CdTe Nanocrystals Studied through *in-situ* Electro-Modulation Spectroscopy

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Abstract. *Non-linear optical properties of weakly confined CdTe nanocrystals in a glass matrix were studied by electro-modulation spectroscopy. Copper electrodes of about 10 nm thick were deposited on both sides of glass samples of thickness 0.8 mm by physical vapor deposition. Optical transmission spectra of the samples were recorded under dc high voltage applied to the electrodes. The absorption band is observed to broaden. This is most likely caused by state filling.*

Key words: nanocrystals, CdTe quantum dots, electro-modulation spectroscopy.

I. INTRODUCTION

Nanocrystals are of special interest due to their potential applications in solar panels for the purpose of increasing light to electric current conversion efficiency [1]. Linear and nonlinear optical properties of Cd chalcogens including CdSe and CdS have been scrutinized [2-3]. The other less studied member of group II-VI, CdTe has a band gap of around 1.5 eV which is at the optimum value for converting solar energy to electrical energy. The size dependent electro-modulation spectroscopy plays an important role in understanding electronic band structure and the extent to which the band gap energy is modified. In this work, CdTe nanocrystals embedded in glass were characterized by optical absorption spectroscopy. Their non-linear optical properties under high voltage have been studied by in situ electro-modulation spectroscopy.

II. EXPERIMENTAL

Commercially available Schott color glass filter RG830 was used as starting material; this commercial glass is already doped with CdTe nanocrystals. The RG830 samples were not treated in any way so that any nanoparticles present were considered to have weak/intermediate confinement; the optical absorption spectrum of the as-received glass sample is presented in Fig. 1. The optical absorption edge spectrum for bulk CdTe crystal reported in ref. [4] is shown in the same graph for comparison. The asymptotic absorption edge of 1.44 eV for bulk CdTe is blue shifted by 170 meV for as-received glass doped with CdTe nanocrystals due to confinement of charged particles (electrons and holes). The confinement energy of ΔE = 170 meV is related to average radius for nanocrsytals through the relation,

$$\Delta E = \frac{0.376}{\mu [R(nm)]^2} \qquad (1)$$

where μ = 0.106 is the electron hole reduced mass in unit of electron rest mass. We find an average radius of R = 4.57 nm for the ensemble of nanocrystals. The Bohr radius of CdTe can be calculated as approximately 7.5 nm using the effective mass approximation [5].

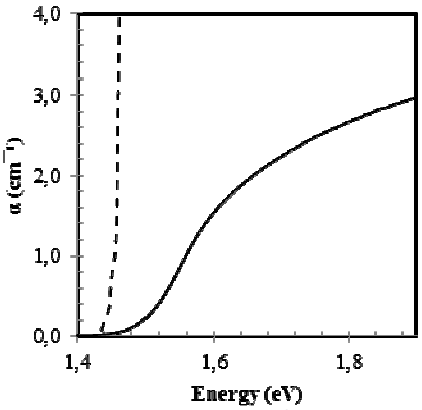

Fig. 1. Optical absorption edge spectra for as-received colour glass filter doped with CdTe (solid curve) and for bulk CdTe (dashed curve) (obtained by digitizing the curve for 297 K in Fig. 5 in ref. [4])

Copper electrodes of about 10 nm thick were deposited on both sides of as-received sample of thickness 0.8 mm by physical vapor deposition. Optical transmission spectra of the samples were recorded under a high voltage of 5 kV applied to the electrodes. The optical absorption spectra with no electric field (solid curve) and with electric field (dashed curve) applied to the sample are shown in Fig. 2.

The differential optical absorption coefficient calculated according to,

$$\Delta\alpha = -\frac{In\left(I_{fieldon}/I_{fieldoff}\right)}{d} \qquad (2)$$

where $I_{field\ on}$ ($I_{field\ off}$) is the transmitted intensity with the field applied (with no field applied). The change in absorption $-\Delta\alpha = [\alpha(\text{field on}) - \alpha(\text{field off})]$ is plotted against energy (electro-modulation spectrum) in Fig. 3.

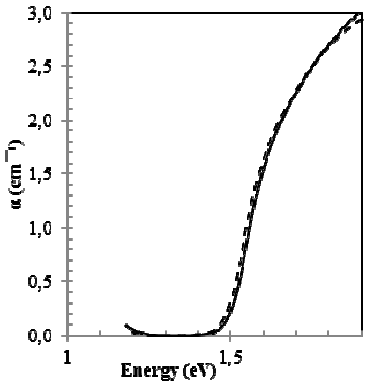

Fig. 2. In-situ optical absorption spectra under 5 kV dc applied to the sample (dashed curve) and the spectrum with no field applied (solid curve).

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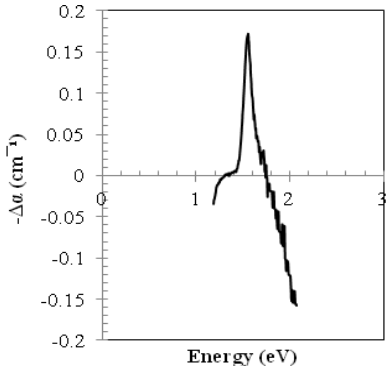

Fig. 3. Electro-modulation spectrum for glass doped with CdTe nanocrystals under 5 kV dc high voltage.

III. DISCUSSION

A Gaussian absorption band was assumed for the exciton peak in the optical absorption spectrum to explain the observed structure in Fig. 3 [6]. The effect of red shift and broadening with absorption saturation in the Gaussian absorption band on the electro-modulation spectra was shown in Fig. 4 [7]. A red shift and a broadening with a decrease in absorption in a Gaussian-like first exciton absorption band correspond to a first derivative and a second derivative line shape respectively in the electro-modulation spectra as seen in Fig. 4 (upper) and (center). The former has an asymmetric and the latter a symmetric structure. A mixture of the two structures produces the profile shown in Fig. 4 (lower). The structure observed in Fig. 3 is consistent with the structure consisting of a single lobe as observed in Fig. 4 (center). That is why it is reasonable to assume that the applied field causes broadening in optical absorption spectra. Earlier studies on nanometer sized semiconductor-doped glasses show that the state filling is responsible for a positive peak due to the bleaching of the absorption. We presume that dc electric field modifies recombination of electrons and holes and therefore quantized states are filled. This mechanism results in absorption saturation.

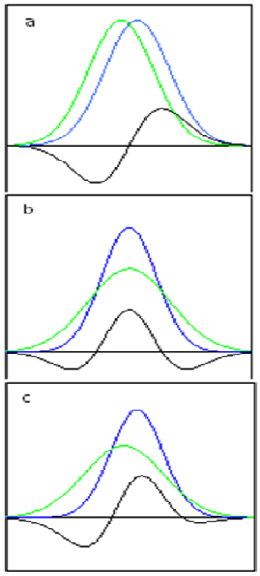

Fig. 4. Schematic plots of differential optical absorption spectra (wavy curve) due to a shift (upper plot), a broadening (center plot) and a shift plus a broadening (lower plot) in a Gaussian absorption band [7].

IV. CONCLUSION

Electro-modulation spectra show that the exciton band in optical absorption spectra for CdTe nanocrystals embedded in glass whose average radius is about 5 nm broadens under a dc high voltage of 5 kV. We presume that state filling is responsible for the observed absorption saturation.

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