Nonlinear Absorption Properties of Quantum Dots of CdTe / ZnS and CdTe / CdS

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Abstract. Herein, the nonlinear absorption properties of CdTe / ZnS and CdTe / CdS were investigated. The nonlinear absorption characteristics of these two kinds of quantum dots (QDs) were measured by Z-scan experimental apparatus under the wavelength of 532 nm, pulse widths of 4 ns and 21 ps, respectively, and a repetition frequency of 10 Hz. The results of experiment indicate the nonlinear absorption of CdTe / ZnS QDs and CdTe / CdS QDs show saturation absorption in nanosecond and picosecond laser pulses. By theoretical data fitting, we can draw a conclusion that the nonlinear absorption coefficients of CdTe / ZnS QDs and CdTe / CdS QDs are -2.57×10^{-10} m / W and -2.08×10^{-10} m / W,respectively;at a pulse width of 21 ps, the nonlinear absorption coefficients of CdTe / ZnS QDs and CdTe / CdS QDs are -1.38×10^{-11} m / W and -1.14×10^{-11} m / W,respectively. From the final data analysis, it can be seen that the nonlinear absorption properties of CdTe / ZnS QDs and CdTe / CdS QDs in the effect of nanosecond laser pulses are stronger than those under the condition of picosecond laser pulses. At the same time, it was found that under the different laser pulses of nanosecond and picosecond, CdTe / ZnS QDs showed stronger nonlinear absorption than that of CdTe / CdS QDs.

Keywords: Semiconductor core-shell QDs; Z-scan technique; Nonlinear absorption;

1. Introduction

Quantum dots(QDs) are important low dimensional semiconductor materials. Their dimensions are less than two times of the exciton Bohr radius of their corresponding semiconductor materials[1]. Quantum dots are generally spherical or spheroidal, with diameters often between 2 and 20 nanometers. Common quantum dots consist of IV, II-VI, IV-VI or III-V elements. Semiconductor quantum dots have a lot of superior fluorescence characteristics[2], such as: wide excitation spectrum with continuous distribution, narrow and symmetrical emission spectrum, adjustable color, high photochemical stability, as well as long fluorescence life. The unique nature of quantum dots stems from its own quantum effect. If the size of a particle reaches the nanometre, it will lead to the size effect[3], the quantum confinement effect, the macroscopic quantum tunneling effect and the surface effect, The different low-dimensional physical properties of the system and the microscopic system show many physicochemical properties different from that of the macroscopic materia[4]. Modern quantum dots technology dates back to the mid-1970s, initially to address the global energy crisis.

Through the study of photoelectrochemistry, the interface between the semiconductor and the liquid is generated, so that the energy is generated by utilizing the excellent surface area ratio of the nanocrystalline particles[5]. The initial semiconductor quantum dots study began with Louis Brus, Bell Labs, in the early 1980s and Alexander Efros and Victor.I. Klimov, the former Yoffe Institute of the Soviet Union[6]. Further research on subsequent quantum dots started in the early 1990s with CdSe quantum dots embedded in glass[7]. In 1993, the preparation of CdSe nanocrystals was a very successful case, efficient luminescence of CdSe quantum dots was first synthesized by Bawendi et al.Since its development in 1997, with the constantly enhancement of quantum dots manufacture technology, quantum dots have been gradually used in biomarkers and other aspects[8]. In 1998, Alivisatos and Nie respectively published the thesis about the quantum dots as biological probes respectively in Science. For the first time, they applied quantum dots to living cell systems for biomarker, which has caused the research craze of quantum dots[9-10].

In this paper, using the Z-scan technique, under the action of 532 nm laser wavelength, 4 ns pulse width and 21 ps pulse width, the nonlinear absorption properties of CdTe / ZnS quantum dots and CdTe / CdS quantum dots were investigated when the laser pulses widths were different. The results of test indicate the nonlinear absorption type of CdTe / ZnS and CdTe / CdS semiconductor quantum dots show saturation absorption under nanosecond and picosecond laser pulses. The nonlinear absorption properties of CdTe / ZnS and CdTe / CdS in the effect of nanosecond laser pulses are stronger than those in the effect of picosecond. The nonlinear absorption properties of CdTe / ZnS under nanosecond laser pulses and picosecond laser pulses are both stronger than that of CdTe / CdS.

2. Experiment

The samples used in this experiment were purchased.Under the nanosecond laser pulse width, the linear transmittances of CdTe / CdS QDs and CdTe / ZnS QDs were 59% and 69%, respectively. Under the picosecond laser pulse width, the linear transmittances of CdTe / CdS QDs and CdTe / ZnS QDs were 59% and 57%, respectively. The UV-visible absorption spectra of CdTe / CdS QDs and CdTe / ZnS QDs are shown in Figure 1.

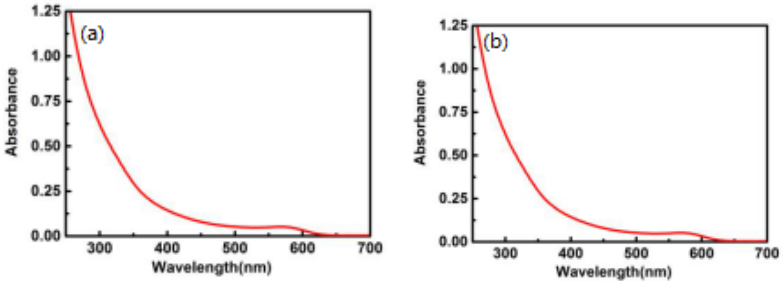

Figure 1. Absorption spectrums of **(a)** CdTe / CdS quantum dots and **(b)** CdTe / ZnS quantum dots

The laser source used in this experiment is Nd: YAG ns / ps laser. The output wavelength of the laser light source is 532 nm. The output light source has the pulses width of 4 ns and 21 ps, respectively. The repetition frequency is 10 Hz. Nanosecond output single pulse energy is 1uJ, picosecond output single pulse energy is 0.35uJ. In the experiment, we employed the Z-scan technique to measure the nonlinear properties of CdTe / CdS QDs and CdTe / ZnS QDs under nanosecond and picosecond laser pulses. The simple schematic diagram of the optical path of experimental equipment is shown in Figure 2, the attenuated laser pulses through the lens to focus on the sample, and change the position of the sample on the optical axis , The light passing through the sample is fall into two beams by the beam splitter, and the reflected light enters detector D_1 to measure the nonlinear absorption characteristics of the material, that is, an Open aperture Z-scan; the light penetrated through the beam splitter passes through an adjustable size of the hole, is received by the detector D_2 to detect the nonlinear refraction characteristics, namely Closed aperture Z-scan. Open aperture and Closed aperture Z-scan characteristic diagrams are shown in Figure 3-1, Figure 3-2, Figure 4-1 and Figure 4-2.

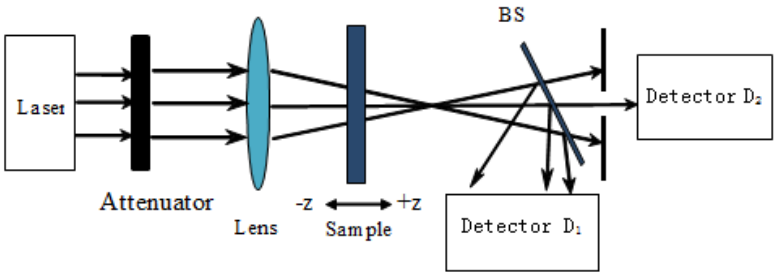

Figure 2. Structure of experimental device of Z-scan

3. Theoretical analysis

The open aperture Z-scan technique is one way could be applied on the study of the optical nonlinear absorption characteristic.In a general way, nonlinear materials absorption properties incorporating saturable absorption and reverse saturable absorption. The reverse saturable absorption is that nonlinear absorption coefficient increase with the beam intensity increases, and the curve shows as a valley, otherwise known as the saturable absorption. Saturated absorption as shown in Figure 3-a. Reverse saturation absorption as shown below in Figure 3-b.

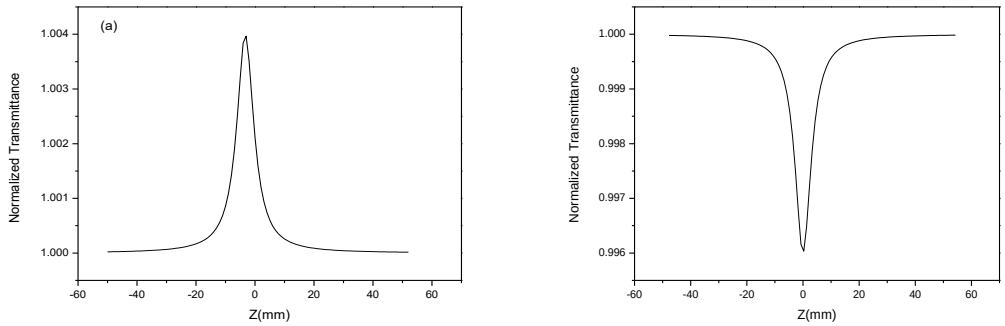

Figure 3 (a) Saturated absorption **(b)** Reverse saturation absorption

The closed aperture Z-scan technique,which is usually used to study the optical nonlinear refraction characteristic. Nonlinear refraction properties incorporating self-focusing and self-defocusing. If the consequence indicates just like valley-peak shape, the refraction properties are self-focusing with a positive nonlinear refractivity. If the picture indicates like peak-valley shape, the refraction properties is self-defocusing with a negative nonlinear refractivity. Self-focusing effect as shown in Figure 4-a. Self-defocusing effect as shown in Figure 4-b.

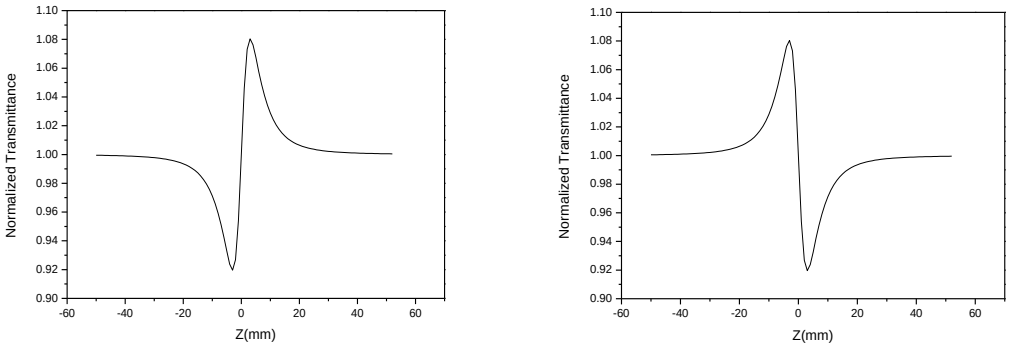

Figure 4 (a) Self-focusing effect **(b)** Self-defocusing effect

The theoretical analysis of Z-scan experimental results are presented by the following formula. The absorption of the material is equal to the linear absorption part plus the nonlinear absorption part, as follows:

$$\alpha(I) = \alpha_0 + \beta I \tag{3-1}$$

Where α_0 is the linear absorption coefficient, I is the light intensity, and β is the nonlinear absorption coefficient.

The normalized energy transmission of open aperture Z-scan can be expressed as[11]:

$$T(z) = \frac{1}{\sqrt{\pi} q_0(z,0)} \int_{-\infty}^{\infty} \ln\left[1 + q_0(z,0) e^{-r^2}\right] dr \tag{3-2}$$

$$q_0(z,0) = \beta I_0 L_{eff} / (1 + z^2 / z_0^2) \tag{3-3}$$

Where I_0 is the on-axis peak intensity at the focus (z=0), E is single pulse energy of the pulsed laser, ω_0 is beam radius size of the focus, τ is pulse width, β is the nonlinear absorption coefficient, Z_0 is the diffraction length of the beam, $L_{eff} = (1 - T_0) \cdot l / (-\ln T_0)$ is the effective thickness of the sample, l is the thickness of sample cell, T_0 is linear transmittance of the solution.

When $|q_0|$ less than 1,the transmittance of medium can be expressed as:

$$T(z) = \sum_{m=0}^{\infty} \frac{[-q_0(z,0)]^m}{(m+1)^{3/2}} \tag{3-4}$$

When m is 0 and 1, Equations (3-4) is changed to:

$$T(Z) = 1 - \frac{q_0(z,0)}{2^{3/2}} = 1 - \frac{\beta I_0 L_{eff}}{\sqrt{8}(1 + Z^2 / Z_0^2)} \tag{3-5}$$

$$A = \beta I_0 L_{eff} \tag{3-6}$$

The normalized transmittance of closed aperture Z-scan curve is[12]:

$$T(z, \Delta\phi) = 1 + \frac{4x\Delta\phi(t)}{(x^2 + 1)(x^2 + 9)} \tag{3-7}$$

Where $\Delta\phi(t) = k I_0(t) n_2 L_{eff}$ is the nonlinear phase shift at the focus, n_2 is the nonlinear refractive index coefficient, $x = Z / Z_0$.

When we consider only the third-order nonlinear of the material, the relationship between the real and the imaginary parts of the third-order nonlinear polarizability and the nonlinear refractive index and the nonlinear absorption coefficient is:

$$\mathrm{Re}\,\chi^{(3)}(esu) = \frac{c n_0^2}{720\pi^2} \cdot n_2 \tag{3-8}$$

$$\mathrm{Im}\,\chi^{(3)}(esu) = \frac{n_0^2 \varepsilon_0 c \lambda}{2\pi} \cdot \beta \times \frac{9}{4\pi} \times 10^8 \tag{3-9}$$

The third-order nonlinear polarizability expression is[13]:

$$\left|\chi^{(3)}\right| = [(\mathrm{Re}(\chi^{(3)}))^2 + (\mathrm{Im}(\chi^{(3)}))^2]^{\frac{1}{2}} \tag{3-10}$$

4. Experimental results and analysis

Experiment results show that the summit wavelength of CdTe / CdS QDs is 565 nm and the summit wavelength of CdTe / ZnS QDs is 580 nm.The bandwidth of CdTe / CdS QDs is 2.19 eV,the bandwidth of CdTe / ZnS QDs is 2.14 eV, based on the UV-visible absorption spectra of these ones.

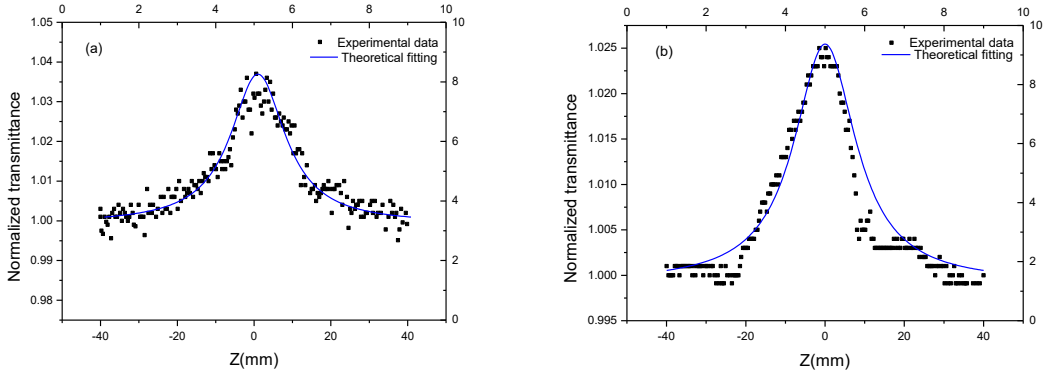

Figure 5. Nonlinear absorption normalized transmittance curves of **(a)** CdTe / CdS quantum dots and **(b)** CdTe / ZnS quantum dots for nanosecond laser pulses

It can be clearly seen from Figure 5 that the nonlinear absorption curves of CdTe / CdS QDs and CdTe / ZnS QDs all exhibit the peak shape under the action of a nanosecond laser pulses. These show that the nonlinear absorption showed saturated absorption, with the increase of light intensity, its transmittance will increase, the absorption will decrease.

The theoretical fitting of Z-scan data using the formulas 3-2 and 3-3 shows that under the condition of nanosecond laser pulse, the nonlinear absorption coefficient of the CdTe / CdS QDs is -2.08×10^{-10} m / W, the nonlinear absorption coefficient of CdTe / ZnS QDs is -2.57×10^{-10} m / W.

Obviously, the nonlinear absorption coefficient of CdTe / ZnS QDs is larger than CdTe / CdS QDs.

Similarly, Repeating the above experiment, we get the normalized curves of the open aperture Z-scan of CdTe / ZnS QDs and CdTe / CdS QDs under picosecond laser pulses, as shown in Figure 6.

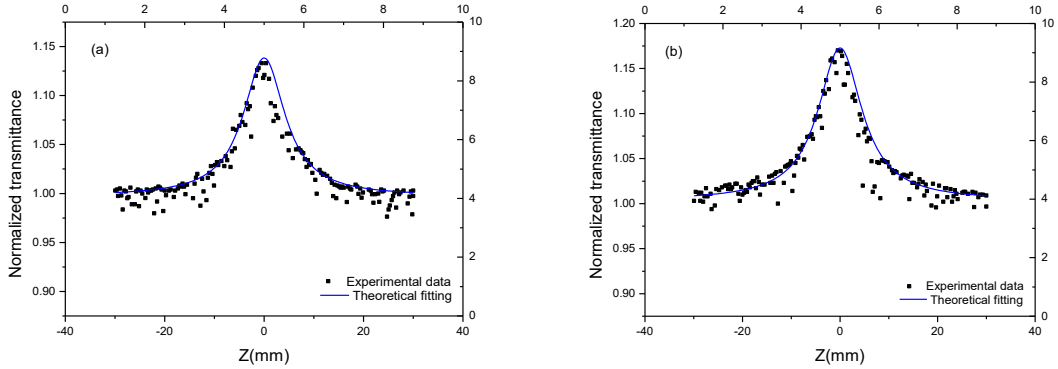

Figure 6. Nonlinear absorption normalized transmittance curves of **(a)** CdTe / CdS quantum dots and **(b)** CdTe / ZnS quantum dots for picosecond laser pulses

From the experimental data fitting, we can see that CdTe / ZnS QDs and CdTe / CdS QDs exhibit a peak shape,and both of samples show saturated absorption.The materials show the decrease of absorption when the increase of incident light intensity. By fitting the experimental data, we can conclude that the nonlinear absorption coefficient of CdTe / CdS QDs is 1.14×10^{-11}m / W and CdTe / ZnS QDs is -1.38×10^{-11}m / W. it can be seen that the nonlinear absorption of CdTe / ZnS QDs is stronger than that of CdTe / CdS QDs under a condition of picosecond laser pulses.

5.Conclusion

In this paper, CdTe / CdS and CdTe / ZnS semiconductor quantum dots as the experimental object,the nonlinear optical characteristics of Z-scan technology were compared and analyzed under nanosecond and picosecond laser pulses.The results of experimental indicate that the nonlinear absorption are saturated absorption under the action of 532 nm nanosecond and picosecond laser pulses. The nonlinear absorption coefficients of CdTe / CdS QDs and CdTe / ZnS QDs under the nanosecond laser pulse are -2.08×10^{-10} m / W and -2.57×10^{-10} m/W, respectively;the nonlinear absorption coefficients in the effect of picosecond laser pulse are -1.14×10^{-11} m/W and -1.38×10^{-11} m/W, respectively.The consequences indicate the nonlinear absorption characteristics of CdTe / ZnS QDs and CdTe / CdS QDs under the condition of nanosecond laser pulse are stronger than that in the effect of picosecond laser pulses. In the meantime, Under these two different laser pulses widths, the nonlinear absorption properties of CdTe / ZnS QDs are both stronger than that of CdTe / CdS QDs.

6.Reference

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