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THE TEMPERATURE COEFFICIENT OF RESISTANCE OF THE HIGH PRESSURE PHASES OF Si, Ge AND SOME III-V AND II-VI COMPOUNDS*

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Abstract

The temperature coefficient of resistance has been obtained for the high pressure phases of Silicon, Germanium, and several III-V and II-VI compounds having the zincblende or wurtzite structure. The high pressure phases of all zincblende compounds were metallic. The high pressure phase of CdS is a semiconductor.

Data were also obtained on CdSe at room temperature and as a function of temperature. The transition found optically is also obtained electrically. The resistance-pressure curve for the high pressure phase has considerable structure. It is metallic.

An upper limit for the transition pressures of Germanium and GaSb at liquid nitrogen temperature was established.

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In two recent papers (1,2) the resistance of silicon, germanium, and a number of III-V and II-VI compounds, having the zincblende or wurtzite structure, was presented. With the exception of CdS all had transitions at high pressure to a phase with quite low resistance. It was speculated that this was a solid metallic phase. Recently, (3) a heating mantle has been devised which permits resistance measurements between 25° and 120°C at high pressure. An accurate pressure calibration has not yet been established at high temperature. The technique used largely to date has been to apply pressure at room temperature measuring the resistance, then to heat at constant applied force, measuring resistance as a function of temperature. Since the resistance varies slowly with pressure in the high pressure region, the temperature coefficient of resistance should be essentially the isobaric value even if there is a small pressure change with temperature.

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[1] S. Minomura and H. G. Drickamer, J. Phys. Chem. Solids (in press).

[2] G. A. Samara and H. G. Drickamer, J. Phys. Chem. Solids (in press).

[3] G. A. Samara and H. G. Drickamer, J. Chem. Phys. (in press).

Table I summarizes the temperature coefficient of resistance for the high pressure phases of all compounds having the zincblende lattice at atmospheric pressure. All of these materials are indeed metallic in the high pressure phase. Since no correction for contact resistance has been made, it is possible that the actual temperature coefficients are larger than those shown.

In Table II are presented a few results for the semiconductor phases expressed in terms of the activation energy. These are about the expected order of magnitude. Since the pressures were not strictly hydrostatic and since no accurate correction for contact resistance could be made, these measurements were not pursued in any detail. It should be mentioned that all measurements on both semiconductor and metallic phase were quite reversible with lowering temperature, with the exception of those on GaAs discussed below.

Special mention should be made of GaAs. It had two transitions at 245 and 280 kilobars, which ran very sluggishly with considerable tendency for overshooting. At all pressures above the first transition, GaAs showed a slight tendency to decrease slightly in resistance with increasing temperature, but lowering the temperature gave a further slight decrease. Apparently it was not possible to get the transition to run to completion so that we were dealing always with mixed phases.

Isotherms were run on several of the compounds at 120°C to establish the temperature coefficient of the phase transition pressure. In all cases the transition appeared to run at slightly lower pressure (5-10 kilobars) at 120° then at 25°C. In view of the fact that the pressure calibration is not well established at high temperature, and that the phases are known to have a strong tendency towards metastability, this should be taken only as indicating a trend.

The temperature coefficient of resistance of CdS was measured at several pressures above the transition at 25 kilobars. In all cases the resistance decreased with increasing pressure, indicating that CdS remains a semiconductor in the high pressure phase. The results are summarized in terms of activation energies in Table III.

In addition to measurements made on compounds studied in the previous papers (1,2), data were also obtained on CdSe both at room temperature and as a function of temperature. The material was the same as that used for optical studies (4). Typical room temperature runs are shown in Figures 1 and 2. The transition observed optically at 30-35 kilobars is also found electrically. The high pressure phase has relatively low resistivity ($\sim 10^{-4}$ ohm cm.). There is considerable structure in the high pressure resistance-temperature curve, which mirrors roughly the structure for CdS at high pressure, but with a much lower resistance. Thirteen room temperature runs were made, and the structure was observed in all of them.

The measurements of temperature coefficient of resistance are summarized in Table IV. The high pressure phase is metallic at all pressures studied.

Very recently (5) the high pressure resistance technique has

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[4] A. L. Edwards and H. G. Drickamer, Phys. Rev. 122, 1149 (1961).

[5] B. Riggleman, R. A. Stager, and H. G. Drickamer (unpublished).

been extended to liquid nitrogen temperature. Isotherms have been obtained on Ge and GaSb. The transitions to the metallic state were obtained at 175 and 170 kilobars respectively. Since the pressure calibration is in doubt and there is a strong tendency for metastability among these materials, these must be considered as only an upper limit for the transition pressure at 77°K.

Table I

Temperature Coefficient of Resistance - Metallic Phase

	Pressure	ρ_H / ρ_c	n*
nSi	237	1.56	1.65
pSi	236	1.53	1.58
nGe	171	1.59	1.72
pGe	152	1.75	2.08
GaAs	255	0.90	--
GaAs	367	0.83	--
GaSb	160	1.092	0.36
InP	168	1.28	0.93
InAs	170	1.135	0.47
ZnS	310	1.45	1.36
ZnTe	180	1.31	1.00
CdTe	130	1.28	0.93

*Calculated for $\frac{\rho_H}{\rho_c} = \left(\frac{T_H}{T_c}\right)^n$

Table II

Temperature Coefficient of Resistance - Semiconductor Phase

	Pressure (kilobars)	ρ_H / ρ_c	E(ev)*
nGe	50	0.0694	0.29
GaAs	141	0.091	0.256
InAs	17	0.112	0.235

*Calculated from $\rho = \rho_0 \exp(\frac{E}{kt})$

Table III

Temperature Coefficient of Resistance - CdS

Pressure (kilobars)	ρ_H / ρ_c	E(ev)*
35	0.563	0.062
311	0.138	0.214

*Calculated from $\rho = \rho_o \ \exp(\frac{E}{kt})$

Table IV

Temperature Coefficient of Resistance - CdSe

Pressure (kilobars)	ρ_H / ρ_c	n*
44	1.238	0.76
160	1.168	0.58
387	1.15	0.55

*Calculated for $\frac{\rho_H}{\rho_c} = \left(\frac{T_H}{T_c}\right)^n$

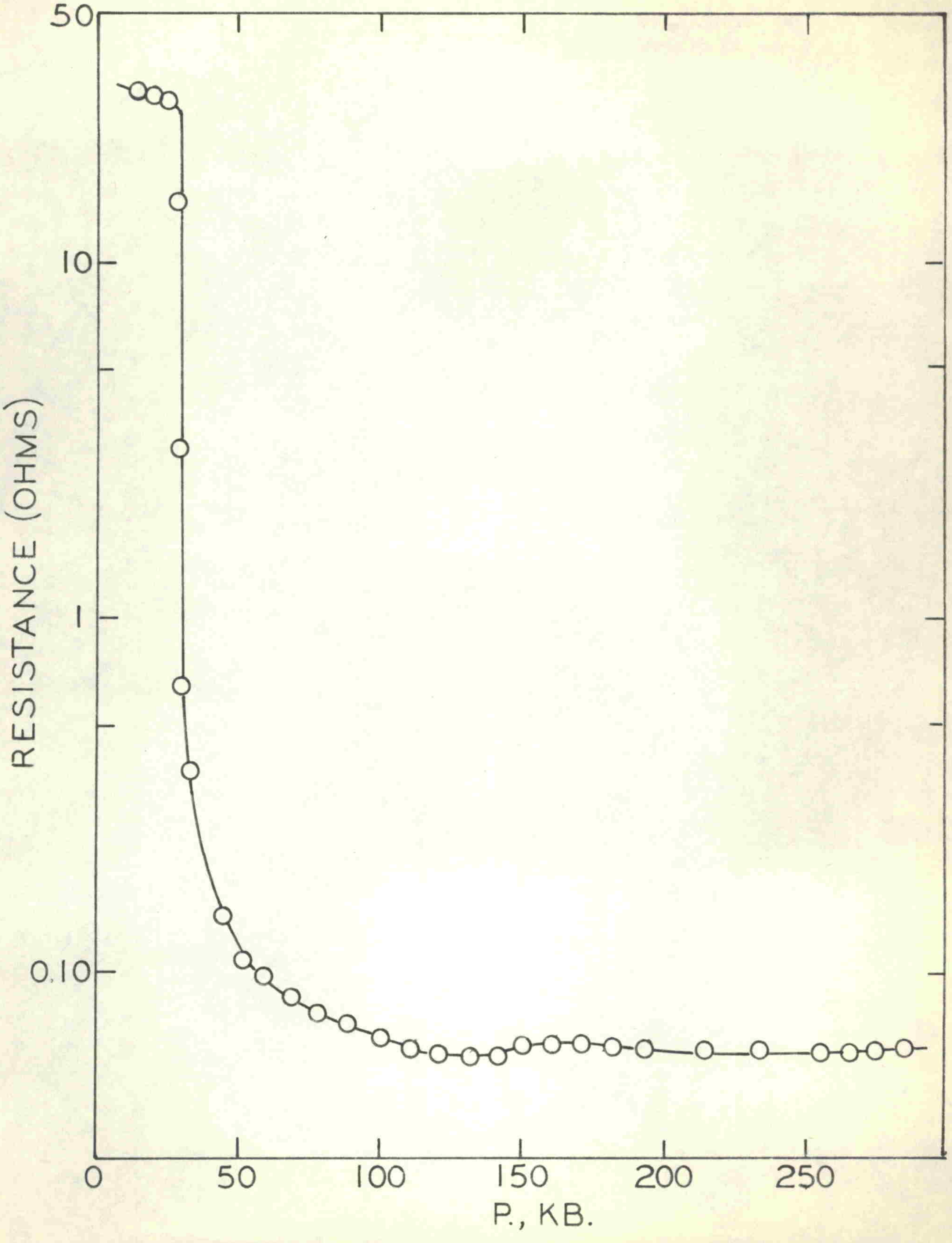

FIG. 1 RESISTANCE VS. PRESSURE FOR CdSe

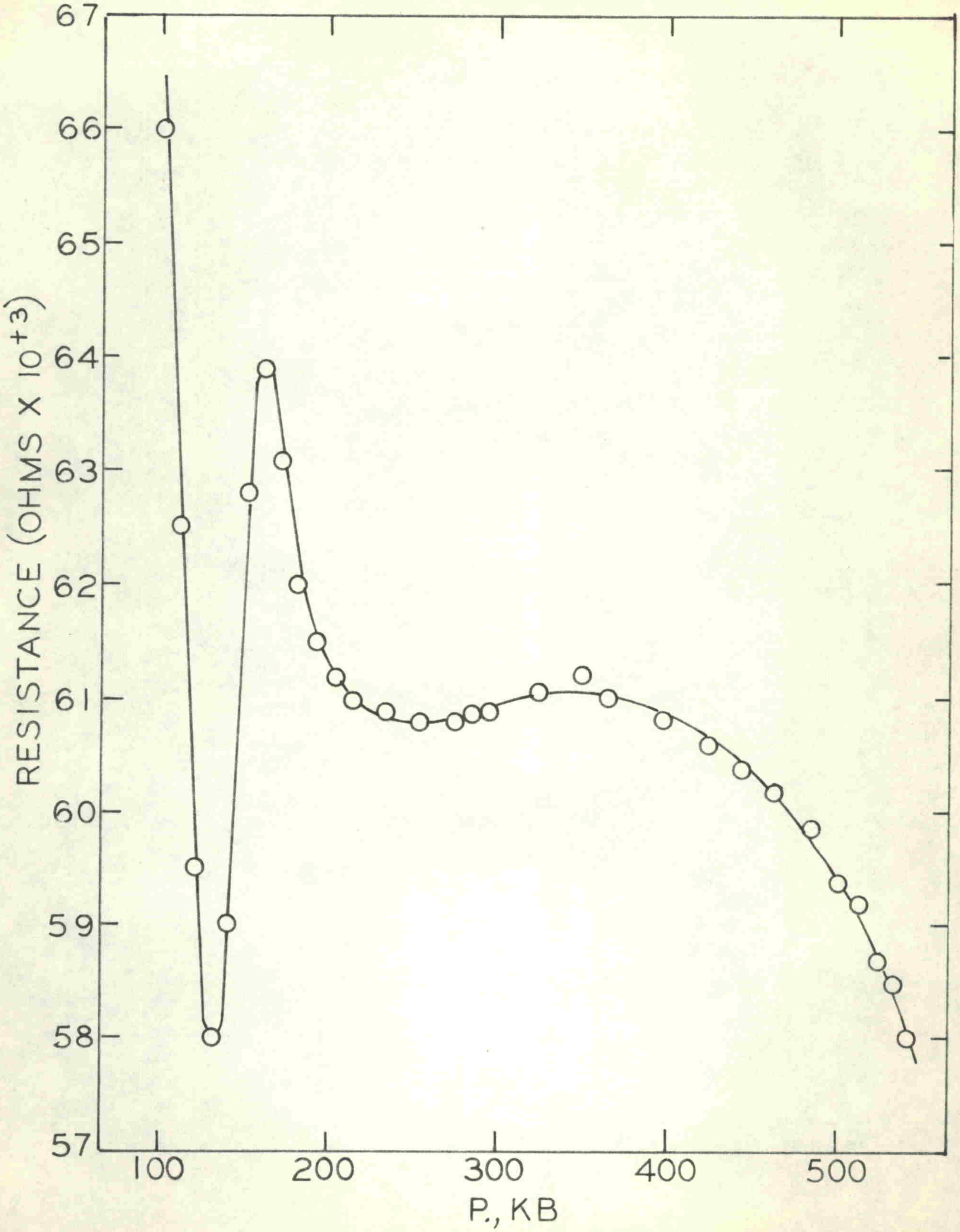

FIG. 2 RESISTANCE VS. PRESSURE FOR CdSe
(HIGH PRESSURE REGION)