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A LITERATURE REVIEW OF PHASE TRANSITION IN CADMIUM SULFIDE

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1. INTRODUCTION

The phase transition of cadmium sulfide(CdS) under high pressure was first discovered in 1959 by Drickamer and his co-workers[1]. Since then, numerous researchers have been involving in the study of CdS phase transition under various pressures and temperatures, and found many anomalous physical phenomena associated with phase transition, such as volume discontinuity, abrupt electric resistance drop, and magnetic anomaly etc. CdS is a semiconductor and is one of the II-VI compounds. It is probably the most well-studied one in the II-VI compounds. Up to now, most work in this field is put on the static high pressure field, the work on dynamic phase transition is quite few and lack of reliable and useful information. In this review, the static and dynamic work will be summarized in section 2 and 3, respectively. Some discussions and conclusions will be made in section 4 for future work.

2. PHASE TRANSITON BEHAVIOR OF CdS UNDER STATIC HIGH PRESSURE

A. The discovery of phase transition, phase structure and phase diagram

It is known that CdS under normal conditions occurs in two modifications, one having the wurtzite lattice, the other the zincblende. The phase transition of cadmium sulfide induced by pressure was first discovered by Drickamer and his colleagues[1][2], who found that the absorption edge spectrum of CdS sample with wurtzite structure had a great red shift($\sim$ 6000 wave numbers) at about 27.5 Kbar shown in Fig. 1. They realized that a phase transiton occured at this pressure, but they presumed it was due to the transformation from wurtzite to zincblende. Samara and Drickamer[3](1962) found that there was a very sharp drop of at least 5 orders of magnitude of electric resistance at 20 Kbar, with a sharp minimum at about 30 Kbar(see Fig. 2). But they also thought it was due to wurtzite to zincblende transformation.

Table 1. Lattice constant a_o and volume change

Investigators	Lattice constant a_o ($\mathring{A}$)	Volume change (%)	References
Rooymans	5.30	25	[6]
Kabalkina et al	5.56	29.6	[7]
Smith et al	5.24	21	[8][9]
Mariano et al	5.32	-	[11]
Corll	5.464	-	[12]

From the behaviors of some II-VI compounds with wurtzite or zincblende structure under pressure, Rooymans[5](1963) suggested that the high pressure phase of CdS might have rock salt structure. Jayaraman et al[10](1963) studied the compressibility and found 10% volume change at 28 Kbar They also suggest that it has NaCl or some closely related structure because the difference in volume between wurtzite and zincblende polymorphs of same substance is rarely more than 3%. This infer-

ence was directly confirmed by Rooymans[6][13](1963) and Kabalkina and Troiskaya[7](1963) indepandently using the X-ray diffraction method under high pressure. It was also verified by Smith et al[8][9](1963), Mariano and Warekois[11](1963) and Corll[12](1963), respectively. The lattice constants of high pressure phase i.e. rock salt phase from different authors are shown in Table 1.

It is clear now that the wurtzite phase will tranform into rock salt phase at about 20-30 Kbar. Does it exist new phases at higher pressure? It is not found up to 160-200 Kbar[2][8][9][18]. Samara and Drickamer[3] studied the electric resistance behavior with pressure up to 600 Kbar. Besides the anomaly between 20-30 Kbar, they found that the resistance reached a sharp maximum at about 465kbar(It can be seen in Fig. 2). They could not explain this phenomenon. Recently, Suzuki et al[37](1983) reported their high-pressure in situ X-ray diffraction study on CdS using a diamond anvil cell up to 680 Kbar at room temperature. They found that rock salt structure of CdS transformed to a new high pressure polymorph at about 560 Kbar(starting from 500 Kbar according the paper). The X-ray diffraction pattern of new polymorph can be indexed by the lowest temperature KCN structure. The volume change accompanied with the transformation was calculated to be about 0.8%. These arguements are based on the ionic model, but the bonding in CdS is mainly of covalent rather than ionic, so this explanation needs to be confirmed. But the sharp maximum of electric resistance at about 465 Kbar reported by Samara et al[3] might be related to this new phase transition, although Suzuki et al did not propose this connection, considering the difficulties of accurate measurement in high pressure experiments.

Miller et al[16](1966) studied the P-T equilibrium of CdS polymorphs in the range of over 50 kbar and 700^{o}C in opposed anvil and hydrothermal pressure apparatus. The results were shown in Fig. 3 and a triple point was located at 425$^{o}\pm5^{o}C$ and 16.5±0.5 Kbar between the phase fields of CdS-I(wurtzite and also CdS-I', metastable zincblende), CdS-II(rock salt) and CdS-III(a new polymorph of B23 structure). From Fig. 3 the slope of the II-III phase boundary is positive, so this new high pressure phase(B23) probably is not the high pressure phase beyond 500 Kbar at room

temperature in Ref. [37]. If this is true, then there are probably other triples and new phases beyond the triple in Fig. 3.

Osugi et al[19](1966) investigated the wurtzite-rock salt phase boundary of single crystal CdS over a P, T range of about 25 Kbar and 700°C by observing electrical resistance behavior in a cubic compact anvil device. They found the transition pressure was lowered with increasing temperature with a slope of $-74.4°C/Kbar$, which was contrary to the result of $130°C/Kbar$ in Ref. [16]. Samara and Giardini[14](1965) reported that the volumetric experiments exhibited an increase of the transition pressure of about $83.3°C/Kbar$, while the resistance experiments exhibited a comparable decrease of the transition pressure with temperature. They concluded that the transition pressure is weakly dependent on temperature. This was also conformed by Kaminskii et al[25](1971) and Malyushitskaya and Kabalkina[33](1980), who found the transition pressure slightly decreased with temperature. All of them found the hysteresis deceased with temperature. Perhaps this behavior of transition boundary of CdS is helpful for analysis of the shock data, because it is not an isothermal process under shock loading. In any case, the phase diagram is still worth to investigate in-depth.

The lattice structure of wurtzite hexagonal, zincblende cubic and rock salt face centered cubic are shown in Fig. 4. No information can be available for other polymorphes if they exist.

B. The pressure range of phase transition from wurtzite to rock salt

A broad range of transition pressures is reported for CdS (15-35 Kbar), the results at room temperature are listed in Table 2. The various reasons are suggested to explain the apparent discrepacies, such as the type of sample, grain size, preparation of the samples and type of experimental apparatus. Yu and Gielisse[24](1971) suggested a thermodynamic transition model using Gibbs' free-energy function of pressure (Fig. 5). According to the model, when pressure is above P_o, the lowest free-energy condition is created by zincblende phase nucleation and the sample becomes a disordered mixture.

The G-P curve peels off from the equiliblium wurtzite G-P curve to the dotted curves which is related with the different pressurization rates in the mixture region. When the dotted G-P curves meet the metastable extension of the rock salt G-P curve, a rock salt transformation takes place immediately. From Fig. 5 there exists a pressure range for P_t^{W-R}.

C. Recovery behavior and shear effect on phase transition

The recovery behavior of CdS is quite complicated and depends on the history of stress and temperature the sample experienced, even on the preparation of the sample. Basically, the results of experiments[7][14][19][24][25][27] demonstrate that there are two main phase transition modes: one is W→R→W mode, i.e. under hydrostatic pressure process the recovery material is wurtzite structure; and another is W→R→Z mode, i.e. the recovery material is zincblende structure or wurtzite and zincblende mixed structure if the shear stress exists. But Dodson and Venturini[35](1981) did not find the structure change, eventhough the shear stress does exist in shock experiments.

Rock salt structure can be recovered only by means of special treatments. The rock salt phase was first recovered by Corll[12](1964) when the starting material was unannealed CdS powder H_2S precipitated from CdCl. This precipitate is a very strained mixture of wurtzite and zincblende structures. Osugi[19] also obtained the recovery rock salt phase using a special quenching treatment. Brown et al[34](1980) recovered the zincblende and rock salt mixed structure using a special "pressure quenching" technique, i.e. the sudden release of pressure at rates greater than 10^6 bar/sec from above 40 Kbar. The sample treated with pressure quenching demonstrates anomalous diamagnetic behavior as described in Section 2F.

The rock salt or zincblende phases recovered in the experiments will not be stable and they will transform into wurtzite after anneal or time effect treatments. It indicates that at normal conditions only wurtzite structure is stable.

Table 2. The phase transition pressure from wurtzite to rock salt at room temperature

Ref.	Sample[a]	Method[b]	Phase transition Pressure (Kbar) Loading(W→R[c]) p_i	p_e	p_t	Unloading (R→W/Z)	Hysteresis	Volume change (%)
[1][2]	S1,S2	C2	27.5	40	-	10	-	-
[3]	S1,S2	C4	20	30	-	-	-	-
[6]	-	C1	-	-	-	-	-	25
[7]	-	C1	18	35	-	-	-	29.6
[8][9]	S3	C1	25	-	-	-	-	21
[10]	S2	C3	20	-	28	11	5	10
[14]	S1,S2	C3	23	35-37	-	-	12	21
	S1,S2	C4	23	31	-	-	12	-
[15]	S1	C3	23.4	-	17.5	11.4	-	16
[17]	S1	C5 c-axis	-	-	31.5	-	-	17
	S1	C5 a-axis	-	-	28	-	-	18
[19]	S1	C4	22.5	42	-	-	12	-
[24]	S3	C4	28.5-31.5	-	-	-	-	-
[27]	S1	C4	23.1	-	-	-	12-15	-
[29]	S3	C5,C4	24	-	-	-	-	-
[33]	S3	C1	21-28	-	-	-	-	18.7
[36]	S1	C2	27	-	-	-	15	-

[a]S1=single crystal, S2=polycrystalline, S3=powder.

[b]C1=X-ray, C2=optical absorption, C3=volume, C4=electric resistance, C5=shock.

$^{c}p_i$, p_e and p_t are initial, ending and nominal transition pressures respectively.

D. Compressibility and elastic constants

The volume changes with phase transition are listed in Table 2. Several researchers studied the compressibilities at both low-pressure and high-pressure phases. Samara and Giardini[14] obtained the P-V curve at room temperature, which is shown in Fig. 6. The bulk modulus are:

$$\begin{aligned} &W-phase\ (0-23\ Kbar) \quad K = 18.3\times10^{-4}Kbar^{-1} \\ &R-phase\ (40-60\ Kbar) \quad K = 9.5\times10^{-4}Kbar^{-1} \end{aligned} \tag{1}$$

It is very close to the data of Ref. [7]:

$$\begin{aligned} &W-phase\ (0-27\ Kbar) \quad K = 15.3\times10^{-4}Kbar^{-1} \\ &R-phase\ (20-90\ Kbar) \quad K = 9.2\times10^{-4}Kbar^{-1} \end{aligned} \tag{2}$$

Corll[21](1967) obtained the elastic constants of CdS using ultrasonic method. They are

$$\begin{aligned} C_{33} &= 0.9361 \quad C_{11} = 0.8565 \\ C_{13} &= 0.4614 \quad C_{44} = 0.1487 \\ C_{66} &= 0.1622 \end{aligned} \tag{3}$$

Fuller[26](1973) determeined the complete set of the second and the third-order elastic constants of wurtzite CdS using ultrasonic technique under pressure. The second constants are:

$$\begin{aligned} C_{11}^S &= 0.8578 \quad C_{12}^S = 0.5335 \quad C_{44}^S = 0.14859 \\ C_{33}^S &= 0.9362 \quad C_{13}^S = 0.4614 \quad C_{66}^S = 0.16212 \end{aligned} \tag{4}$$

where C_{13}^S is picked up from Corll's data[21], since Fuller did not measure C_{13}^S and the other constants measured by Corll are very close to Fuller's. The third order isentropic constants are listed as following:

$$
\begin{aligned}
C^S_{333} &= -3.27 \qquad C^S_{111} = -4.59 \\
C^S_{133} &= -3.06 \qquad C^S_{222} = -3.55 \\
C^S_{144} &= -0.271 \qquad C^S_{112} = -2.07 \\
C^S_{155} &= 0.093 \qquad C^S_{113} = -1.82 \\
C^S_{344} &= -0.692 \qquad C^S_{123} = -2.35
\end{aligned} \tag{5}
$$

The unit in Eqs. (4) and (5) is Mbar.

E. Electric resistance, optical properties and color change

The results of electric resistance, optical properties of CdS are listed in Table 2, also shown in Figs. 2 and 1. There exist the color changes accompanied with the phase transition. Samara and Giardini[14] directly observed the color change under pressure using an flake sample and pointed out that it was bright yellow for wurtzite phase, brown for the mixture of wurtzite and rock salt, deep red for rock salt and bright orange for zincblende. Corll[12], Osugi et al[19] reported the rock salt pellets were almost black with submetallic luster. The reason of different color reported of rock salt phase above probably is that the thickness of sample Samara et al used is much thinner than that others used.

F. Magnetic anomaly and other properties

Homan and MacCrone et al[30][31][32][34] reported that CdS samples with so-called "pressure quenching" treatment at 77^oK exhibited the anomalous diamagnetism which might be related to superconductivity at high temperature. If it is the case, it is a remarkable discovery. So it attracts many physicists' attention[41]-[44] in recent years.

Other properties such as luminescence and raman spectra[38], impurity etc., are also studied.

3. PHASE TRANSITION UNDER SHOCK CONDITIONS

The study of phase transition induced by shock waves is important for learning about the behavior and mechanism of phase transition of solids. But up to now the work of CdS in this field is quite few and only three papers are found.

Kennedy and Benedick[17](1966) observed the two-wave structures both along c-axis and a-axis of single crystal CdS samples using plane explosive lense technique and quartz gauges(Fig. 7). The volume change calculated from the records are 17% and 18% along c-axis and a-axis respectively, which are colse to that obtained in static experiments. It has shown evidently that the phase transition from wurtzite to rock salt can occur and complete within 1 μs.

Berlinsky and Rosenberg[29](1979) studied the shock response of porous CdS using a powder gun and manganian gauges and obtained the Hugoniot data which can be approximately in 20-50 Kbar range by the linear relation

$$p = 85u_p - 7 \tag{6}$$

where p is pressure in Kbar and u_p the particle velocity in $mm/\mu s$. From the electric resistance records measured during the experiments, it appears that a sudden drop starts near 24 Kbar. Dodson and Venturini[35] reported that no residual structure change were detected via X-ray diffraction in the CdS powder sample recovered from shock loading, but large densities of defects were found using ESR technique. The axial defect seems to be connected with the wurtzite to rock salt transition in CdS.

4. DISCUSSION AND CONCLUSIONS

From the review above we can get several conclusions as follows:

(1). Crystal CdS has a phase transition from wortzite structure to rock salt structure accompanied with volume, electric resistance, and other physical property abrupt change at pressure about 23 Kbar

with about 10 Kbar hysteresis.

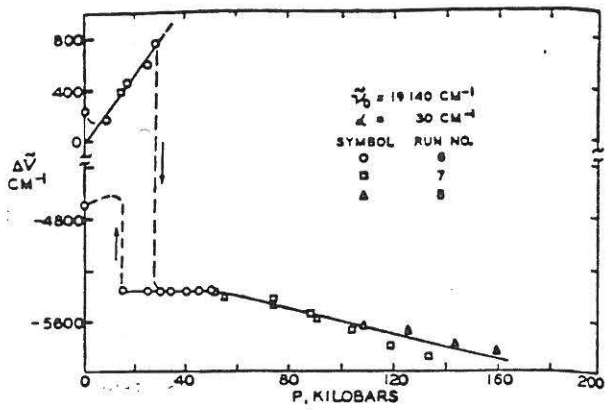
(2). The mechanism of this phase transition is not diffusion type since it can complete within 1 μs according to the shock experiments. Other mechanisms should be considered.

(3). A great deal work has been done in static area. The present studies are concentrated in the new physical properties such as potential superconductivity. But we suggest that new phase transition and new triples at P-T diagram under higher pressure and temperature conditions should be studied further and the theory about the phase transition of CdS should be developed.

(4). The studies of the dynamic response of CdS (including the dynamic phase transition , dynamic behaviors of both low and high pressure phases) are quite few. So the Hugoniot of CdS and the dynamic phase transition should be studied further. Because of the high strength of CdS, studying the effect of shear effect on the phase transition is important as proposed by Duvall and Graham[28](1977). By comparing the dynamic and static results, the mechanism of phase transition of CdS might be understood further.

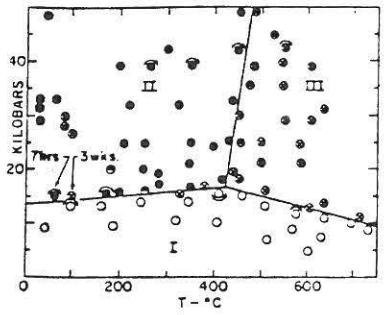
(5). CdS probably is the most well-studied in the II-VI compounds. There are common and different physical and chemical properties among them. Investigating the transition behaviors of other II-VI compounds is valuable to know the relation among the phase transition, micro-structure and element components.

Figures 1-4:



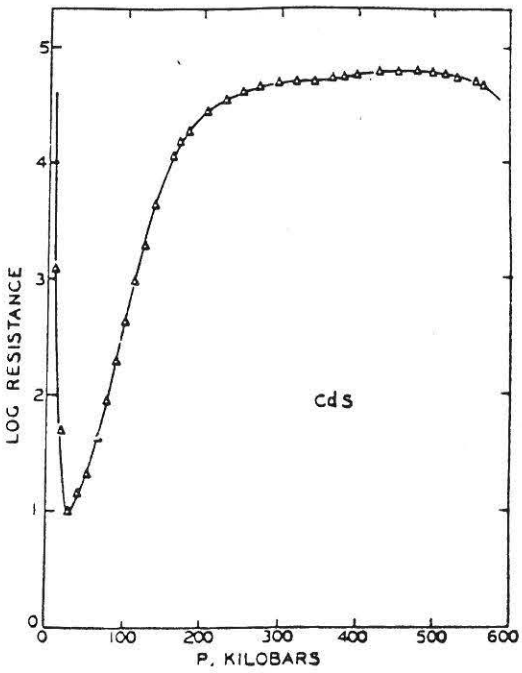
Shift of CdS absorption edge with pressure.

Fig. 1. From Ref. [2].



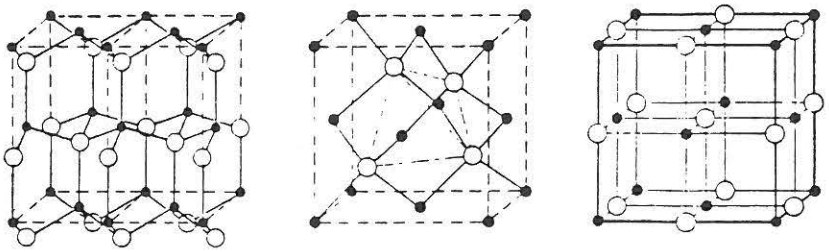
Pressure–temperature equilibrium diagram of the system CdS. Open circles, CdS-I or wurtzite; filled circles, CdS-II or rocksalt structure; sectored circles, quenched to CdS-I'' (see text); double arrow arces indicate oscillating shear type runs. The CdS-II was obtained from runs at pressures as high as 70 kbar. Note that *all* the partially filled circles on the I–II boundary indicate that both CdS-I and II were present.

Fig. 3. From Ref. [16].



Resistance vs. pressure—CdS.

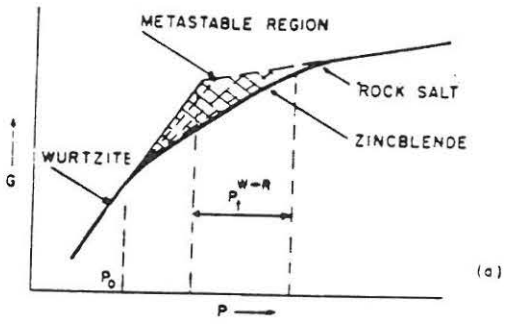
Fig. 2. From Ref. [3].



The arrangement of Cd atoms and S atoms in the wurtzite, zinc blende and rock salt forms of CdS (left to right) ●: Cd ○: S

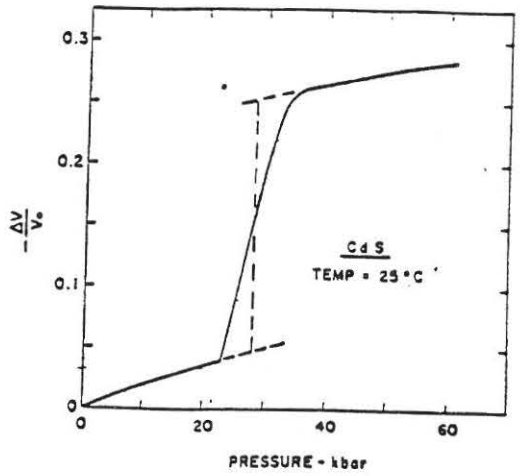
Fig. 4. From Ref. [19].

Figures 5-7:



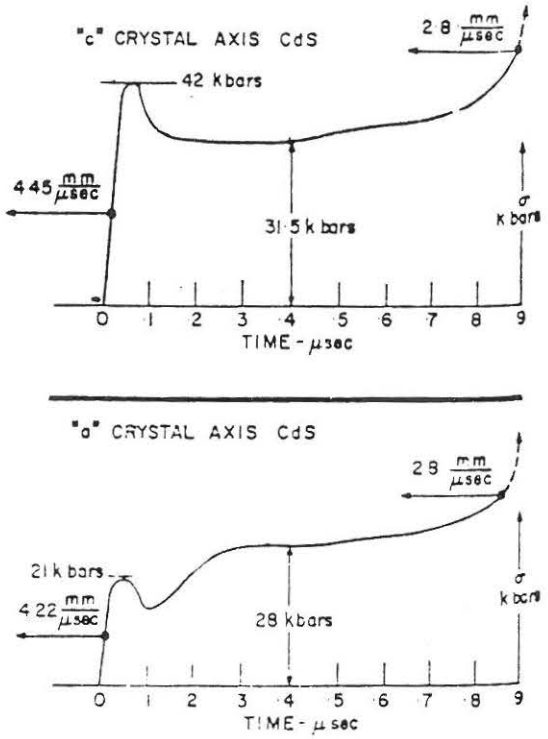
Schematic Representation of Free Energy as a Function of Pressure for CdS, CdSe and CdTe (R = rock salt; W = wurtzite; Z = zincblende)

Fig. 5. From Ref. [24].



Compression curve of CdS at 25°C.

Fig. 6. From Ref. [14].



Stress vs. time profiles for *c*-axis and *a*-axis CdS crystals.

Fig. 7. From Ref. [17].

REFERENCES

[1] A.L. Edwards, T.E. Slykhouse and H.G. Drickamer, The effect of pressure on zinc blende and wurtzite structures, J. Phys. Chem. Solids, 11, 140-148, (1959).

[2] A.L. Edwards and H.G. Drickamer, Effect of pressure on the absorption edges of some III-V, II-VI, and I-VII compounds, Physical Rev., 122(4), 1149-1157, (1961).

[3] G.A. Samara and H.G. Drickamer, Pressure induced phase transitions in some II-VI compounds, J. Phys. Chem. Solids, 23, 457-461, (1962).

[4] S. Minomura, G.A. Samara and H.G. Drickamer, Temperature coefficient of resistance of the high pressure phases of Si, Ge, and some III-V and II-VI compounds, J. Appl. Phys., 33(11), 3196-3197, (1962).

[5] C.J.M. Rooymans, A phase transformation in the wurtzite and zinc blende lattice under pressure, J. Inorg. Nucl. Chem., 25, 253-255, (1963).

[6] C.J.M. Rooymans, Structure of the high pressure phase of CdS, CdSe and InSb, Phys. Letters, 4(3), 186-187, (1963).

[7] S.S. Kabalkina and Z.V. Troiskaya, A study of the structure of cadmium sulfide at high pressure up to 90 kilobars, Soviet Phys. Dok., 8(8), 800-802, (1964).

Note: This paper originally published at Doklady Akademii Nauk SSSR, 151(5), 1068-1070, (1963).

[8] P.L. Smith and J.E. Martin, The high-pressure structures of cadmium sulphide and cadmium telluride, Phys. Letters, 6(1), 42, (1963).

[9] N.B. Owen, P.L. Smith, J.E. Martin and A.J. Wright, X-ray diffraction at ultra-high pressures, J. Phys. Chem. Solids, 24, 1519-1524, (1963).

[10] A. Jayaraman, W. Klement, Jr. and G.C. Kennedy, Melting and Polymorphic transitions for some group II-VI compounds at high pressures, Physical Rev., 130(6), 2277-2283, (1963).

[11] A.N. Mariano and E.P. Warekois, High pressure phases of some compounds of groups II-VI, Science, 142, 672-673, (1963).

[12] J. Corll, Recovery of the high pressure phase of cadimium sulfide, J. Appl. Phys., 35(10), 3032-3033, (1964).

[13] C.J.M. Rooymans, Recent solid-state studies under high-pressure high-temperature conditions, Ber. Deut. Keram. Ges., 41(2), 52-59, (1964).

[14] G.A. Samara and A.A. Giardini, Compressibility and Electrical Conductivity of cadmium sulfide at high pressures, Physical Review, 140(1A), 388-395, (1965).

[15] C.F. Cline and D.R. Stephens, Volume compressibility of BeO and other II-VI compounds, J. Appl. Phys., 36(9), 2869-2873, (1965).

[16] R.O. Miller, F. Dachille, and R. Roy, High pressure phase-equilibrium studies of CdS and MnS by static and dynamic methods, J. Appl. Phys., 37(13), 4913-4918, (1966).

[17] J.D. Kennedy and W.B. Benedick, Shock induced phase transition in single crystal CdS, J. Phys. Chem. Solids, 27, 125-127, (1966).

[18] G.K. Lewis, E.A. Perez-Albuerne and H.G. Drickamer, Effect of very high pressure on the compressibilities of NH4Cl, TlCl, CdO, and CdS, J. Chemical phys., 45(2), 598-600, (1966).

[19] J. Osugi, K. Shimizu, T. Nakamura and A. Onodera, High pressure trasition in cadmium sulfide, Rev. Physical Chem. of Japan, 36(2), 59-73, (1966).

[20] J. Osugi, K. Shimizu, T. Nakamura and A. Onodera, Electrical conductivity of cadmium sulfide under high pressure and high temperature, Rev. Physical Chem. of Japan, 36(2), 74-80, (1966).

[21] J.A. Corll, Effect of pressure on elastic parameters and structure of CdS, Physical Review, 157(3), (1967).

[22] K.A. Gale and B.A. Kulp, Recovery of rocksalt atructure CdS to room pressure, J. Phys. Chem. Solids, 28, 1233-1235, (1967).

[23] C.J.M. Rooymans, The behaviour of some groups of chalcogenides under very- high-pressure conditions, in "Advances in High Pressure Research", vol.2, Edited by R.S. Bradly, 1-100, Academic Press, London, (1969).

[24] W.C. Yu and P.J. Gielisse, High pressure polymorphism in CdS, CdSe and CdTe, Mat. Res. Bull., 6, 621-638, (1971).

[25] E.Z. Kaminskii, A.V. Omel'chenko and E.I. Estrin, Phase transition in CdS at high pressures, Soviet Phys.-Solid State, 12(11), 2697-2698, (1971).

[26] E.R. Fuller, The study of covalent bonding by means of elastic constants, Ph.D. Thesis, University of Illinois, (1973).

Note: The abstract of this thesis is in "Dissertation Abstracts International B The Science and Engineering", 34(1), 364-B, (July 1973).

[27] R.T. Johnson, Jr., and B. Morosin, High pressure effects on electrical resistivity and structure of single crystal cadimium sulfide, High Temperatures-High Pressures, 8, 31-44, (1976).

[28] G.E. Duvall and R.A. Graham, Phase transition under shock-wave loading, Review of Modern Physics, 49(3), 523-579, (1977).

[29] Berlinsky, Y. and Rosenberg, Z., Dynamic phase transition in porous CdS at high pressures, J. Phys. D: Appl. Phys., 11(18), 2535-2540, (1978).

[30] C.G. Homan and D.P. Kendall, Electron-hole transport in semiconductors, Bull. of Am. Phys. Sociaty, 24, 316, (1979).

[31] C.G. Homan, D.P. Kendall and R.K. MacCrone, Magnetic moment of pressure quenched cadmium sulfide, Solid State Communications, 32, 521-524, (1979).

[32] R.K.MacCrone and C.G. Haman, Paramagnetic properties in pressure quenched CdS, Solid State Comm., 35, 615-618, (1980).

[33] Z.V. Malyushitskaya and S.S. Kabalkina, Polymorphism of CdS at pressure up to 8.0 GPa and

temperature up to 773 K, Sov. Phys. Solid State, 22(3), 518-520, (1980).

[34] E. Brown, C.G. Homan and R.K. MacCrone, Flux exclusion in CdS at 77k: superconductivity at high temperature?, Phys. Review Letters, 45, 478-481, (1980).

[35] B.W. Dodson and E.L. Venturini, Shock-induced deffects in cadmium sulfide, in "Shock Waves in Condensed Matter-1981(Menlo Park)", Edited by W.J. Nellis, L. Seaman and R.A. Graham, American Institute of Physics, New York, 335-339, (1982).

[36] B. Batlogg, A. Jayaraman, J.E. Van Cleve and R.G. Maines, Optical absorption, resistivity, and phase transformation in CdS at high pressure, Phys. Rev. B, 27(6), 3920-3923, (1983).

[37] T. Suzuki, T. Yagi, S. Akimoto, T. Kawamura, S. Toyoda and S. Endo, Compression behavior of CdS and BP up to 68 GPa, J. Appl. Phys., 54(2), 748-751, (1983).

[38] U. Venkateswaren, K. Chandrasekhar and H.R. Chandrasekhar, Luminescence and raman spectra of CdS under hydrostatic pressure, Phys. Review B, 30, 3316-3319, (1984).

[39] P.J. Cote, G.P. Capsimalis and W.C. Moffatt, Thermal and X-ray analisis of pressurized CdS containing chlorine impurities, Mat. Res. Soc. Symp. Proc., vol. 22, Part I, 219-222, Elsevier Science Publishing Co., Inc., (1984).

[40] M. Chandrasekhar and T.C. Collins, Spin dependence of possible excitonic superconducting states in CdS, Mat. Res. Soc. Symp. Proc., vol. 22, Part I, 223-226, Elsevier Science Publishing Co., Inc., (1984).

[41] M.W. Ribarsky, Local field effects on exciton coupling in CuCl and CdS under pressure, Mat. Res. Soc. Symp. Proc., vol. 22, Part I, 227-230, Elsevier Science Publishing Co., Inc., (1984).

[42] S.B. Nam, Y. Chung and D.C. Reynolds, Evidence for superconductivity in pressure quenched CdS, Mat. Res. Soc. Symp. Proc., vol. 22, Part I, 231 -233, Elsevier Science Publishing Co., Inc., (1984).

[43] S.B. Nam, T.I. Mah, R. Crane, Y. Chung and D.C. Reynolds, Possible superlattice in high pres-

sure quenched CdS, Mat. Res. Soc. Symp. Proc., vol. 22, Part I, 235-238, Elsevier Science Publishing Co., Inc., (1984).

[44] C.G. Homan and R.K. MacCrone, A nomalous properties of pressure quenched CdS, Mat. Res. Soc. Symp. Proc., vol. 22, Part I, 187-197, Elsevier Science Publishing Co., Inc., (1984).

INTERNAL REPORTS - 1987

1. J.B. Aidun, "Analysis of Tilt in Plate-Impact Experiments", Internal Report 87-01, April, 1987.

2. M. Williams and Y.M. Gupta, "Impact Experiments to Determine the Feasibility of Using Dow Corning Pyroceram 9606 as a Ramp Wave Generator", Internal Report 87-02, August, 1987.

3. P.D. Horn, "Measurements of the Ruby Luminescence Spectrum to 125 Kbar at Room Temperature", Internal Report 87-03, November, 1987.

4. C.S. Yoo, "Electronic Transitions in Carbon Disulfide", Internal Report 87-04, October, 1987.

5. R. Gustavsen, "Temperature Measurements in Shocked Liquids", Internal Report 87-05, May, 1987.