Internal Friction and Photoacoustic Effects in A2B6 and A2B7(HgI2) Single Crystals at Different Levels of Ultrasound Strain Amplitude

B. Kardashev

► To cite this version:

B. Kardashev. Internal Friction and Photoacoustic Effects in A2B6 and A2B7(HgI2) Single Crystals at Different Levels of Ultrasound Strain Amplitude. Journal de Physique IV Proceedings, 1996, 06 (C8), pp.C8-871-C8-874. 10.1051/jp4:19968188 . jpa-00254625

HAL Id: jpa-00254625

<https://hal.science/jpa-00254625>

Submitted on 1 Jan 1996

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.

Internal Friction and Photoacoustic Effects in A_2B_6 and $A_2B_7(HgI_2)$ Single Crystals at Different Levels of Ultrasound Strain Amplitude

B.K. Kardashev

A.F. Ioffe Physico-Technical Institute of the Russian Academy of Sciences, St. Petersburg, 194021, Russia

Abstract. A comparison of effects in damping and Young modulus under the influence of illumination for ZnSe and HgI_2 demonstrates quite different mechanisms of photoacoustic interaction in the crystals: a drift of photocarriers in the electric field which arises due to piezoelectricity for the first case and a dislocation pinning mechanism for the second one. Spectral responses of the photoacoustic effect in both amplitude independent and dependent damping range are presented for mercury iodide crystals. The newly found acousto- and photo-optic effects in the luminescence spectrum of HgI_2 allow one to specify the photosensitive dislocation pinning centre as an exciton state of carriers on a stoichiometric point defect of the lattice (iodine or mercury vacancy or interstitial).

1. INTRODUCTION

Acoustic properties of wide-band-gap semiconductors are usually sensitive to illumination. A_2B_6 crystals reveal photo-acoustic effect (PAE) [1,2] in noticeable changes of damping due to photocarriers (electrons or/and holes) moving in the electric field which arises in piezoelectric materials in the stress field of the acoustic wave [3]. Photoacoustic properties of the non-piezoelectric tetragonal HgI_2 crystal (A_2B_7 family) are described [4,5] in the framework of a dislocation-pinning point interaction model. But it is known that dislocations in A_2B_6 are charged and their mobility may be influenced by photocarriers as well. This influence is revealed in photoplastic effect of the crystals [6].

This paper reports a comparative study of the photo-acoustic properties of ZnSe and HgI_2 crystals in a wide amplitude range so that amplitude dependent damping (ADD), which is clearly of dislocation nature, arises for both materials. One has to mention that photosensitivity of ADD in A_2B_6 was not checked experimentally up-to-now.

A further discussion of the nature of pinning point defects for dislocations in HgI_2 crystal is also presented. This analysis is based on the recent discovery of acousto-optic and photo-optic effects in the photoluminescence spectrum of mercury iodide crystals [7].

2. METHODS AND RESULTS

Nominally pure crystals of ZnSe and HgI_2 were used in this investigation. The ZnSe sample of $(23 \times 2.5 \times 2) \text{ mm}^3$ was cut from the crystal grown from the melt. One of the (111) slip planes was oriented at a 45° angle to the axis of the rod. Crystals of HgI_2 were grown from the vapour phase. The samples had dimensions about $(9 \times 5 \times 0.5) \text{ mm}^3$. The crystallographic orientation of the large faces was (001).

A composite oscillator, consisting of the sample and quartz crystal, was used for the acoustic measurements. The resonant frequencies of longitudinal vibrations were about 100 kHz. Amplitude and time dependencies were investigated. Time dependency measurements were carried out at low and high amplitude levels. So the data were obtained for both amplitude independent (AID) δ_i and amplitude dependent (ADD) δ_h damping (total decrement $\delta = \delta_i + \delta_h$, $\delta_h = 0$ at low amplitudes). It was possible to illuminate the sample with different wave length light at any moment during the time dependency measurement.

The luminescence spectra of HgI_2 were recorded before, during and after ultrasonic excitation of the sample. Pre-illumination by orange (590 nm) light was also used. More details about acousto- and photo-optic investigations of HgI_2 are described in [7].

Fig.1 shows amplitude dependencies of decrement $\delta(\epsilon)$ and resonant frequency $f(\epsilon)$ for both crystals. It is seen that HgI_2 is a much softer material than ZnSe : the level of damping is about two orders of magnitude higher in HgI_2 as well as the deviations in f at high ϵ .

Figure 1. Amplitude dependencies of logarithmic decrement δ and resonant frequency f of a composite oscillator including ZnSe and HgI_2 samples. The arrows identify the direction of changes in amplitude ϵ ; the measurements were made at room temperature in darkness.

The main difference between these two crystals is revealed in illumination effects (fig.2). Only quick and small changes in damping arise in ZnSe , the changes being approximately equal for both amplitude levels; resonant frequencies remain insensitive to the light or darkness. The behaviour of acoustic properties of HgI_2 is more complicated. One can find rapid changes of δ and f at the moment of switching on or off the light and subsequent evolution of opposite sign. Notice very slow changes in darkness after switching off the illumination. There is a significant difference between ADD and AID behaviour for HgI_2 , as is evident in fig 2 and 3. Fig.3 shows spectral responses of PAE for AID and ADD. They were constructed from the available data, like that ones of fig.2, which were obtained for different wave length light illumination. The higher sensitivity of ADD as compared with AID is clearly seen. But for both ADD and AID the peak

Figure 2. Influence of light on the time evolution of δ and f for vibrational amplitudes ϵ : (1) - low ϵ of AID range ($\epsilon=10^{-6}$ for HgI_2 and $2 \cdot 10^{-5}$ for ZnSe); (2) - high ϵ of ADD range ($\epsilon=1 \cdot 10^{-5}$ for HgI_2 and $2 \cdot 10^{-4}$ for ZnSe). The data are for the same samples as in fig.1.

position (590 nm) is almost the same as for photoconductivity [8].

Figs.4 and 5 show HgI_2 photoluminescence spectrum behaviour under the influence of pre-illumination by orange (590 nm) light and HAUE with $\epsilon = 1 \cdot 10^{-5}$ which is in the ADD range. It is clearly seen that only the band at 573 nm is sensitive to pre-illumination and ultrasonic treatments. This band has a doublet structure. The position of the lines in the band differs only about 3 nm. One can notice from the figures that the longer wave length line is more sensitive to the influence of light and ultrasound.

Figure 3. Spectral characteristics of PAE for AID ($\Delta\delta_i$) and ADD ($\Delta\delta_h$) of HgI_2 specimen. The changes in damping correspond to (2880-3600) s time interval of fig.2.

important reason of the lack of the photosensitivity of these parameters in ZnSe may be that the sample was not plastically pre-strained before measurements. So there were no fresh dislocations, and the edge component of dislocation loops, which is electrically charged, did not move at the 100 kHz vibrational stresses used in the experiment, due to, for example, the screening effect of the impurities or, maybe, a high Peierls barrier.

Figure 4. Photoluminescence spectra of HgI_2 at room temperature: (1) - initial state of the sample; (2) - after 30 min of orange light illumination ($\lambda=590$ nm); (3) - during HAUE at $\varepsilon=1 \cdot 10^{-3}$ just after the finishing of illumination. The spectra are shifted along the ordinate axis.

spectrum of HgI_2 . These entities are dislocations and stoichiometric (native) point defects with trapped electron-hole pairs.

This conclusion arises as a result of an analysis of the data of figs.2,3 and 4,5. First of all, it is necessary to mention a well pronounced effect of orange light on both the acoustic properties and luminescence spectrum. It is known [9,10] that damping and, in particular, ADD are very sensitive to

3. DISCUSSION

3.1 Photoacoustic effects in ZnSe and HgI_2 crystals

HgI_2 and ZnSe crystals have band gaps at room temperature of 2.14 and 2.66 eV, respectively; the highest sensitivity of their photoacoustic properties occurs in visible light.

As it was mentioned above ADD in ZnSe is not sensitive to light, as indicated by the almost equal illumination effects at both low and high amplitudes (fig.2). In HgI_2 , ADD shows enhanced sensitivity as compared with AID (fig.2 and 3). So the experimental data of this paper confirm the different nature of the PAE in these crystals which was found earlier [2-5].

The dislocation origin of ADD and amplitude dependent part of resonant frequency ($f_1 - f_2$ in fig.2) is not doubtful. The most

As to HgI_2 , the high sensitivity of ADD to the illumination (fig.3) makes it possible to discuss PAE for this crystal in the framework of dislocation models.

3.2 PAE and dislocation photoluminescence in HgI_2

Simultaneous studies of acoustic (figs.2-3) and optic (figs.4-5) properties under the influence of HAUE and pre-illumination by 590 nm light allow one to specify structural entities (among the crystal defects) which are responsible for PAE and photo- and acousto-optic effects in photoluminescence

variation in dislocation-pinning structure. We assume that point defects are modified by trapping the

Figure 5. Photoluminescence band of 573 nm before (1) and after (2) two hours of HAUE at $\epsilon=1 \cdot 10^{-5}$.

photoinduced carriers and, as a result, concentration of obstacles for dislocation movement increases or decreases at the switching of light. The orange light changes the intensity of the 573 nm luminescence band as well and, in particular, of its longer wave length line (fig.4). We explain this effect by the enhanced concentration (due to pre-illumination) of exciton states of carriers (electron-hole pairs) bound to native HgI_2 point defects since it has been found [11,12] that this band (563 nm at 77 K) arises due to luminescence of that kind of excitons (543 nm band is attributed to free exciton emission). On the other hand, HAUE also influences both acoustic properties (fig.2) and 573 nm luminescence band (figs.4, 5). One can assume that the ultrasonic treatment fractionally destroys the dislocation-pinning point interaction of the exciton so that

the intensity of the band is reduced. The changes in damping and resonant frequencies can also be explained by destruction of obstacles for vibrating dislocations.

The main conclusion, concerning HgI_2 , is that a particular bound exciton state has been found in the vicinity of dislocations. This state has its own energy level: the higher sensitivity of longer wave length line in the 573 nm photoluminescence band to light and ultrasonic treatments as compared with both the shorter wave length one and with the 543 nm free exciton band may be explained by this energy level in the band gap of HgI_2 crystal.

Acknowledgements

The research described in this publication was made possible in part by Grant N°J7G100 from the International Science Foundation and Russian Government. The author thanks Prof. R.De Batist and Prof. V. Tatarchenko for valuable discussions.

References

- [1] Nine H.D., Phys.Rev.Lett. **4** (1960) 359-361.
- [2] Nine H.D. and Truell R., Phys.Rev. **123** (1961) 799-803.
- [3] Gurevich V.L., Sov.Phys.Semicond., **2** (1969) 1299-1325.
- [4] Kardashev B.K., Golyandin S.N., Kustov S.B. and Zaletin V.M., Sov.Phys.Solid State **34** (1992) 1149-1153.
- [5] Kardashev B.K., Journ.All.Comp., **211/212** (1994) 160-163.
- [6] Osip'yan Yu.A., Petrenko V.F., Zaretskii and Whitworth R.W., Adv.Phys. **35** (1986) 115-188.
- [7] Kardashev B.K., Rezvushkin A.V., Stepanov P.A., Stepanov V.A., Chernov V.M. and Zaletin V.M., Fiz.Tverd.Tela, **38** (1996) 1511-1520.
- [8] Suryanarayana P. and Acharya H.N., Journ.Electr.Mat., **18** (1989) 481-485.
- [9] Granato A.V. and Lücke K., Journ.Appl.Phys., **27** (1956) 583-593.
- [10] Gremaud G., In: Mechanical Spectroscopy / Ed. L.B.Magalas. Chapman and Hall, London (in press).
- [11] Merz J.L., Wu Z.L., Van den Berg and Schneppe W.F., Nucl.Instr. and Meth., **213** (1983) 51-64.
- [12] Ovsuk N.N. Sov.Phys.Solid State, **33** (1991) 1939-1940.