Electrical Properties of Mercury Telluride*

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Polycrystalline HgTe, as prepared in sealed quartz tubes, was found to be p type with acceptor concentrations of 10^{18}–10^{19} cm^{-3} and band gap ~0.02 ev. Diffusion of zinc and copper into samples indicates that the former is a donor impurity, the latter an acceptor impurity. Measurements of resistivity and Hall effect extended to liquid hydrogen temperature reveal a marked magneto-Hall effect. The Hall coefficient changes sign at temperatures as low as 20°K. Some measurements of thermoelectric power and thermal conductivity are also given.

INTRODUCTION

MERCURY telluride (HgTe) is a Group II–VI compound on which little work has been reported in this country until recently.[1] Studies of this compound formed from sintered or pressed powders have been described in Russian journals.[2] This paper is principally concerned with extension of measurements of resistivity and Hall coefficient to the liquid hydrogen temperature region where there is an interesting magneto-Hall effect. A few measurements of thermoelectric power and thermal conductivity are also given.

PREPARATION OF COMPOUND

To make HgTe, stoichiometric quantities of mercury and tellurium[3] were placed in a thin-walled quartz boat at one end of a 15-in. quartz tube. The tube was evacuated, sealed off, and then heated by torch at one end ~700°C to partially react the constituents. Care was necessary to avoid building up an excessive mercury pressure.[4] The tube was then inserted into a furnace arranged so that the tellurium and HgTe were held at ~700°C while the other end of the tube was slowly raised to ~350°C. This 350°–700°C furnace arrangement was maintained overnight and then lowered to room temperature slowly to prevent cracking of the compound and quartz boat. In some of the lots produced, the surface of the HgTe was smooth and bright with large crystallites in evidence. Samples of HgTe gave a Debye-Scherrer pattern characteristic of a zinc blende structure with lattice spacings in agreement with literature value for this compound.

Zinc and copper were diffused into several HgTe samples. Microgram quantities of these elements were sealed off with ~5 mg HgTe in small quartz tubes and held near 700°C for hours. The compound is relatively soft and could be ground on fine emery paper to a $2\times4\times10$ mm^3 size suitable for cryostat study. Fair ohmic contacts were made to the compound by applying spring contacts against silver painted areas. Better contacts were made by soldering on indium or tin (with flux in the latter case).

ELECTRICAL MEASUREMENTS

Measurements of resistivity ρ and Hall coefficient R_H were made over the range 20° to 500°K. Typical data of ρ, R_H, and Hall mobility μ_H (taken as R_H/ρ) are plotted in Figs. 1 to 3. R_H is determined at a field of

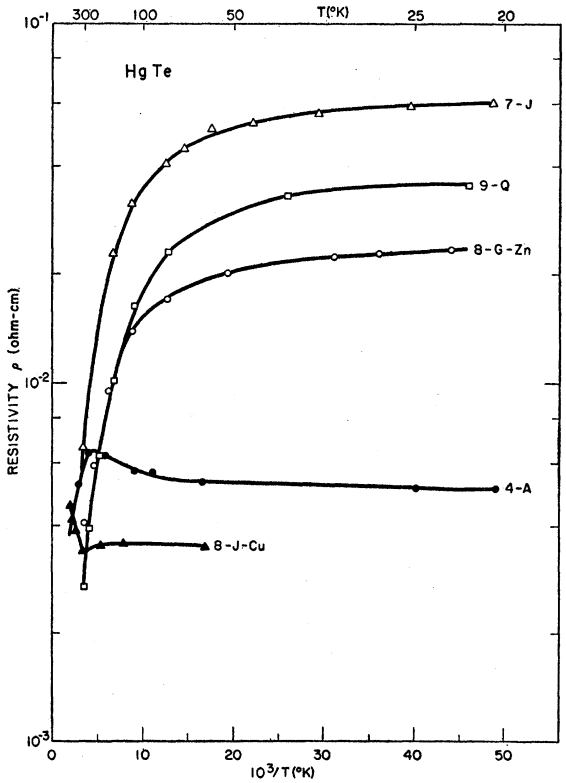

FIG. 1. Resistivity ρ *versus* inverse temperature for five HgTe samples, including one that was doped with zinc and one doped with copper.

* A preliminary report was presented at the St. Louis meeting of the American Physical Society, November 1957 [Bull. Am. Phys. Soc. Ser. II, 2, 347 (1957)].

[1] T. C. Harman and M. J. Logan, Bull. Am. Phys. Soc. Ser. II, 3, 15 (1958); Black, Ku, and Minden, Bull. Am. Phys. Soc. Ser. II, 3, 15 (1958).

[2] E. I. Nikol'skaya and A. R. Regel, J. Tech. Phys. U.S.S.R. 25, 1347, 1352 (1955); O. D. Elpat'evskaya and A. R. Regel, J. Tech. Phys. U.S.S.R. 27, 45 (1957) [translation: Soviet Phys. (Tech. Phys.) 2, 35 (1957)]; I. M. Tsidil'kovskiĭ, J. Tech. Phys. U.S.S.R. 27, 1744 (1957) [translation: Soviet Phys. (Tech. Phys.) 2, 1622 (1957)].

[3] Hg used was triply distilled, of >99.99% purity; Te was of 99.999% purity from American Smelting and Refining Company.

[4] Melting point of HgTe ~680°C; boiling point of Hg=357°C.

6000 gauss in these curves. Adjacent samples from the same lot were studied to check that the polycrystalline nature of the samples did not influence the results. In the temperature region above 60°K, the curves in Figs. 1 to 3 are similar to those on single crystals.[1]

Most samples have a change in sign of R_H and are dominated by acceptor concentrations of 1.5×10^{18} cm^{-3} for sample 7*J* to 4×10^{19} for 8-*J*-Cu.[5] At temperatures above 200°K the samples approach a common curve. At room temperature, the intrinsic electron concentration of 3×10^{17} cm^{-3} dominates the conduction process even though there are more than 10^{18} holes available from acceptor impurities. The slopes of R_H and ρ *vs* $1/T$ yield ~0.1 ev as the apparent energy gap; correcting R_H for the $T^{\frac{3}{2}}$ dependence of density of states near the conduction band edge gives ~0.02 ev as the true gap.[6]

The reversal of R_H at low temperatures indicates a high mobility ratio. One can calculate the mobility ratio b from the ratio of the peak value of $R_H = -(N_A e)^{-1}(b-1)^2/4b$, where N_A is the acceptor concentration, to the extrinsic $R_H = +(N_A e)^{-1}$. Calculated values are in the range of 40 to 100. In order to explain

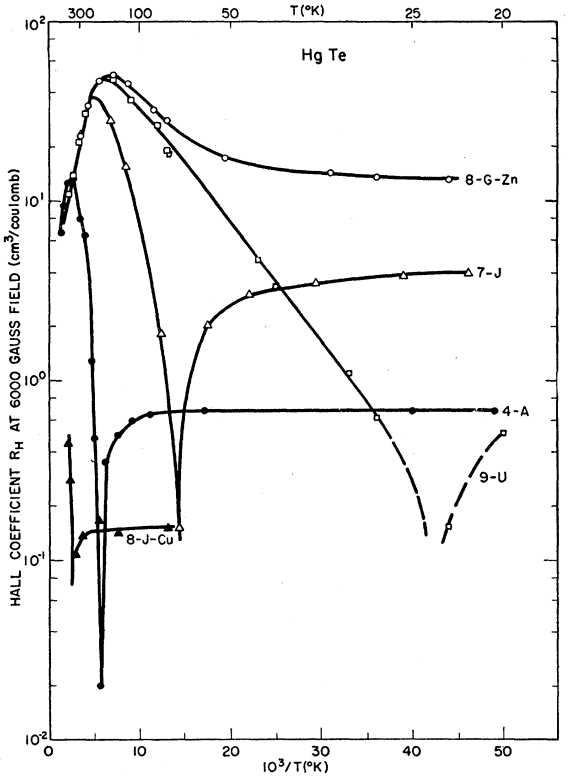

FIG. 2. Hall coefficient R_H *versus* inverse temperature for five HgTe samples. The Hall coefficient is negative at high temperatures and converts sign at lower temperatures in four of these samples. The magnetic field is 6000 gauss.

[5] Sample taken from lot 8 doped with copper by diffusion.

[6] Older Russian literature gave the band gap of HgTe as 0.08 ev but more recent work by Tsidil'kovskiĭ[2] gives 0.025 ev. The reference 1 papers also obtain approximately 0.02 ev.

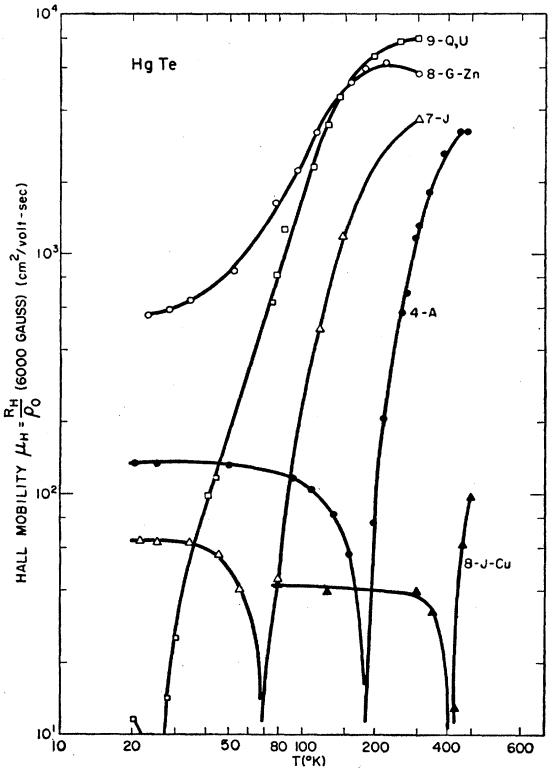

FIG. 3. Hall mobility μ_H *versus* absolute temperature for five HgTe samples. The Hall coefficient R_H is measured at 6000 gauss, resistivity ρ at zero field.

the R_H sign change at temperatures as low as 20°K (where the concentration of intrinsic electrons is calculated to be $<10^{13}$ for band ~0.025 ev and 3×10^{17} cm^{-3} concentration at 300°K), the mobility ratio must be $>10^2$. Since the hole mobility is of order 100 cm^2/volt-sec, then the mobility of the electrons is of order 10 000 cm^2/volt-sec at 20°K, very high for an an impurity concentration 10^{17}–10^{18} cm^{-3}.

MAGNETIC FIELD EFFECTS

The Hall coefficient depends markedly on the field used to measure it, as illustrated in Fig. 4 for two samples. Even at room temperature there is a slight field dependence while at ~100°K, R_H varies linearly with field over the measured range. At very low temperatures, R_H for sample 8-*L*-Zn changes sign at higher fields. The temperature of the R_H sign reversal ($R_H=0$) decreases with decreasing field. In other *p*-type samples, the conversion of sign of R_H is observed for a wider range of fields. For sample 9*U* plotted in Fig. 2, the values of R_H at 20°K range from +0.25 at 1500 gauss to +0.57 at 7600 gauss. Sample 8-*G*-Zn is especially sensitive to field; at 23°K, R_H changes from −8.5 at 7000 gauss to −68 at a 1000 gauss field. The trend of the data suggests that even this sample may convert type at lower temperature and higher fields. Magnetoresistivity effects are also observed, but they are less

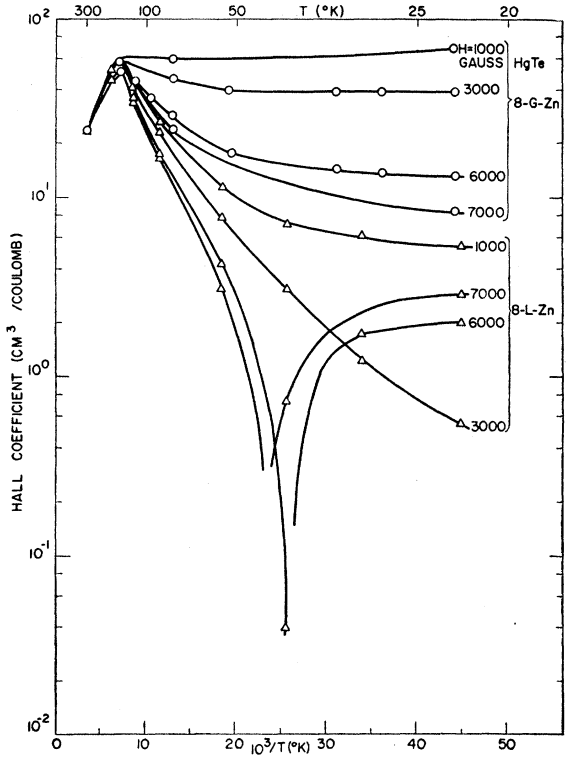

FIG. 4. Hall coefficient for several magnetic field strengths for two HgTe samples doped with zinc. Curves are typical of HgTe samples whether doped or undoped.

pronounced. The maximum change in ρ over a 7000-gauss field range was ~15%.

The magneto-Hall effect in HgTe is reminiscent of data of Willardson *et al.*[7] on *p*-type germanium. They found it necessary to postulate two types of positive charge carriers with different mobilities and effective masses to explain their Hall data. For HgTe, quantitative or even qualitative calculations cannot be made from present data using their model; a wider range of field measurements is required to establish limiting cases of very weak and very strong fields and the orientation of crystal samples must be known.

THERMOELECTRIC POWER AND THERMAL CONDUCTIVITY[8]

The thermoelectric power α ranges from -110 to -150 microvolts/°C at 300°K except for the copper-doped sample 8-*J*-Cu which is $+120$ microvolts/°C. There is a reversal in sign of thermoelectric power of a sample adjacent to 7*J* at ~114°K, as shown in Fig. 5. The temperature of reversal of Hall coefficient of 7*J* (see Fig. 2) is ~65°K. The expression for R_H involves the square of the ratio of electron to hole mobilities or b^2 while that for α involves the first power of b. Hence the effect of intrinsic electrons overrides the effect of the more numerous holes to a lower temperature for R_H than for α. The thermal conductivity of the Fig. 5 sample is 27 mw/cm°C at room temperature and follows approximately the usual $1/T$ law to 100°K. In view of the high impurity concentration and polycrystalline nature of this sample, the values of thermal conductivity in Fig. 5 are only an approximate index of the values for a high-purity single crystal of HgTe.

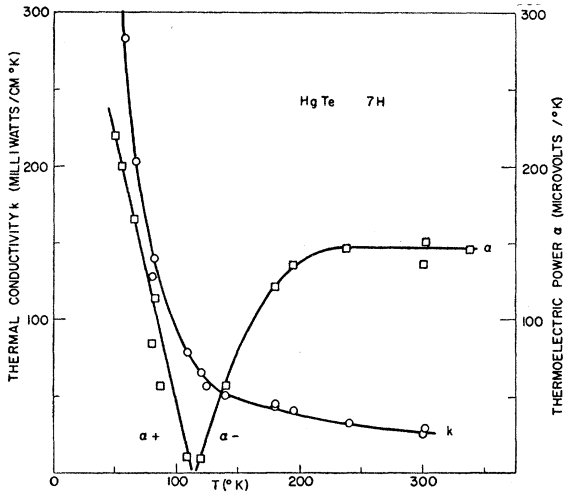

FIG. 5. Thermoelectric power α and thermal conductivity k as functions of absolute temperature for a polycrystalline sample of HgTe. The net acceptor concentration is $\sim 1.5 \times 10^{18}$ cm^{-3}.

CONCLUSIONS

HgTe can be prepared by the two-furnace technique, maintaining a pressure of mercury over the reacting Te. The study of HgTe samples has checked that this compound has ~0.02 ev band gap and a large mobility ratio. A complicated conduction band is suggested by the magneto-Hall effect. Zinc appears to act as a donor impurity and copper as an acceptor impurity in HgTe.

ACKNOWLEDGMENTS

G. Brower carried out much of the preparation work and aided in the electrical measurements; E. A. Taft was very helpful in the initial phases of HgTe preparation. I am indebted to H. Ehrenreich for discussions on the interpretation of the Hall data.

[7] Willardson, Harman, and Beer, Phys. Rev. **96**, 1512 (1954).
[8] These data were taken by W. W. Tyler of this Laboratory.