



HAL
open science

ULTRASONIC ATTENUATION AND VELOCITY IN $\text{Cd}_{0.55}\text{Mn}_{0.45}\text{Te}$

P. Maheswaranathan, R. Sladek, U. Debska

► **To cite this version:**

P. Maheswaranathan, R. Sladek, U. Debska. ULTRASONIC ATTENUATION AND VELOCITY IN $\text{Cd}_{0.55}\text{Mn}_{0.45}\text{Te}$. Journal de Physique Colloques, 1985, 46 (C10), pp.C10-513-C10-516. 10.1051/jphyscol:198510113 . jpa-00225314

HAL Id: jpa-00225314

<https://hal.science/jpa-00225314>

Submitted on 4 Feb 2008

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

ULTRASONIC ATTENUATION AND VELOCITY IN $\text{Cd}_{0.55}\text{Mn}_{0.45}\text{Te}^+$

P. MAHESWARANATHAN, R.J. SLADEK AND U. DEBSKA

Purdue University, West Lafayette, IN 47907, U.S.A.

Abstract - We deduce the electromechanical coupling factor, piezoelectric constant (e_{14}), and electrical conductivity of $\text{Cd}_{0.55}\text{Mn}_{0.45}\text{Te}$ from the attenuation maximum and velocity change of piezoelectrically-active [110][001] ultrasonic shear waves which occur as a function of temperature, T . Electro-mechanical coupling and e_{14} are much larger in $\text{Cd}_{0.55}\text{Mn}_{0.45}\text{Te}$ than in CdTe due to less bond charge transfer in the former because, we believe, of hybridization of Mn 3d orbitals into the tetrahedral bonds. The dc resistivity was measured and found to be an exponential function of $1/T$ in accord with the electrical conductivity deduced from our ultrasonic data. The conductivity activation energy we identify with the ionization energy of centers which provide mobile charge carriers (holes).

I - INTRODUCTION

The diluted magnetic semiconductor $\text{Cd}_{1-x}\text{Mn}_x\text{Te}$ has been the subject of extensive studies /1/ because of its important semiconducting, optical and magneto-optic properties and the growth of CdTe - CdMnTe superlattices by molecular beam epitaxy /2/. Ultrasonic velocity measurements on $\text{Cd}_{1-x}\text{Mn}_x\text{Te}$ have been made down to low temperatures /3/ and as a function of hydrostatic pressure /4/ in this laboratory. In addition recent ultrasonic attenuation and velocity studies on $\text{Cd}_{1-x}\text{Mn}_x\text{Te}$ by us /5/ have revealed a maximum in the attenuation and a concomitant change in velocity as a function of temperature for piezoelectrically active ultrasonic waves because of drastic temperature dependence of the electrical conductivity.

In this paper we present 10 MHz fast shear wave velocity data not reported previously and dc resistivity data for comparison with the electrical conductivity deduced from our ultrasonic results. We analyze these velocity data and our previously obtained /5/ 30 MHz attenuation data to obtain a value for the electro-mechanical coupling factor and suggest an interpretation of the latter. The defect/impurity ionization energy deduced from our ultrasonic and dc resistivity results are reported and discussed.

II - EXPERIMENTAL DETAILS

The ultrasonic sample and the experimental details for our ultrasonic attenuation and velocity measurement have been described in ref. 5. A rectangular parallelepiped of $Cd_{0.55}Mn_{0.45}Te$ was prepared from the ultrasonic sample and its dc resistivity was measured by means of a standard four-probe technique.

III - RESULTS AND DISCUSSION

The attenuation of 30 MHz piezoelectrically active ultrasonic waves as a function of inverse temperature is shown in Fig. 1 for our $Cd_{0.55}Mn_{0.45}Te$ sample. Use of $1/T$ as the abscissa allows one to note that after the background attenuation is subtracted the peak is symmetric as would be expected for a thermally activated relaxation process. As will become evident the peak depends on the relaxation of the electrical conductivity and the availability of mobile charge carriers (holes) to respond to the piezoelectric field associated with the ultrasonic strain.

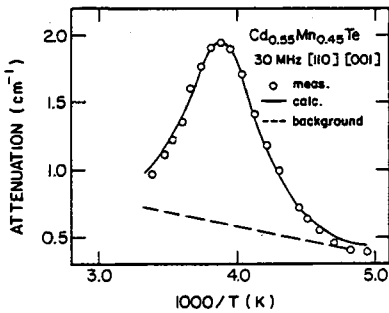


Fig. 1 - Attenuation of 30 MHz [110] [001] waves in $Cd_{0.55}Mn_{0.45}Te$ versus inverse temperature. The solid curve was calculated using the background attenuation given by the dashed line.

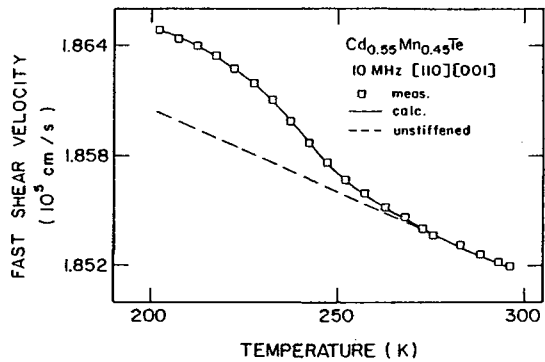


Fig. 2 - Fast shear velocity of 10 MHz [110][001] waves in $Cd_{0.55}Mn_{0.45}Te$ versus temperature. The solid curve was calculated using unstiffened values given by the dashed line.

In order to analyze the attenuation maximum and velocity changes (shown in Fig. 2) we use the theory of Hutson and White /6/ for elastic wave propagation in piezoelectric semiconductors. When there are negligible carrier diffusion and small conductivity modulation as are true in our case, the piezoelectric attenuation α_{pz} and the velocity of shear waves propagating in the [110] crystallographic direction and polarized in the [001] direction are given by /6/

$$\alpha_{pz} = \frac{e_{14}^2}{2\epsilon C_{44}} \frac{\omega}{v_0} \left[\frac{\omega_c/\omega}{1 + (\omega_c/\omega)^2} \right] \tag{1}$$

$$v = v_0 \left[1 + \frac{e_{14}^2/2\epsilon C_{44}}{1 + (\omega_c/\omega)^2} \right] \tag{2}$$

where $e_{14}^2/\epsilon C_{44}$ is the electromechanical coupling factor, ω is 2π times the ultrasonic frequency, $v_0 = (C_{44}/\rho)^{1/2}$ is the ultrasonic velocity in the absence of piezoelectric fields and $\omega_c = \sigma/\epsilon$, where σ is the electrical conductivity, and ϵ is the dielectric permittivity. The background attenuation in Fig. 1 is obtained from the attenuation measured near 200 K where piezoelectric attenuation is not present and from the slope of the background attenuation /5/ of 30 MHz ultrasonic waves in $Cd_{0.48}Mn_{0.52}Te$. From the maximum value of the experimental piezoelectric attenuation

and eq.(1) with $\omega = \omega_C$, we deduce that the electromechanical coupling factor $e_{14}^2/\epsilon C_{44}$ has a value of 0.0049 ± 0.0005 for our $Cd_{0.55}Mn_{0.45}Te$ sample.

Fig. 2 shows the velocity of 10 MHz ultrasonic fast shear waves as a function of temperature for $Cd_{0.55}Mn_{0.45}Te$. It can be seen that there is an extra increase in velocity with decreasing temperature below 250 K. This is due to the presence of piezoelectric fields which are not screened out by the charge carriers. The stiffened and unstiffened values of the fast shear velocity shown in Fig. 2 and eq. (2) gives $e_{14}^2/\epsilon C_{44} = 0.0047 \pm 0.0005$. This value is within experimental error of that obtained from the 30 MHz attenuation results shown in Fig. 1 (see Table 1). The unstiffened values in Fig. 2 are obtained from a linear extrapolation of the fast shear velocity above 270 K.

Table I - Values of $e_{14}^2/\epsilon C_{44}$ deduced for $Cd_{0.55}Mn_{0.45}Te$ from $[110][001]$ ultrasonic waves.

$e_{14}^2/\epsilon C_{44}$	Frequency	Method
0.0049 ± 0.0005	30 MHz	attenuation
0.0047 ± 0.0005	10 MHz	velocity
0.0042 ± 0.0004	30 MHz	velocity
0.0037 ± 0.0004	10 MHz	attenuation

^afrom ref. 5.

From Table I it can be seen that the values of the electromechanical coupling factor deduced from various ultrasonic data are within experimental error except for the 10 MHz attenuation value being somewhat less than the others. The reason for the latter is not known at present. In any case the electromechanical coupling factors shown in Table I for $Cd_{0.55}Mn_{0.45}Te$ are much larger than that of CdTe which has a value of 0.0007 [ref. 5] or 0.0005 [ref. 7]. The enhanced electromechanical coupling in $Cd_{0.55}Mn_{0.45}Te$ is due to e_{14} being larger since ϵ [ref. 8]

has nearly the same value in it as in CdTe. The larger value of e_{14} can be understood as follows. According to Martin /9/

$$e_{14} = e_{T}^* \zeta / a^2 - e \Delta Q / a^2 \quad (3)$$

where a is the lattice parameter, e_{T}^* is the transverse macroscopic (Born) effective charge, ζ is the internal strain parameter, e is the electronic charge, and ΔQ is the quadrupolar bond charge transfer. Now the ionic internal strain component $e_{T}^* \zeta / a^2$ is only about 1.5% smaller in $Cd_{0.5}Mn_{0.5}Te$ than in CdTe [ref. 5] so that e_{14} enhancement must be due to Mn reducing the bond charge transfer term by about 10%. We suggest that the influence of Mn on the bond charge transfer term is due to Mn 3d electrons hybridizing with sp^3 bonding orbitals /5/.

To obtain the calculated curves shown in Figures 1 and 2 we used Equations (1) and (2) with $\omega_C = \omega_C(0) \exp(-E_a/kT)$ obtained from the 10 MHz, attenuation versus temperature results /5/ and the electromechanical coupling factor deduced already. As can be seen from Figures 1 and 2 we obtain very good fits to our experimental results. This indicates that the electrical conductivity must be an exponential function of temperature characterized by a single activation energy of 0.36 eV.

The dc resistivity is shown as a function of inverse temperature in Fig. 3. Also shown in Fig. 3 is the calculated resistivity using our 10 MHz attenuation versus temperature results /5/. The agreement is very good at all temperatures except perhaps at temperatures which are well above that of the peak attenuation.

The 0.36 eV conductivity activation energy of our $Cd_{0.55}Mn_{0.45}Te$, which is p-type, is similar to that observed in $Cd_{1-x}Mn_xTe$ /10/ ($0.05 \leq x \leq 0.20$) which had been subjected to annealing in the presence of Cd, Au, or Cu. Such values have been attributed to complexes containing residual chemical impurities and lattice defects.

IV - CONCLUSION

Investigation of the attenuation and velocity of piezoelectrically active ultrasonic waves in $Cd_{0.55}Mn_{0.45}Te$ has revealed an attenuation maximum and a velocity change

associated with thermally activated electrical conductivity which indicates stronger electromechanical coupling in $\text{Cd}_{0.55}\text{Mn}_{0.45}\text{Te}$ than in CdTe . The enhanced electromechanical coupling is due to a smaller strain-induced transfer of bond charge, caused by the hybridization of Mn 3d states into the tetrahedral bonding orbitals. The conductivity activation energy, which gives the defect ionization energy, is similar to that observed by others in $\text{Cd}_{1-x}\text{Mn}_x\text{Te}$ with various values of x .

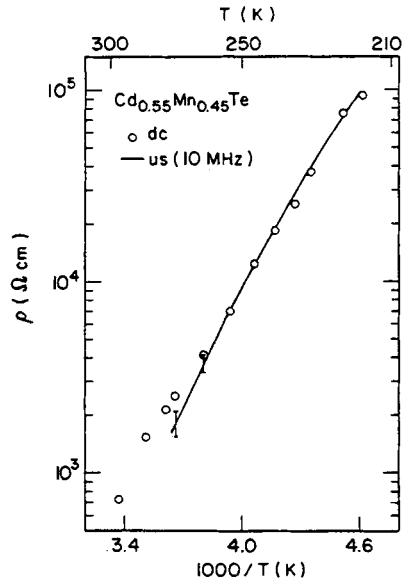


Fig. 3 - ρ , the dc resistivity of $\text{Cd}_{0.55}\text{Mn}_{0.45}\text{Te}$ versus inverse temperature. The solid curve shows the resistivity calculated using 10 MHz ultrasonic results. The \circ symbols indicate experimental error.

REFERENCES

* Supported by NSF-MRL Grant DMR80-20249, Purdue Research Foundation and NSF Grant DMR79-08538A3 at various times.

- /1/ See for example, Furdyna, J. K., *J. Appl. Phys.* **53** (1982) 7637.
- /2/ Venugopalan, S., Kolodziejcki, L. A., Gunshor, R. L., and Ramdas, A. K., *Appl. Phys. Lett.* **45** (1984) 974 and Bicknell, R. N., Giles-Taylor, N. C., Blanks, D. K., and Schetzina, J. F., *Appl. Phys. Lett.* June 15, 1985.
- /3/ Wu, A. Y. and Sladek, R. J., *J. Phys. (Paris) Colloq.* **42**, (1981) C6-646.
- /4/ Maheswaranathan, P., Sladek, R. J., and Debska, U., *Phys. Rev.* **B31** (1985) 5212.
- /5/ Maheswaranathan, P., Sladek, R. J., and Debska, U., *Bull. Am. Phys. Soc.* **30**, (1985) 216 and *Phys. Rev. B*, June 15, 1985.
- /6/ Hutson, A. R. and White, D. L., *J. Appl. Phys.* **33** (1962) 40.
- /7/ Berlincourt, D., Jaffe, H. and Shiozawa, L. R., *Phys. Rev.* **129** (1963) 1009.
- /8/ Peek, D., Guerra-Vela, C., and Sladek, R. J., *J. Appl. Phys.* **57** (1985) 4803.
- /9/ Martin, R. M., *Phys. Rev.* **B5** (1972) 1607.
- /10/ Stankiewicz, J. and Aray, A., *J. Appl. Phys.* **53** (1982) 3117.