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Pulsed laser induced absorption (one-four) dependence of electron mobility in CdI_2 and ZnS crystals

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Abstract. The photoconductivity and electron mobility of CdI_2 and ZnS crystals have been studied using N_2-laser, fundamental and frequency doubled Nd:YAG laser. Low values of the electron mobilities obtained in the present case have been attributed to laser-induced-absorption. It is low in one photon excitation and increases with the order of absorption.

Keywords: Multiphoton processes; electron mobility; photoconductivity.

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1. Introduction

During some of our recent investigations on the photoconductivity properties, we have reported different aspects of the multiphoton processes going on in case of ZnS and CdI_2 crystals (Singh *et al* 1988, 1989a, b). Both these crystals have a band gap of more than three electron-volts, therefore one gets one-photon absorption using N_2-laser, howsoever, powerful it may be, and multiphoton absorption using Nd:YAG, frequency doubled Nd:YAG and Ruby lasers. In conformity with the results reported by the earlier investigators (Mylnikov and Kozyrev 1977), the electron mobility is quite low in most of these cases showing variation with frequency of laser used, in comparison to its value reported in the case of *cw* excitation using Xe arc lamp or mercury lamp. Due to the coherence, the properties of laser radiation are altogether different, so one cannot come to a quick decision while comparing the signals with those generated by conventional light sources. The extremely low value of the electron mobility ($\sim 10^{-3}\,cm^2/V\,s$) in the case of ZnS using N_2-laser excitation has been attributed, by Mylnikov and Kozyrev to laser to laser-induced-absorption, a phenomenon not understood properly. Due to this reason, and also because ZnS gives a very strong reflectance as well as photoconductivity signal at N_2-laser frequency, we have investigated the photoconductivity and electron mobility of CdI_2 and ZnS crystals using different lasers (N_2-laser, fundamental and frequency doubled Nd:YAG laser), and the studies are reported here.

2. Experimental procedure

The experimental details for charge *vs* photon density (Q *vs* I_p characteristics) measurements were the same as described earlier. All the measurements were made in the range $-\tau_L < t < 0$, where τ_L is the pulse width of the laser used. Electrical contacts were made using silver paint for CdI_2 and indium coated electrodes with silver paint for ZnS. In all the cases, light falls perpendicular on the surface on which the electrodes were attached.

3. Result and discussion

Figure 1 shows the electron mobilities in case of CdI_2 crystal under N_2-laser excitation whereas figures 2 and 3 represent electron mobilities in CdI_2 and ZnS crystals under Nd:YAG and frequency doubled Nd:YAG laser excitations. The value of electron mobility increases with the excitation intensity in all the cases as expected according to the standard relation (Smith and Rose 1955). However, the values of electron mobility obtained in these cases show marked difference. In the case of N_2-laser excitation the electron mobility is in the range $\sim 10^{-3}\,cm^2/V\,s$ in both ZnS and CdI_2 (Singh *et al* 1989) crystals, while in the case of Nd:YAG laser excitation the maximum values obtained are $33\,cm^2/V\,s$ and $24{\cdot}7\,cm^2/V\,s$ in CdI_2 and ZnS crystals respectively. In the case of frequency doubled Nd:YAG laser shown in figure 2 (inset) and figure 3 (inset) the mobility lies in between the two. Since the band gaps of CdI_2 and ZnS

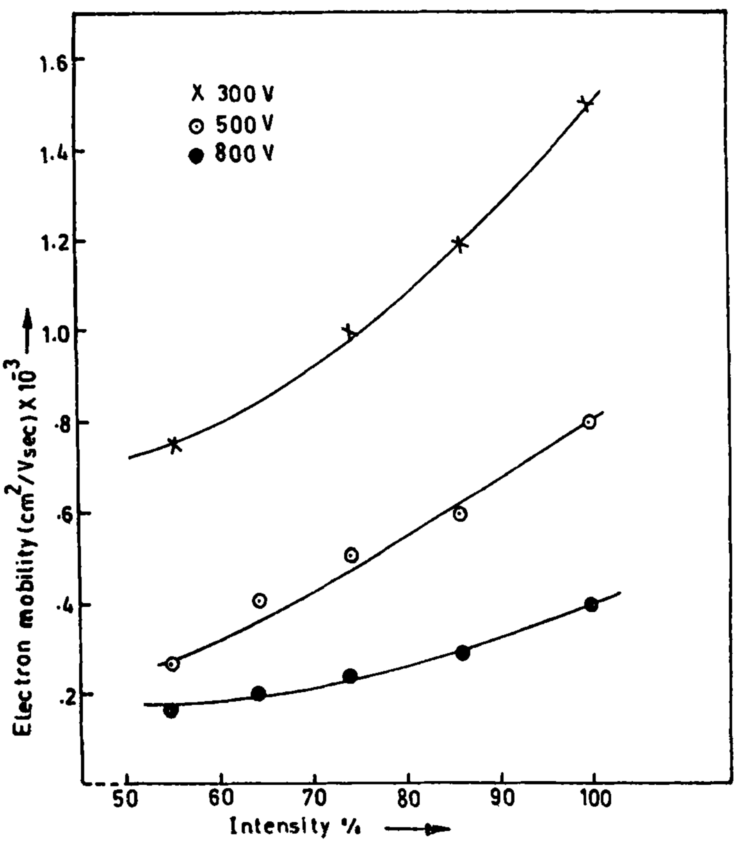

Figure 1. Increase in mobility of CdI_2 crystal with an increase of intensity at different electric fields using N_2-laser excitations.

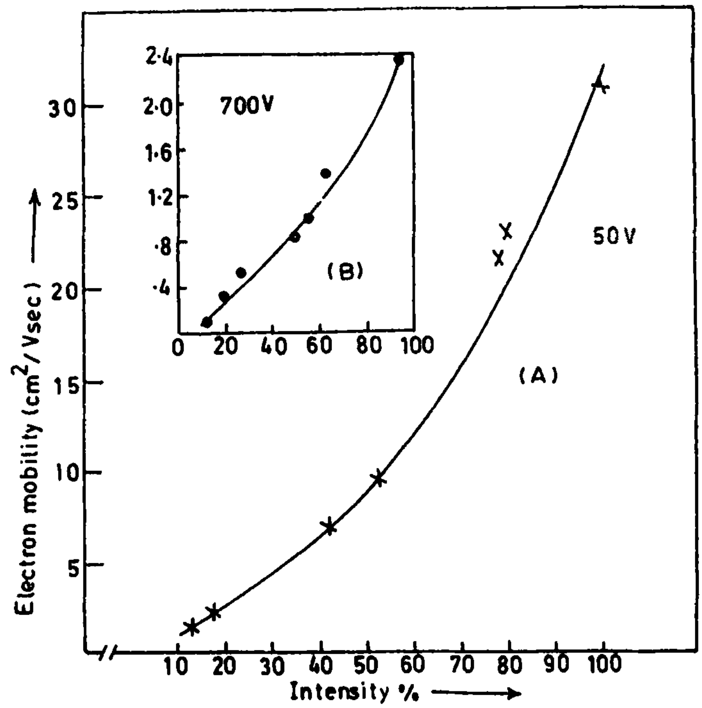

Figure 2. Increase in electron mobility of CdI_2 crystal with intensity under (A) Nd:YAG laser and (B) frequency doubled Nd:YAG laser excitation.

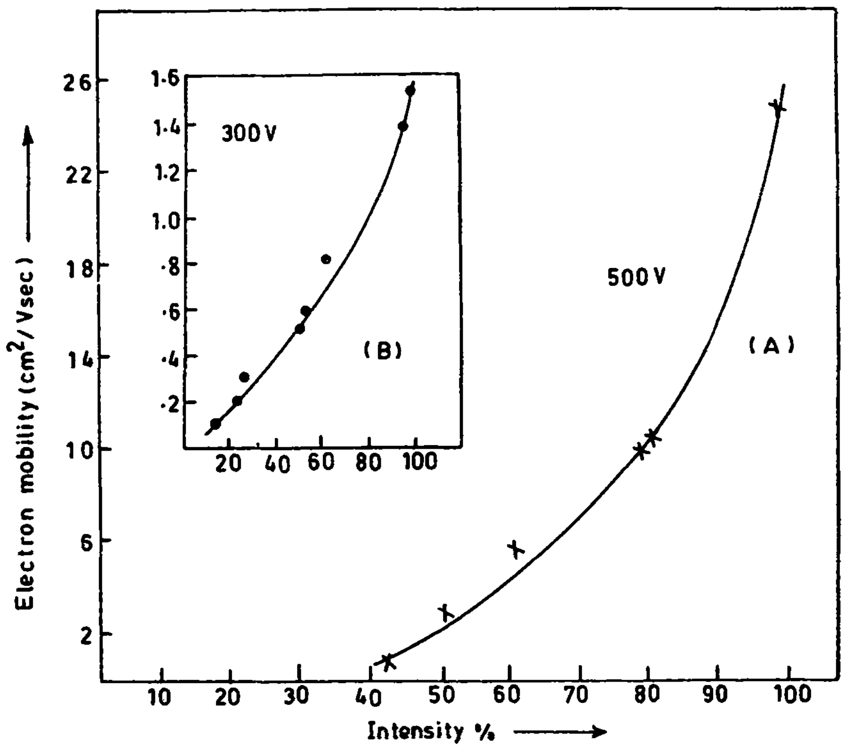

Figure 3. Increase in electron mobility of ZnS crystals with intensity under (A) Nd:YAG laser and (B) frequency doubled Nd:YAG laser excitation.

crystals as reported earlier are 3·2 eV and 3·68 eV respectively, we expect one, two and three photon excitations in CdI_2 using N_2-laser, frequency doubled, and fundamental Nd:YAG lasers respectively, while ZnS, two and four photon excitation is possible using frequency doubled and fundamental Nd:YAG lasers. Extremely small value of the electron mobility in the case of N_2-laser excitation can be understood to be due to the dominance of surface effect in one-photon absorption. With the increase of the order of absorption, the absorption cross-section decreases (Singh *et al* 1989), therefore the volume effect starts dominating rather than the surface effect. This argument is particularly relevant in the present case due to the geometry of the experimental set up where the electrodes are attached to the surface of the crystal on which light is falling. For an alternative arrangement when one electrode is at the front surface and the other at the back surface greater volume of the sample may be involved even in the case of one-photon absorption. But this can be done only at the cost of the photocurrent, which may become too feeble to be detected.

Excitation by a pulsed laser, which is the case of all the multiphoton absorption using high power lasers, must be understood in a different frame than those of *cw* excitations involving one-photon absorption using ordinary light sources. Under the condition $\tau_L \ll \tau_{eh}$ (where τ_{eh} is the recombination time), the carrier density N is given by (Eichler *et al* 1988)

$$N = \frac{\alpha \xi_{ad}}{h\gamma}, \tag{1}$$

where α is the absorption coefficient, ξ_{ad} is the energy area density and $h\gamma$ is the energy of the photon.

The electron mobility μ is given by (Yu 1969)

$$\mu = \frac{I_{ph}}{eaNE}, \tag{2}$$

where E is the applied electric field and a the separation between the two electrodes.

Using (1) and (2), the value of μ can be written as

$$\mu = \frac{I_{ph} h\gamma}{eaE\alpha\xi_{ad}}. \tag{3}$$

In laser excitation, ξ_{ad} is very large in comparison to the excitation by ordinary light, so μ is expected to be quite low. This is sometimes called laser-induced-absorption. This argument goes well so long as the absorption is one-photon and α relatively high. But in the case of two/multiphoton absorption, larger volume of the optical material is involved due to the low value of absorption coefficients which also reduces N. As a result electron mobility increases due to this reduction of the carrier density N. The large value of N in the case of one-photon absorption also explains the appearance of photocurrent in ZnS using N_2-laser excitation, though there is a strong reflection band at this frequency. As the electrodes are deposited on the front surface of the crystal, a large contribution to the photocurrent is due to the surface rather than the volume of the sample. In the case of spectrophotometers where we use Xe-lamp having photon density much smaller than the N_2-laser, volume effects dominate over the surface effects and hence the physical processes going on in the two cases are altogether different.

4. Conclusion

The electron mobility is low in one-photon absorption using pulsed lasers. This is attributed to the high concentration of charge carriers produced at the surface due to the relatively large absorption cross-section. With the increase in the order of absorption the absorption cross-section decreases which results into an increase in the value of the electron mobility.

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