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Photoacoustic properties of HgI_2 single crystals at different levels of ultrasound strain amplitude

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Abstract

Amplitude and time dependences of ultrasonic damping and Young's modulus of HgI_2 single crystals are investigated at room temperature by means of a composite oscillator technique at a frequency of longitudinal vibrations of about 100 kHz. It is found that acoustic parameters such as damping and resonant frequency of the sample (Young's modulus deficiency) are strongly influenced by light. The spectral response of the photoacoustic effect at small amplitudes appeared to be almost the same as that of photoconductivity. It is shown that the behaviour of the effect at high amplitudes is quite different that at small amplitudes. It is supposed that the photoacoustic properties of HgI_2 can be explained by the pinning of dislocations by centres which are created under light as a result of photoelectrons or holes.

1. Introduction

Mercuric diiodide single crystals have great interest as materials for a new generation of nuclear radiation detectors which can operate at room temperature. However, currently available crystals usually have a large number of defects, which undoubtedly must affect the detector quality. Acoustic techniques, in particular amplitude-dependent damping, are used widely in studies of dislocations and point defects as well as the force of interaction between them. It has been supposed in ref. 1 that photoacoustic effects arise in HgI_2 crystals mainly as a result of this interaction.

In this paper new results on the internal friction and Young's modulus deficiency behaviour under light illumination are presented. They have been obtained on various quality HgI_2 samples.

2. Method and results

Crystals of HgI_2 were grown from the vapour phase by the method of static sublimation. Samples used in the ultrasonic investigations were plates of dimensions about $9 \times 5 \times 0.5$ mm^3. The crystallographic orientation of the large faces was (100). The other two directions were close to the [110] axis. Longitudinal vibrations travelled along the 9 mm edge of the plate.

A computerized set-up was used for investigation of the acoustic properties of solids at frequencies of about 100 kHz by the resonant composite oscillator technique [2]. Suitable programs made it possible to measure the amplitude and time dependences of the decrement δ and resonant frequency f of the composite (piezoquartz and sample) oscillator.

The curves plotted in Figs. 1–3 give an impression of the behaviour of the amplitude dependences of internal friction and Young's modulus of three samples of HgI_2 crystals in photoacoustic experiments. In Figs. 2 and 3 is illustrated the influence of illumination by orange (Figs. 2 and 3) and UV (Fig. 3) light on the investigated acoustic parameters. One can notice a substantial difference in the curves between high and small amplitude behaviour and between orange and UV light photoacoustic effects.

The changes in the vibrational amplitude levels and in the illumination of the samples cause the appearance of time dependences of the acoustic parameters. Figures 4(a) and 4(b) show the curves which were obtained for sample 1 under the influence of orange light at two amplitude levels: 2.0×10^{-7} and 1.0×10^{-6} (amplitude dependences for this sample are in Fig. 1). One can see that illumination reduces the decrement considerably and the resonant frequency becomes higher.

The results obtained could be used to estimate the influence of light not only on the directly measured quantities δ and f at different strain amplitudes but also on the amplitude-dependent part of the decrement Δ_h and frequency F_h as well (see Figs. 4(c) and 4(d)):

$$\Delta_h = \delta_2 - \delta_1; \quad F_h = f_1 - f_2$$

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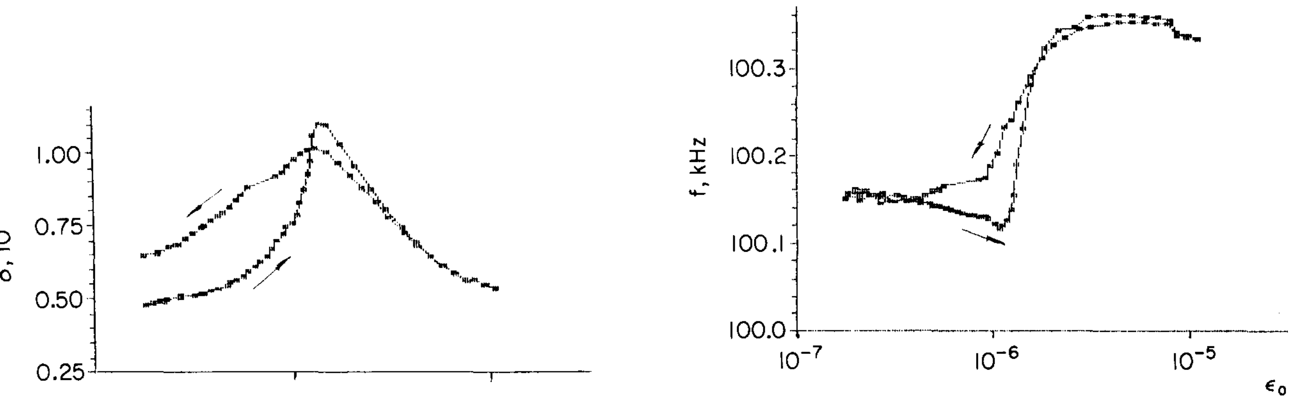

Fig. 1. Amplitude dependences of the logarithmic decrement δ and of the resonance frequency f of a composite oscillator including mercury diiodide crystal sample 1, recorded during a gradual increase and reduction in the vibrational strain amplitude ϵ_0. The arrows identify the direction of changes in the amplitude. The measurements were made at room temperature in darkness.

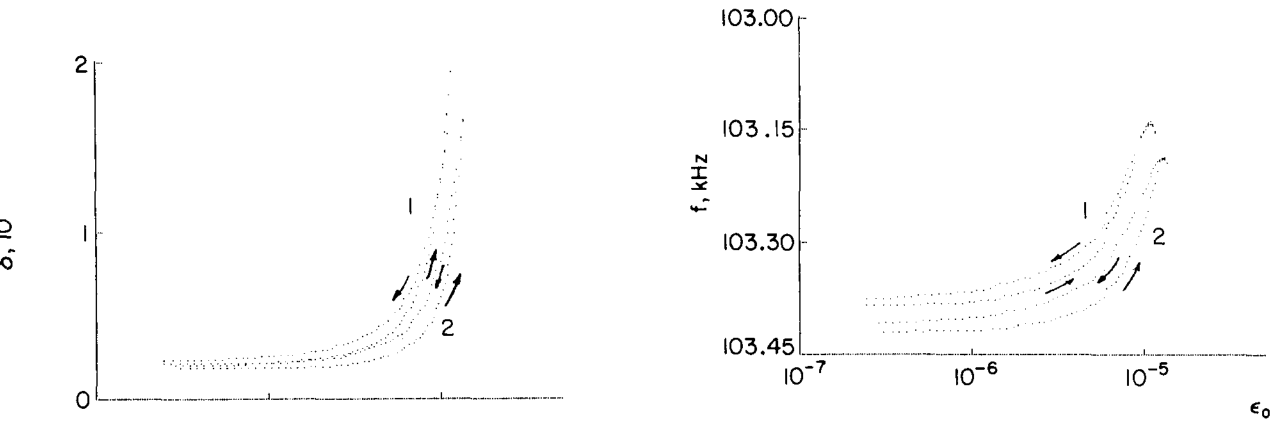

Fig. 2. The experiment of Fig. 1 for sample 2: curves 1, obtained in darkness; curves 2, after 10 min of illumination with orange light.

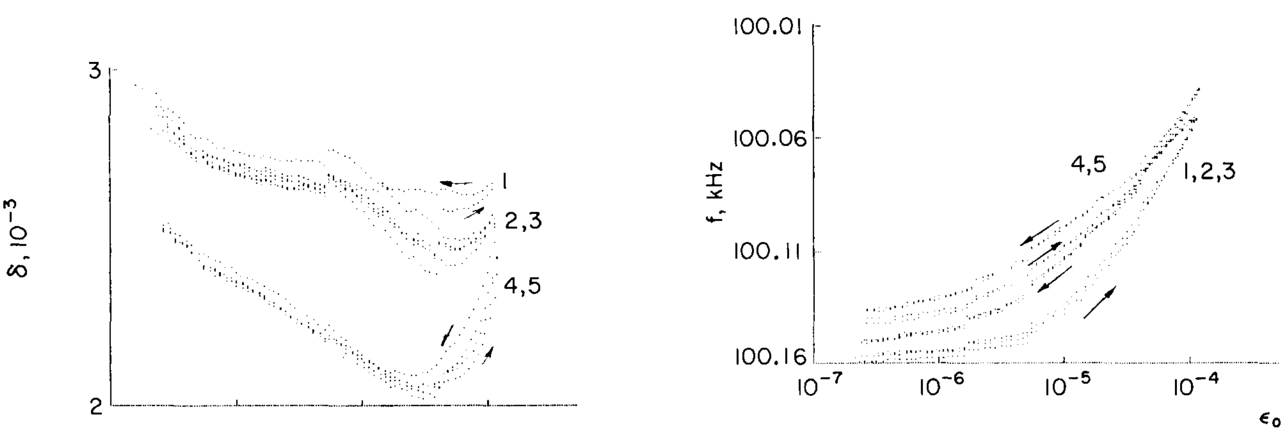

Fig. 3. The experiment of Fig. 1 for sample 3: curves 1, measurements in darkness; curves 2, 3, two successive measurements after 10 min of illumination with UV light; curves 4, 5, the same under the influence of orange light.

Here δ_1, δ_2, f_1 and f_2 correspond to curves 1 and 2 on Figs. 4(a) and 4(b). One can see the quite different behaviours of amplitude-independent (δ_1, f_1) and amplitude-dependent (Δ_h, F_h) acoustic parameters.

After discovery of the photoacoustic effect in HgI_2 crystals we tried to determine its spectral characteristics. Unfortunately it was possible to do this correctly only for low amplitude range. The main reason for this difficulty lies in strong time dependences (illumination and amplitude "prehistory" of the sample) at higher amplitudes. In Fig. 5 one can see the spectral response of the amplitude-independent δ and f ($\epsilon_0 = 2.0 \times 10^{-7}$)

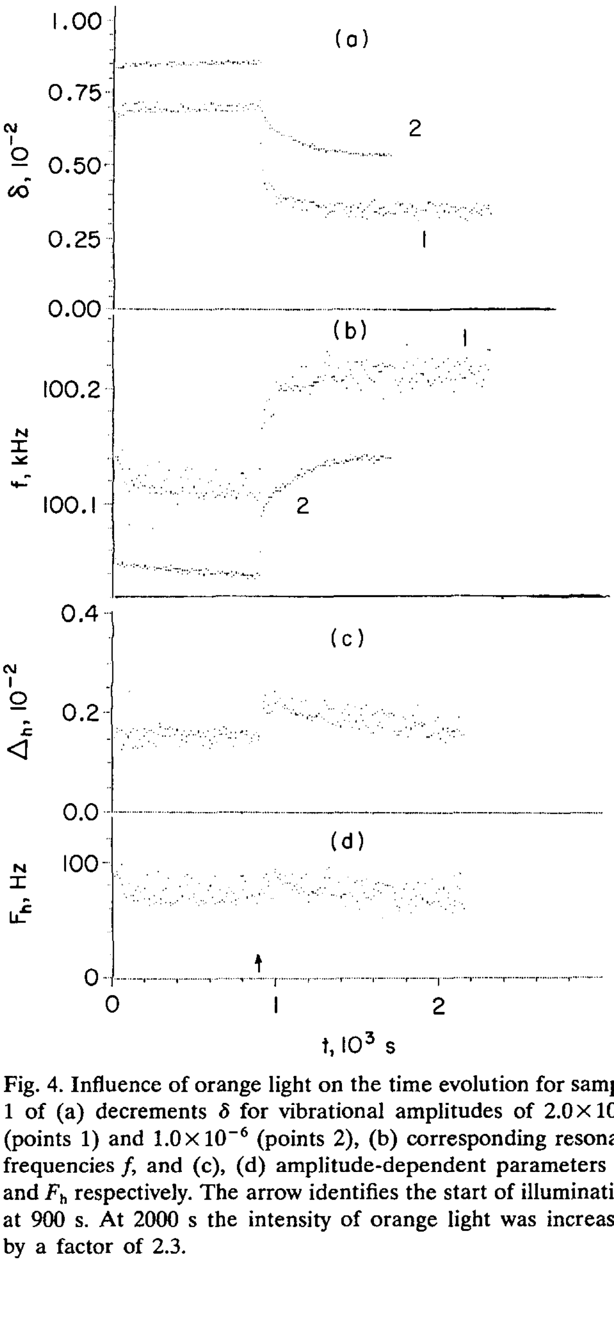

Fig. 4. Influence of orange light on the time evolution for sample 1 of (a) decrements δ for vibrational amplitudes of 2.0×10^{-7} (points 1) and 1.0×10^{-6} (points 2), (b) corresponding resonant frequencies f, and (c), (d) amplitude-dependent parameters Δ_h and F_h respectively. The arrow identifies the start of illumination at 900 s. At 2000 s the intensity of orange light was increased by a factor of 2.3.

of sample 1. The parameters of the photoacoustic effect were defined as follows:

$$\Delta\delta_i=\delta_1(2000)-\delta_1(900);\quad \Delta f_i=f_1(2000)-f_1(900)$$

The arguments 900 and 2000 in the above expressions represent the time interval (1100 s) of the illumination with the light of any selected wavelength.

It is necessary to notice that the spectral response of the photoacoustic effect at higher amplitudes must differ considerably from the spectrum in Fig. 5. This is clear from Figs. 3 and 4. Some more details about this work can be found in ref. 1.

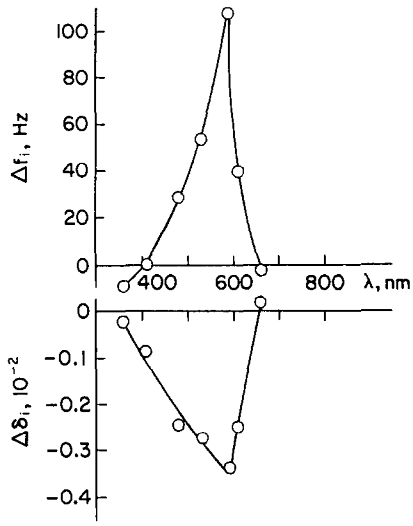

Fig. 5. Spectral characteristics of the photoacoustic effect in sample 1 in the amplitude-independent (Δf_i, $\Delta\delta_i$, $\epsilon_0=2.0\times10^{-7}$) range of vibrational strain amplitude ϵ_0.

3. Discussion

3.1. Photoacoustic effects

Our investigations have revealed three ranges of amplitudes where the photoacoustic effect behaves differently [1]: (1) low amplitude range, where time dependences of the acoustic parameters are absent (sometimes it is an amplitude-independent damping range as in Figs. 1 and 2; sometimes it may be an amplitude-dependent range as in Fig. 3); (2) moderate amplitudes, where the decrement becomes higher the higher the amplitude; (3) the highest amplitude range, where the attenuation of ultrasound decreases on increase in the amplitudes (Fig. 1).

Some analysis in ref. 1 shows that the observed phenomena can be explained qualitatively by the appearance or disappearance under the influence of light of a given wavelength of long-lived pinning centres which interact with dislocations. The appearance of additional obstacles for dislocations vibrating under ultrasonic stress should reduce the decrement and increase the effective Young's modulus according to the Granato and Lucke theory [3]. In the case of HgI_2 crystals it has been found that the strongest effect of illumination is observed in the low amplitude range if orange light of wavelength 590 nm is used (Figs. 3 and 5).

It is interesting to note that the spectral characteristics of the photoacoustic effect at low amplitudes are almost the same as those of photoconductivity [4]. Consequently, one can assume that photoactive dislocation-pinning centres are formed with direct participation of photocarriers (electrons or holes).

3.2. Amplitude dependences

Different samples of HgI_2 crystals reveal a large variety in the curves (Figs. 1–3). The samples differ not only in the levels of the decrement and Young's modulus defect at small and high amplitudes but also in the forms of the curves. We believe that the main reason for this is a large variety in the number and various kinds of dislocations, mobile and immobile point defects (dislocation-pinning centres) of different nature. It may be the appearance of an unknown phase transition in HgI_2 crystals which arises under the action of ultrasound stress: a large increase in the resonant frequency at high amplitudes in the case of sample 1 (Fig. 1) may be due to this effect.

It should be mentioned that because of investigations of the spectral response of the photoacoustic effect at different strain amplitudes it is possible to discern the stable characteristics and high quality of nuclear radiation detectors made of HgI_2 crystals [5].

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