

## Pressure Dependence of the Carrier Concentrations in *p*-Type Alloys of $\text{Hg}_{1-x}\text{Cd}_x\text{Te}$ at 4.2 and 77°K\*

C. T. Elliott,<sup>†</sup> John Melngailis, T. C. Harman, J. A. Kafalas, and W. C. Kernan  
*Lincoln Laboratory, Massachusetts Institute of Technology, Lexington, Massachusetts 02173*  
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Electrical transport measurements have been made on *p*-type samples of  $\text{Hg}_{1-x}\text{Cd}_x\text{Te}$  with  $x$  near 0.15 at temperatures of 4.2 and 77°K and at hydrostatic pressures up to 9 kbar. A sharp transition is observed in both the Hall coefficient and conductivity versus pressure at 4.2°K. The pressure dependence of the carrier concentrations and mobilities has been obtained from magneto-Hall and magnetoresistance data. Analysis using  $\vec{k}\cdot\vec{p}$  theory yields values for the Fermi energy, measured with respect to the valence-band edge, of more than 9 meV, which are independent of pressure. A possible model to account for this behavior is described. Magnetic freeze-out effects have been observed and attributed to the lowest-energy, spin-split, zero-order Landau level passing through the Fermi energy. A value of  $7\times 10^{-6}$  eV/bar is obtained for the pressure coefficient of the energy gap at 77°K. Non-Ohmic behavior has been observed at 4.2°K during the magnetic freeze-out.

### INTRODUCTION

A continuous range of  $\text{Hg}_{1-x}\text{Cd}_x\text{Te}$  alloys can be formed between the semimetal HgTe and the semiconductor CdTe. The general features of the band structure are now well established (see review papers by Long and Schmit<sup>1</sup> and Harman<sup>2</sup>). HgTe is a semimetal with an inverted band structure, like that proposed for gray tin,<sup>3</sup> with a negative  $\Gamma_6-\Gamma_8$  energy gap of 0.3 eV, at low temperature. The energy gap increases approximately linearly with  $x$ , going through zero for  $x\approx 0.15$  at low temperature. At higher values of  $x$  the alloys are semiconducting with a band structure qualitatively like that of the direct-gap III-V compounds. A large number of investigations (see review papers for references) have established that the dispersion relation for the conduction band is well described by Kane's  $\vec{k}\cdot\vec{p}$  model.<sup>4</sup> A recent determination<sup>5</sup> from magnetoreflexion measurements yielded a value of  $8.4\times 10^{-8}$  eV cm for the Kane matrix element.

The behavior of *n*-type  $\text{Hg}_{1-x}\text{Cd}_x\text{Te}$  is now relatively well understood, but the valence-band parameters have yet to be established. Reported values for the heavy-hole mass range from  $0.3m_0$  to  $7m_0$ ,<sup>5-11</sup> and the band overlap energy in the semimetallic alloys, due to the warping of the heavy-hole band, has not been reliably determined. In general, the

electrical transport properties of the *p*-type alloys have proved complex and difficult to interpret.<sup>5,12-14</sup>

The object of this work was to obtain information on the valence-band structure and on acceptor levels near the valence-band edge. Measurements of the electron and hole concentrations have been made on *p*-type, nearly zero-band-gap semiconducting samples, as the energy gap was opened up with hydrostatic pressure. Because of the high electron-to-hole mobility ratio the minority electrons can dominate the transport properties in the semimetallic state and large changes in the transport coefficients occur during the semimetal-semiconductor transition produced by applying pressure.

Hydrostatic pressure measurements have been made previously only on *n*-type  $\text{Hg}_{1-x}\text{Cd}_x\text{Te}$ <sup>15</sup> and HgTe<sup>16,17</sup> at 300 and 77°K, and on *p*-*n* junctions in  $\text{Hg}_{1-x}\text{Cd}_x\text{Te}$ .<sup>18</sup> The values obtained for the pressure coefficient of the energy gap vary from 8 to  $14\times 10^{-6}$  eV/bar.

In this paper we describe first the experimental procedure, then the results obtained, and finally the analysis and interpretation of the results.

### EXPERIMENTAL PROCEDURE

#### Sample Preparation

Single crystals of  $\text{Hg}_{1-x}\text{Cd}_x\text{Te}$  were grown by a

SEP 21 1972