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ULTRASONIC PHONONS IN Hg$_{0.8}$Mn$_{0.2}$Te: DEPENDENCES OF ELASTIC MODULI ON PRESSURE AND TEMPERATURE

M.H. Chao and R.J. Sladek

Department of Physics, Purdue University, West Lafayette, Indiana 47907, U.S.A.

Abstract. - Ultrasonic transit times have been measured for Hg$_{0.8}$Mn$_{0.2}$Te, a semimagnetic semiconductor, as a function of pressure up to 4 kbar at 296 K and of temperature from 1.5 to 296 K. They are used to deduce the second order elastic stiffness constants SOEC and also force constants and third order elastic constants at 296 K. The shear modulus $C_S = (C_{11} - C_{12})/2$ is decreased by pressure implying a structural transformation at 10 kbar. No elastic effects attributable to the magnetic moments of the Mn ions are observed even at low temperatures.

Hg$_{1-x}$Mn$_x$Te crystals with $x \leq 0.35$ have the cubic zinc-blende structure. The magnetic susceptibility, $x$, and heat capacity of Hg$_{1-x}$Mn$_x$Te exhibit effects at low temperatures which depend on the magnetic moments of the Mn ions. Since the elastic properties of Hg$_{1-x}$Mn$_x$Te are unknown for $x > 0$, we have begun studying them in crystals with different concentrations of Mn and report herein the elastic behavior of semiconducting Hg$_{0.8}$Mn$_{0.2}$Te.

The transit times of 30 MHz longitudinal and transverse ultrasonic waves propagating along the [110] direction were measured as a function of hydrostatic pressure up to 4 kbar at 296 K and of temperature from 1.5 to 296 K at 1 bar.

We obtain values of $C_{11}$, $C_{12}$, $C_{44}$ and $C_S = (C_{11} - C_{12})/2$ for Hg$_{0.8}$Mn$_{0.2}$Te within 8% of those for HgTe. All elastic stiffness moduli of Hg$_{0.8}$Mn$_{0.2}$Te have linear dependences on pressure. As can be seen from Table I, the shear moduli $C_S$ and $C_{44}$ decrease, while $C_{11}$ and $C_{12}$ increase with increasing pressure. For Hg$_{0.8}$Mn$_{0.2}$Te the pressure derivatives of $C_{11}$, $C_{12}$, and $C_S$ are within 9% of those for HgTe. However, $dC_{44}/dp$ is much smaller in Hg$_{0.8}$Mn$_{0.2}$Te than in HgTe in which it equals -0.12. Our results, along with the fact that HgTe transforms to the cinnabar structure at 14 kbar, implies that Hg$_{0.8}$Mn$_{0.2}$Te will have a similar transformation at somewhat lower pressure which we estimate to be 10 kbar by assuming it occurs when $C_S/B$ reaches 0.17 as in HgTe. ($B$ is the bulk modulus $(C_{11} + 2C_{12})/3$.) Elastic gammas calculated from our data using the relation $\gamma_{ij} = \frac{1}{2} B T \ln C_{ij}/\delta P - 1/6$ are listed in Table I also. The negative shear mode gammas imply that the thermal expansion coefficient of Hg$_{0.8}$Mn$_{0.2}$Te will be negative at low temperatures as is the case for HgTe.

Using equations from the literature, which we corrected for some errors, and our data we deduced the force constants and third order elastic stiffness constants.
Table I. Values and pressure derivatives of elastic stiffness moduli and the anharmonicity parameters (elastic gammas) of Hg$_{0.8}$Mn$_{0.2}$Te at 296 K.

| $C_{ij} (10^{11} \text{ dyn/cm}^2)$ | $\partial C_{ij}/\partial P|_{P=1\text{ bar}}$ | $\Gamma_{ij}$ |
|---------------------------------|----------------------------------|----------------|
| $C_{11}$                        | 5.15                             | 3.51           |
| $C_{12}$                        | 3.55                             | 4.25           |
| $C_{44}$                        | 1.96                             | -0.29          |
| $(C_{11} - C_{12})/2$           | 0.80                             | -0.37          |

(TOEC) for our Hg$_{0.8}$Mn$_{0.2}$Te sample as shown in Table II -- $\alpha$ and $\gamma$ are bond-stretching while $\beta$ and $\delta$ are bond-bending constants, whereas $\epsilon$ is a mixed bond stretching-bending constant.

Table II. Harmonic force constants $\alpha$ and $\beta$ (in $10^4 \text{ dyn/cm}$), anharmonic force constants $\gamma$, $\delta$, and $\epsilon$, and third order elastic stiffness constants $C_{ijk}$ (in $10^{12} \text{ dyn/cm}^2$) of Hg$_{0.8}$Mn$_{0.2}$Te at 296 K.

<table>
<thead>
<tr>
<th>$\alpha$</th>
<th>$\beta$</th>
<th>$\gamma$</th>
<th>$\delta$</th>
<th>$\epsilon$</th>
<th>$C_{111}$</th>
<th>$C_{112}$</th>
<th>$C_{123}$</th>
<th>$C_{144}$</th>
<th>$C_{166}$</th>
<th>$C_{456}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.687</td>
<td>0.247</td>
<td>-1.609</td>
<td>-0.205</td>
<td>-0.221</td>
<td>-3.32</td>
<td>-1.62</td>
<td>-1.46</td>
<td>-1.06</td>
<td>-0.106</td>
<td>-0.004</td>
</tr>
</tbody>
</table>

Our value of $\beta/\alpha$ for Hg$_{0.8}$Mn$_{0.2}$Te is equal to that found for HgTe$^3$ implying that both materials have the same Phillips ionicity (0.65) in view of Ref. 8. Our values of $\delta/\gamma$ and $\epsilon/\gamma$ for Hg$_{0.8}$Mn$_{0.2}$Te are consistent with how these ratios depend on $f_1$ for various III-V and II-VI compounds.$^7$ The SOEC, the force constants, and three of the TOEC are smaller in Hg$_{0.8}$Mn$_{0.2}$Te than in HgTe. This seems consistent with the lower transition pressure we have deduced for Hg$_{0.8}$Mn$_{0.2}$Te compared to HgTe.

The SOEC of Hg$_{0.8}$Mn$_{0.2}$Te increase smoothly in the usual manner as temperature is decreased from 296 K to 1.5 K. The overall temperature dependences of the SOEC are somewhat smaller than in HgTe. This may be due to the $\Gamma_{ij}$ and TOEC$^5$ having different values in the two materials. To look more closely for possible effects associated with the increase of magnetic susceptibility$^1$ at low temperatures we show in Fig. 1 data only for 100 K and below. From Fig. 1 there seems to be no evidence for effects which might be associated with the magnetic moments of the Mn ions. The absence of anomalies in the SOEC is consistent with there being no cusp in $\chi$ and no spin glass transition for $x = 0.20$ at low temperatures.$^1$

In summary, from our ultrasonic measurements on Hg$_{0.8}$Mn$_{0.2}$Te we conclude that its bonding is weaker and transition pressure smaller than in HgTe and that the SOEC are not affected appreciably by the magnetic moments of the Mn ions.
Fig. 1. Temperature dependences of normalized second order elastic constants. At 100 K, $C_{11} = 5.503$, $C_{12} = 3.845$, and $C_{44} = 2.027$, all in units of $10^{11}$ dyn/cm$^2$.

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References