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Elastic Moduli in Cadmium Selenide Doped with Chromium

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Abstract

Temperature dependence of elastic moduli $(C_{11}-C_{12})/2$, C_{33}, and C_{44}, the latter for the piezo-active and non-piezo-active versions, have been measured in the interval of 4 - 180 K at 28 - 262 MHz in a CdSe: Cr^{2+} crystal. Anomalies below 40 K have been found for all the moduli, except C_{33}. The interpretation of the results has been carried out involving the Jahn-Teller effect and relaxation between the equivalent distortions of the tetrahedral CrSe$_4$ centers.

Keywords

Piezo-Electric Crystal, Ultrasound, Elastic Moduli, Jahn-Teller Effect, Relaxation

1. Introduction

Our previous investigations of a number of crystals doped with $3d$ ions in orbital degenerate states revealed anomalies in the temperature dependence of attenuation and phase velocity of ultrasonic waves (see [1] [2] [3] [4] and references therein). The anomalies have the typical form of a relaxation process with a temperature dependent relaxation time τ, for which at the frequencies of the ultrasonic wave $\omega/2\pi$ = 30 - 300 MHz the parameter of frequency dispersion $\omega\tau(T_1)$ = 1. In all the experiments T_1 proved to be lower than 40 K. The peak of attenuation and a step-like variation of the velocity (or elastic modulus) have been observed in the vicinity of $T = T_1$, the latter actually indicating the point of transformation of the wave propagation from isothermal to adiabatic at lower temperatures. We suggest that the ultrasound relaxation attenuation occurs due to the independent Jahn-Teller (JT) centers formed buy the $3d$ ion and its nearest neighbors, while the relaxation takes place between the equivalent JT distortions.

The CdSe crystal under consideration in the present paper is a piezo-electric crystal (often used in devices). Hence, relaxation in this crystal can be observed also in the system of electric current carriers (electrons and holes). Low temperature peaks of attenuation observed at 10, 30 and 90 MHz in CdSe [5] were interpreted as due to such relaxations described by the modified Hutson and White model [6]. The authors justified such interpretation of the nature of these relaxations based on the fact that the anomalies were found only for piezo-active modes. Therefore, starting experiments on the CdSe: Cr^{2+} system, we expected to find two relaxation processes: one in the JT subsystem, subject to the $T_2 \otimes (e + t_2)$ problem, and another in the electric subsystem. These two subsystems are essentially independent, and their contributions to the complex elastic moduli are additive (the real part of them describes dispersion and imaginary one–dissipation). The aim of the present work is also to find out whether or not both of the relaxation mechanisms manifest themselves in an ultrasonic experiment carried out on high-quality CdSe: Cr^{2+} crystals.

2. Experiment

The sample of the CdSe crystal doped with Cr^{2+} ions was cut off a single crystal grown in P. N. Lebedev Physical Institute of the Russian Academy of Sciences. The seeded physical vapor transport method reported in [7] was used with CrSe source for doping. The concentration of the chromium impurities n_{Cr} was about 10^{18} cm^{-3}. Measurements were carried out with the help of setups operating as frequency variable bridge at Dresden High Magnetic Field Laboratory and at Ural Federal University. Ultrasonic waves were generated and registered by $LiNbO_3$ piezoelectric transducers at the frequencies of 28 - 262 MHz.We have carried out the experiments using the waves propagating along crystal axes described by the following moduli: $(C_{11} - C_{12})/2$, C_{33}, and C_{44} (the latter for piezo-active and non-piezo-active versions) (see **Table 1**). The choice of the moduli was done in view of possible manifestation of both the Jahn-Teller effect (JTE) subject to the expected in this case $T_2 \otimes (e + t_2)$ problem, and the relaxa-

Table 1. Elastic moduli studied and properties of corresponding waves.

Elastic modulus	Wave propagation axis	Direction of displacements	Polarization type (symmetry)	Piezo-activity
$(C_{11} - C_{12})/2$	[100]	[010]	shear (E)	non-piezo-active
C_{44}	[100]	[001]	shear (T)	piezo-active
C_{44}	[001]	⊥ [001]	shear (T)	non-piezo-active
C_{33}	[001]	[001]	longitudinal	piezo-active

tion in the electric subsystem. In other words, we studied (i) the moduli which should reveal anomalies due to the JTE without piezo-electricity (namely, $\left(C_{11}-C_{12}\right)/2$) and non-piezo-active version of C_{44}), (ii) the modulus which is piezo-active and, besides, should reveal the JT anomalies (piezo-active version of C_{44}), and (iii) the modulus C_{33}, which is piezo-active but should not be sensitive to the JTE.

3. Results

Anomalies of relaxation type (e.g., shown in **Figure 1**) have been observed in the moduli corresponding to distortions of trigonal (T-type, C_{44}, both versions: piezo-active and non-piezo-active) and tetragonal (E-type, $\left(C_{11}-C_{12}\right)/2$) symmetry, justifying their JT nature. Meanwhile, no anomalies were found in the C_{33} modulus, which is piezo-active, but does not correspond to any symmetry distortions of the $T_2\otimes(e+t_2)$ JT problem in the active centers of this crystal. **Figure 2** shows the temperature dependence of two piezo-active moduli: C_{44} and C_{33}. One can see that the relaxation type anomaly is observed only for the symmetry modulus of the $T_2\otimes(e+t_2)$ JT problem. This fact proves that the contribution of the electric subsystem to the elastic moduli is negligible (within the accuracy achieved in our experiments).Actually this result is in contradiction with the conclusions of Ref. [5]. The possible reason of this controversy maybe in the quality of our crystal: the method of its growth makes it possible to achieve lower conductivity.

4. Summary

The temperature dependence of the elastic moduli $\left(C_{11}-C_{12}\right)/2$, C_{33}, and

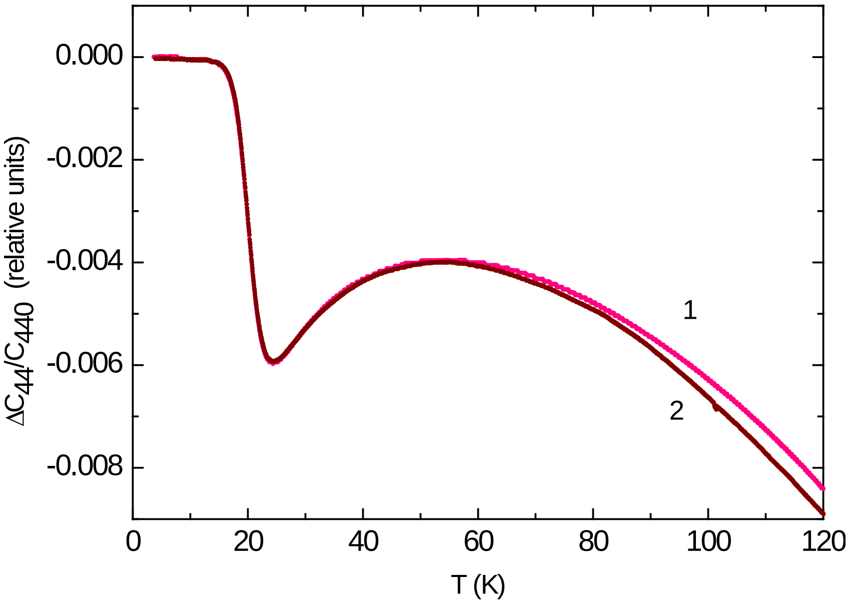

Figure 1. Temperature dependence of the non-piezo-active and piezo-active elastic moduli C_{44} (curves 1 and 2, respectively). $\Delta C_{44}=C_{44}\left(T\right)-C_{440}$, $C_{440}=C_{44}(4K)$. Frequency: 53 MHz.

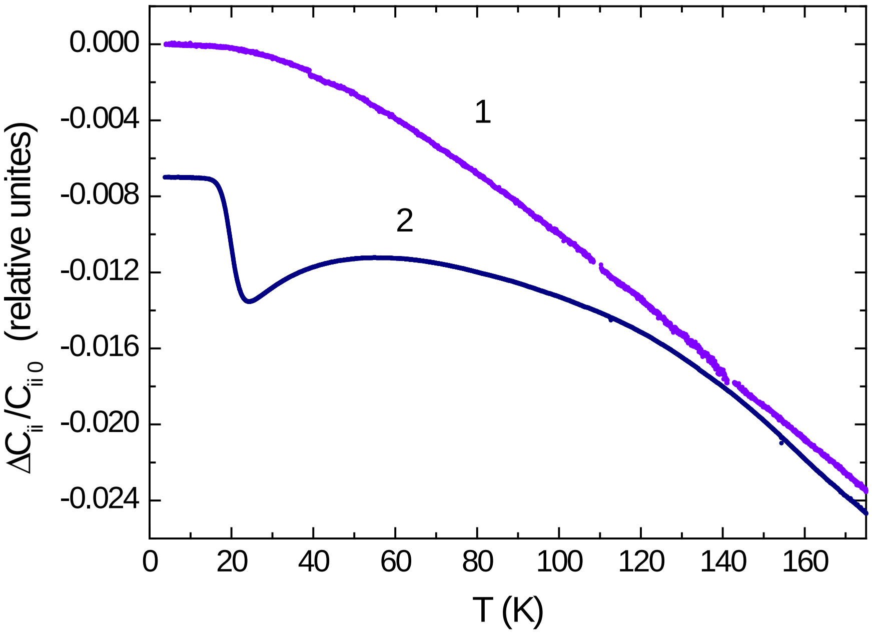

Figure 2. Temperature dependence of the piezo-active elastic moduli C_{33} (measured at 50 MHz) and C_{44} (53 MHz) (curves 1 and 2, respectively). $\Delta C_{ii} = C_{ii}(T) - C_{ii0}$, ii = 33 or 44, $C_{ii0} = C_{ii}(4K)$. Curve 2 is shifted for clarity.

C_{44} (the latter for piezo-active and non-piezo-active versions) have been measured in the interval of 4 - 180 K at 28 - 262 MHz in CdSe:Cr^{2+} crystals grown with the use of the seeded physical vapor transport method. Low temperature anomalies of relaxation origin have been found for all the moduli, congruent to distortions of the $CrSe_4$ centers due to the $T_2 \otimes (e + t_2)$ JT problem, but independent of their piezoelectric properties. No relaxation type anomalies has been found for the modulus C_{33}, which is not related to symmetry moduli, but it is a piezo-active mode. These facts prove that piezoelectricity does not contribute to the moduli within the accuracy of our experiments, and all the observed anomalies of relaxation origin in this system are due to the JTE.

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