of HgTe and of a dark sample were recorded. The high values of the photoelectric current of the illuminated sample as the distance decreased may be due to the impurity conductivity, that can be higher than the band conduction predominating at higher incident energy. In the dark, the impurity conductivity is always low compared to the band conductivity occurring at the higher incident energy of mercury light. The low mobility and the increase of the activation energy with increasing temperature suggest that more than one conduction mechanism is involved. The high density of acceptor centres in the thin layer of HgTe may affect the conduction current in certain temperature ranges.

The dielectric constant of the HgTe thin film was measured at different temperatures. The increase of the dielectric constant might be due to point defects which are Hg-vacancy or Te-interstitial acceptors. HgTe has an excess of Te and the net hole concentration $(p-n)$ can be altered by increasing the ionized acceptor defects which migrate through the cubic crystallites to accumulate at the electrodes, giving rise to the dielectric constant.

Mercury telluride is a semiconductor with an inverted band structure [1, 2]. Recent papers concerning the physical properties of HgTe present consistent information about conduction band parameters [3–7] and electron scattering mechanisms [8, 9]. The parameters of the valence band and the properties of the holes in HgTe have been investigated at times. The acceptor states have been observed in all reported investigations on HgTe samples, even those of very high purity.

In the present paper the I–V characteristics of dark and illuminated HgTe thin films are presented. The temperature-dependence of the dielectric constant and the effect of temperature on log current are discussed.

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Experimental procedure

HgTe thin films were prepared by evaporation at 4.5×10^{-5} torr. They were evaporated onto glass substrates provided with indium electrodes in such a way that all the desired measurements could be performed on the same sample. Before evaporation the substrates were cleaned. HgTe of 99.999% purity was evaporated to a film 1 μm in thickness. The temperature of the silica glass substrate was 100°. Electrical measurements were performed using a d.c. voltage provided by a constant power supply, and the current was recorded by an electronic Avometer. The voltage across the sample was monitored by a TM10 D.C. Microvoltmeter. Sample temperatures are monitored with a small chromel-alumel thermocouple attached to the substrate. The dielectric constant was determined using a signal generator type TRI_0AG–203 and Avometer to record the a.c. voltage at different frequencies. The a.c. current was recorded as a function of temperature.

The dielectric constant, ϵ, was determined from the relationship:

$$\epsilon = 4\pi dI/WVA,$$

where V is the a.c. voltage drop across the sample, A the area of the sample surface, d the thickness of the film I the current, and W the measured frequency ($= 2\pi f$).

Identification of the prepared HgTe thin film

The X-ray diffraction pattern of the HgTe thin film was recorded with an XD–3 diffractometer with CuK_{∞} radiation, and is shown in Fig. 1. The Bragg angles 2θ, the corresponding spacings d and the relative intensities of the diffraction lines are listed in Table 1. The results confirm the preparation of cubic crystals of HgTe.

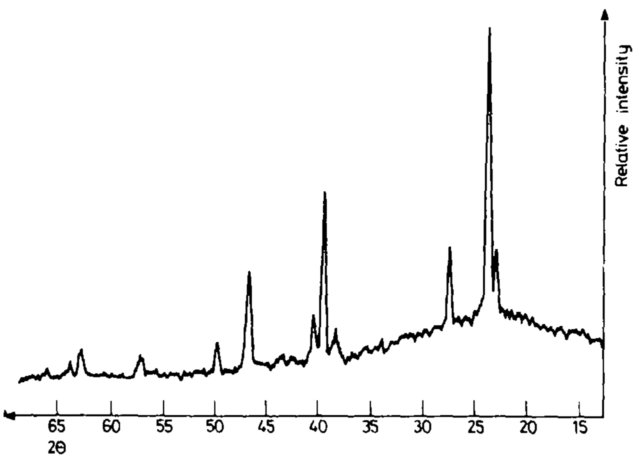

Fig. 1 X-ray diffraction pattern of HgTe thin film

Table 1 Bragg angles and the corresponding intensities of reflections for HgTe thin film

2θ	I	d, Å
23.00	6	3.85
23.75	17	3.75
27.60	6	3.23
33.80	2	2.66
38.30	3	2.35
39.40	9	2.28
40.30	3	2.23
43.35	1	2.00
46.60	5	1.95
49.65	2	1.83
57.10	1	1.62
62.60	1	1.48
63.60	1	1.46

I–V characteristics of dark and illuminated thin films of HgTe

The effects of mercury light at a frequency of 366 nm on the I–V properties of HgTe film at different distances apart and at room temperature are shown in Fig. 2. An increase of the photoelectric current is noticed with decrease of the distance

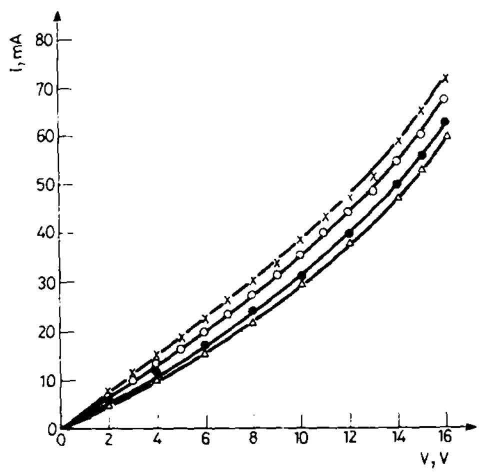

Fig. 2 I–V characteristic of illuminated sample with mercury light at different distances from the sample; × 5 cm, ○ 10 cm, ● 15 cm, △ dark sample

apart. This can be explained as follows: The defects are either Hg vacancies or Te interstitial acceptors. It is plausible that a very high concentration of traps could lead to impurity conductivity. In the dark, the impurity conductivity always has low values compared to the band conductivity occurring at higher temperature. In the light, the impurity conductivity can have a higher value than the band conduction which predominates at low distance apart. This follows because the impurity conduction will depend on the number of occupied traps, which can be many times the number of free carriers, but the traps do not become sufficiently filled to result in impurity conduction while the incident intensity of light is too low for photoexcited electrons to be collected. The possible objection that the second carriers are holes rather than carriers in an impurity band or hopping carriers can be ruled out, because the hole concentration increases with increase of the intensity of photoelectric energy, and at the same time the electron concentration increases. This results in higher values of the photoelectric current.

Effect of temperature on photoconduction current

The effects of temperature on the photoelectric current for the dark and illuminated samples are shown in Fig. 3. The photoelectric current increased with temperature. This might be explained by the possibility of additional centres which may, for example, act as recombination centres or traps under photoexcitation, with two effects. First, if the centres are always filled or empty in the dark, then the effective number of acceptors is changed. Second, if the occupation of the centres is temperature-dependent, the activation energy is changed and will be governed by more than one activation energy. This causes the increase of the photoconduction with temperature.

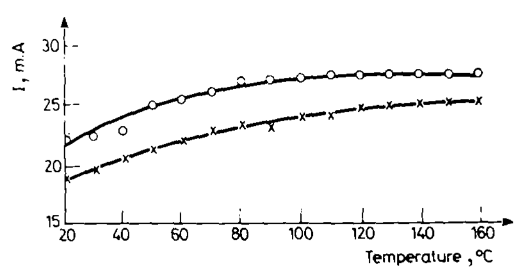

Fig. 3 Effect of temperature on the electric current; dark HgTe thin film, ○ illuminated sample

Temperature-dependence of log current

At the low potential of 5 V, the current varies with temperature in accordance with the equation

$$I = I_0 \exp^{-\Delta E/KT} \tag{1}$$

where ΔE is the activation energy for donors or traps, and

$$I_0 = q\mu N_d \frac{V}{d} A \tag{2}$$

where q is the electronic charge, μ is the mobility
N_d is the impurity density, V is the voltage,
d is the effective electrode separation and
A is the effective area.

A plot of log I against $\frac{1}{T}$ is shown in Fig. 4. According to Eq. 1, the gradients yield consistent activation energies $\Delta E \simeq 0.05$, 0.38 and 0.28 eV. With $N_d \simeq 6 \times 10^{18}$ cm^{-3}, the mobility was estimated to be 4.86×10^{-7} cm^2 V^{-1} sec^{-1}. This low value may be due to the hole mobility, which is limited by the scattering on the barriers among crystallites. There was a transition from a straight line with a low gradient to one with a higher gradient as the temperature was increased. This suggests that more than one conduction mechanism is involved. The high density of acceptor centres in the bulk of the HgTe may affect the conduction in certain temperature ranges.

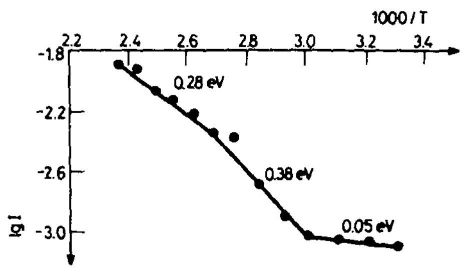

Fig. 4 Temperature dependence of log I

Effects of temperature on the dielectric constant of HgTe thin film

The temperature-dependence of the dielectric constant at different frequencies is shown in Fig. 5. The dielectric constant increases with increasing temperature. This can be explained as follows.

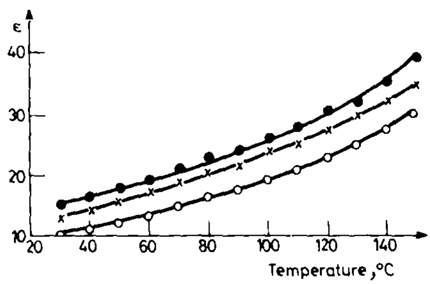

Fig. 5 Effect of temperature on the dielectric constant at different frequencies; ● 1 kc/s, × 50 kc/s, ○ 100 kc/s

The predominant point defects are Hg-vacancy or Te-interstitial acceptors. It is a well-known experimental fact that HgTe always has an excess of Te and that the net hole concentration $p-n$ can be altered by rising temperature. It is generally believed that the excess holes result from the ionization of acceptor defects associated with the presence of a stoichiometric excess of Te. The increase of temperature increased the ionized acceptor defects which migrate through the lattice to accumulate at the electrode surfaces. This gave rise to the sample capacitance.

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Zusammenfassung — Die Strom-Spannungs-Charakteristik eines dünnen HgTe-Filmes wurde bei Einfall von Licht und im Dunklen registriert. Die hohen Werte des photoelektrischen Stromes der beleuchteten Probe bei abnehmenden Abstand können der durch Verunreinigungen bedingten Leitfähigkeit zugeschrieben werden, die bei größerer Einfallsenergie größer als die Bandleitfähigkeit sein kann. Im Dunklen ist die durch Verunreinigungen bedingte Leitfähigkeit immer gering im Vergleich zur Bandleitfähigkeit beim Einfall größerer Energiemengen von Hg-Licht. Die geringe Mobilität und der Anstieg der Aktivierungsenergie mit ansteigender Temperatur deuten darauf hin, daß am Vorgang mehr als nur ein Leitungsmechanismus beteiligt ist. Die hohe Dichte der Akzeptorzentren in der dünnen HgTe-Schicht beeinflußt den Leitfähigkeitsstrom in bestimmten Temperaturbereichen. Die dielektrische Konstante des dünnen HgTe-Filmes wurde bei verschiedenen Temperaturen gemessen. Der Anstieg der dielektrischen Konstante kann punktförmigen Gitterfehlern, nämlich Hg-Vakanzen oder interstitionellen Te-Akzeptoren zugeschrieben werden. HgTe hat einen Te-Überschuß, und die

Gitterfehlstellenkonzentration kann durch Vermehrung der ionisierten Akzeptordefekte verändert werden, die durch die kubischen Kristallite migrieren, sich an den Elektroden anhäufen und so das dielektrische Verhalten bewirken.

Резюме — Измерены вольтамперометрические характеристики (I–V) освещенного и неосвещенного образца HgTe. Высокие значения фотоэлектрического тока освещенного образца при уменьшении расстояния может быть обусловлено примесной проводимостью, которая может быть более высокой, чем зона проводимости, преобладающая при большей энергии облучения. Примесная проводимость в неосвещенном образце всегда ниже по сравнению с зоной проводимости, имеющейся при более высокой энергии освещения ртутной лампой. Низкая подвижность носителей и увеличение энергии активации с увеличением температуры предполагает, что для данного образца имеется более чем один тип проводимости. Высокая плотность акцепторных центров в тонком слое HgTe может затрагивать электропроводность в определенных областях температуры. При различных температурах измерена диэлектрическая проницаемость тонкопленочного HgTe. Увеличение диэлектрической проницаемости может быть обусловлено точечными дефектами, которые являются Hg-вакансиями или Te-междуузельными акцепторами. Теллурид ртути имеет некоторое избыточное количество теллура и полная концентрация дырок $(p-n)$ может быть изменена увеличением ионизированных акцепторных дефектов, которые, мигрируя через кубические кристаллиты, аккумулируются на электродах и тем самым приводят к увеличению диэлектрической постоянной.