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THERMALLY INDUCED NONLINEAR REFRACTION IN $Cd_{1-x}Mn_xTe$[*]

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Self-focusing of laser beams is observed in $Cd_{0.5}Mn_{0.5}Te$ at room temperature. The far-field patterns of laser beam after passing through the cadmium manganese telluride crystal are investigated. The values of focal length as well as the absorption coefficient were measured as a function of intensity of laser radiation. From these measurements the values of nonlinear refractive index for $Cd_{0.5}Mn_{0.5}Te$ are determined. The results indicate that the self-focusing observed in $Cd_{1-x}Mn_xTe$ is due to a thermally induced change in refractive index.

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A well-known third-order nonlinear optical effect of great interest is the phenomenon of self-focusing of light. Self-focusing may occur when the refractive index of the nonlinear medium increases with the beam intensity,

$$n = n_0 + \Delta n,$$

where Δn is the laser induced refractive index and n_0 is the index of refraction for low intensity light.

One of the most important physical mechanism responsible for Δn in semiconductors is heating by CW laser beam with photon energies close to the band gap energy. It leads to dispersive nonlinearity induced by a shift of the band gap energy. In case of a laser beam with a Gaussian transverse profile propagating into the semiconductor with $\mathrm{d}n/\mathrm{d}T > 0$, the central part of the beam sees a larger refractive index than the edge. Consequently, the beam is focused by itself. Dispersive nonlinearity induced by a thermal shift of the band gap energy has been studied in several semiconductors [1].

In this paper the investigations of self-focusing of laser beam in $Cd_{0.5}Mn_{0.5}Te$ is reported.

It should be noticed that in $Cd_{1-x}Mn_xTe$ crystals with $x \geq 0.5$ the fundamental absorption is obscured by transitions within Mn^{++} ions [2]. Therefore,

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thermally induced refractive index changes in the region of absorption edge are caused by a thermal shift of the transitions within localized states of manganese.

The experiment was performed on a 1.5 mm thick slab of $Cd_{0.5}Mn_{0.5}Te$ at room temperature. The far-field patterns of the self-focused dye laser beam with photon energies just below the absorption edge were observed on a screen. Figure 1 shows the power dependence of the transmitted beam profile 182 cm behind the sample for different incident powers. The beams in absence of the sample and on transmission through the sample at low laser powers were nearly Gaussian in cross-section. As the incident power is increased, the far-field profile breaks up into a set of rings of ever increasing radius and number.

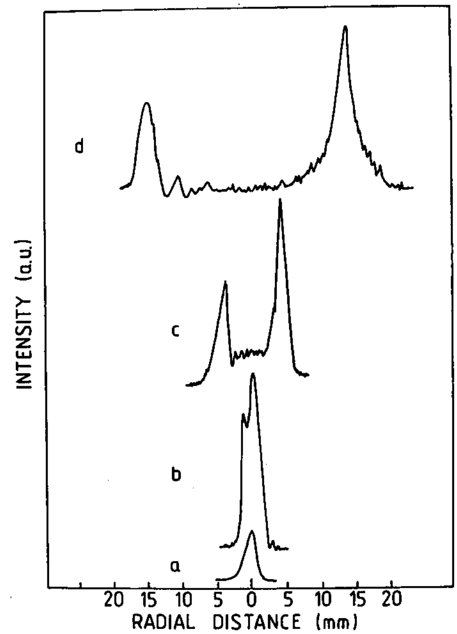

Fig. 1. Diametric beam profiles in the far field (182 cm) behind the sample for different incident density powers: (a) 1.4 W/cm^2 (sample out), (b) 3.6 W/cm^2, (c) 11 W/cm^2, (d) 40 W/cm^2. Incident spot 700 μm diameter, laser wavelength 595 nm. The asymmetry in these traces may be due to slight imperfections in the incident beam.

The focal length of thermally induced lens was found by measuring image size. These results were also checked by direct observation of the focal position. The reciprocal of the measured focal length as a function of the laser power density is shown in Fig. 2 indicating that the focal length decreases with the laser power density. Figure 2 shows that at longer wavelength where the absorption is smaller, smaller self-focusing is observed.

For high laser power density we used in experiment, absorption coefficient depends on power density. The relationship between the measured absorption coefficient α and the laser density of power is plotted in Fig. 3. The increase in

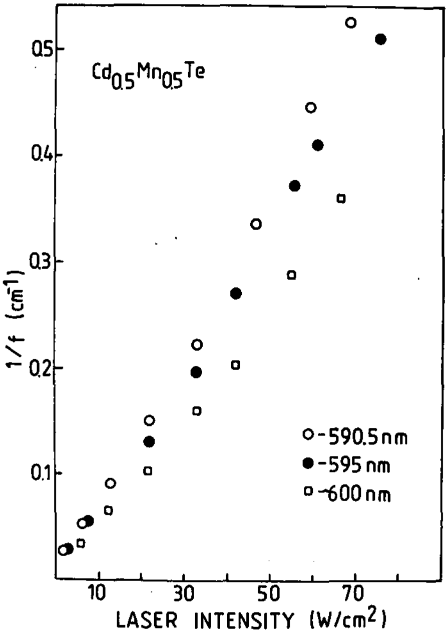

Fig. 2. Thermal lens power (the reciprocal of the measured focal length) as a function of laser intensity.

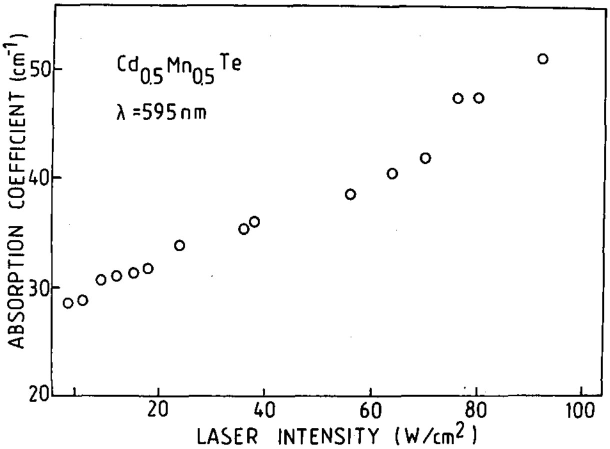

Fig. 3. Measured absorption coefficient as a function of laser intensity.

absorption coefficient for higher power density may be explained by thermally induced shift of transitions within Mn^{++} ions to smaller energy. Decrease in the energy of transitions within manganese ions with increase in temperature was observed in [2].

In order to estimate the value of nonlinear refractive index, we use the model of a laser beam induced thermal lens [3]. The focal length f of the observed self-induced thermal lens is approximately given [3] by

$$f = \frac{r_0^2 \alpha}{\Delta n(1 - \mathrm{e}^{-\alpha l})}, \tag{1}$$

where r_0 is the half-width of laser beam, Δn is the refractive index change at the centre of the Gaussian beam, α is the absorption coefficient of the sample, and l is the thickness of the sample.

The change Δn is expressed [3] as

$$\Delta n = n_2 I, \tag{2}$$

where n_2 is the nonlinear refractive index and I is the laser intensity. Substituting Eq. (2) into Eq. (1), the relationship between the focal length f and the laser intensity is obtained as

$$f = \frac{r_0^2 \alpha}{n_2 I(1 - \mathrm{e}^{-\alpha l})}. \tag{3}$$

With the measured values of f, I, r_0, l, and α, the nonlinear refractive index n_2 is obtained from Eq. (3) as $n_2(595\ \mathrm{nm}) = 3 \times 10^{-4}\ \mathrm{cm^2/W}$ for $\alpha = 29\ \mathrm{cm^{-1}}$, $I = 4\ \mathrm{W/cm^2}$ and $n_2(595\ \mathrm{nm}) = 4.3 \times 10^{-4}\ \mathrm{cm^2/W}$ for $\alpha = 45\ \mathrm{cm^{-1}}$, $I = 76\ \mathrm{W/cm^2}$.

The values of n_2 obtained in this paper are smaller than values of n_2 determined for $\mathrm{Cd_{0.4}Mn_{0.6}Te}$ in [4], where the observed nonlinear refractive index was attributed to a thermally induced shift of energy gap (n_2 of $\mathrm{Cd_{0.4}Mn_{0.6}Te}$ $(599\ \mathrm{nm}) = 1.4 \times 10^{-3}\ \mathrm{cm^2/W}$ for $\alpha = 18.3\ \mathrm{cm^{-1}}$).

In conclusion, we should notice that the values of thermally induced nonlinear refraction index n_2 obtained for $\mathrm{Cd}_{1-x}\mathrm{Mn}_x\mathrm{Te}$ with $x \geq 0.5$ are significantly larger than n_2 for other semiconductors. In bulk ZnSe, where the self-focusing plays an important role in bistability effect, thermally induced nonlinear refractive index is $n_2 \approx 10^{-6}\ \mathrm{cm^2/W}$ [5]. Furthermore, $\mathrm{Cd}_{1-x}\mathrm{Mn}_x\mathrm{Te}$ seems to be suitable material for cavityless optical bistability, because a shift of transitions within Mn^{++} ions and self-focusing occurs due to the temperature rise of $\mathrm{Cd}_{1-x}\mathrm{Mn}_x\mathrm{Te}$ as the laser irradiance is increased. These two mechanisms are believed to provide the feedback necessary for bistable operation.

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