Optical nonlinearities and optical limiting properties of PbS semiconductor nano-belts

Bei Cao (曹 贝)[1], Yundong Zhang (掌蕴东)[1], Honggang Zhang (张宏刚)[2], and Junjie Zhu (朱俊杰)[3]

[1]*National Key Laboratory of Tunable Laser Technology, Institute of Opto-Electronics, Harbin Institute of Technology, Harbin150001*

[2]*Shenyang Normal University, Shenyang 110034*

[3]*College of Chemistry and Chemical Engineering, Nanjing University, Nanjing 210093*

The third-order nonlinearities of PbS nano-belts have been investigated using the Z-scan technique with nanosecond laser pulses at 532 nm. The effect of the PbS semiconductor nano-belt size on the third-order optical nonlinearities and optical limiting properties was studied. We found that the nonlinear absorption and nonlinear refraction have not strict dependence on the nano-belt size under our investigated condition, but their optical limiting behavior is different. The optical limiting mechanism of materials is discussed.

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In the quantum-confined region, semiconductor nanoparticles exhibit novel nonlinear optical properties[1−3]. Nanometer-sized semiconductor material with large third-order optical nonlinearity and fast response time, due to application prospects in optical limiting and optical switching devices, is a hot topic in theoretical and experimental research at all times. In this paper, we investigated the effect of the PbS semiconductor nano-belt size on the third-order optical nonlinearities and optical limiting properties by Z-scan and nonlinear transmission technique with 8-ns pulse excitation at 532 nm. The optical limiting mechanism of PbS nano-belts is discussed in terms of nonlinear refraction and nonlinear absorption.

We synthesized PbS nano-belts by chemical method, the nano-belt size is 240–1400 nm in length, 10–60 nm in width. Figure 1 shows the TEM photos of PbS nano-belts, the size of PbS samples is listed in Table 1. We can find that the linear absorption spectra of the PbS nano-belts exhibit blue shift in the absorption edges compared with that of the bulk PbS[4] in Fig. 2. The longer tail of the absorption band may be attributed to the size distribution of nano-belts and defects on particle surface.

The Z-scan technique is a sensitive single-beam method for measuring both the nonlinear refractive index and nonlinear absorption coefficient for a wide variety of materials[5]. We first calibrate experimental configuration by the measured Z-scan result of CS_2. A doubled-frequency Nd:YAG pulse laser at 532 nm with 8-ns pulse width is used in experiment with repetition rate of 1 Hz to avoid the thermal accumulation. The laser pulse has a Gaussian spatial profile and was focused by a lens with $f = 31$ cm, and the beam waist was $\omega_0 = 50$ μm. The incident peak intensity is 0.19 GW/cm^2. The thick of the quartz cuvette is 2 mm, and hence, the condition of thin sample approximation is satisfied in this experiment[5]. The PbS sample under investigation was placed near the waist of a focused Gaussian beam and moved in the direction of propagation of the light. The transmission

Table 1. The Nonlinear Refractive Iindex, Nonlinear Absorption Coefficient, and Size of PbS Nano-Belts

	0515	0514	0520	0504
Width (nm)	10	20	40	60
Length (nm)	240	350	1400	1100
γ ($\times10^{-4}$ cm^2/GW)	6.96	5.55	5.92	6.15
β (cm/GW)	7.02	6.93	6.61	6.64

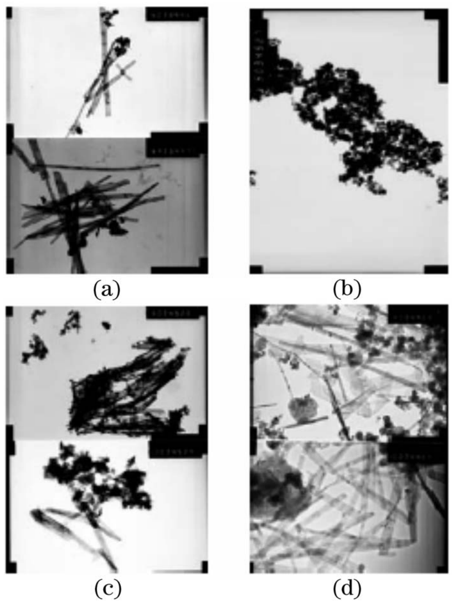

Fig. 1. The TEM image of PbS nano-belts.(a) 0504; (b) 0515; (c) 0514; (d) 0520.

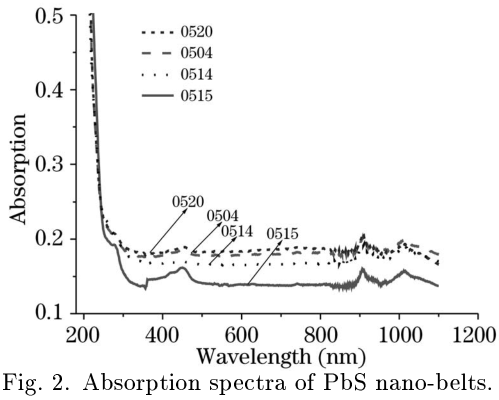

Fig. 2. Absorption spectra of PbS nano-belts.

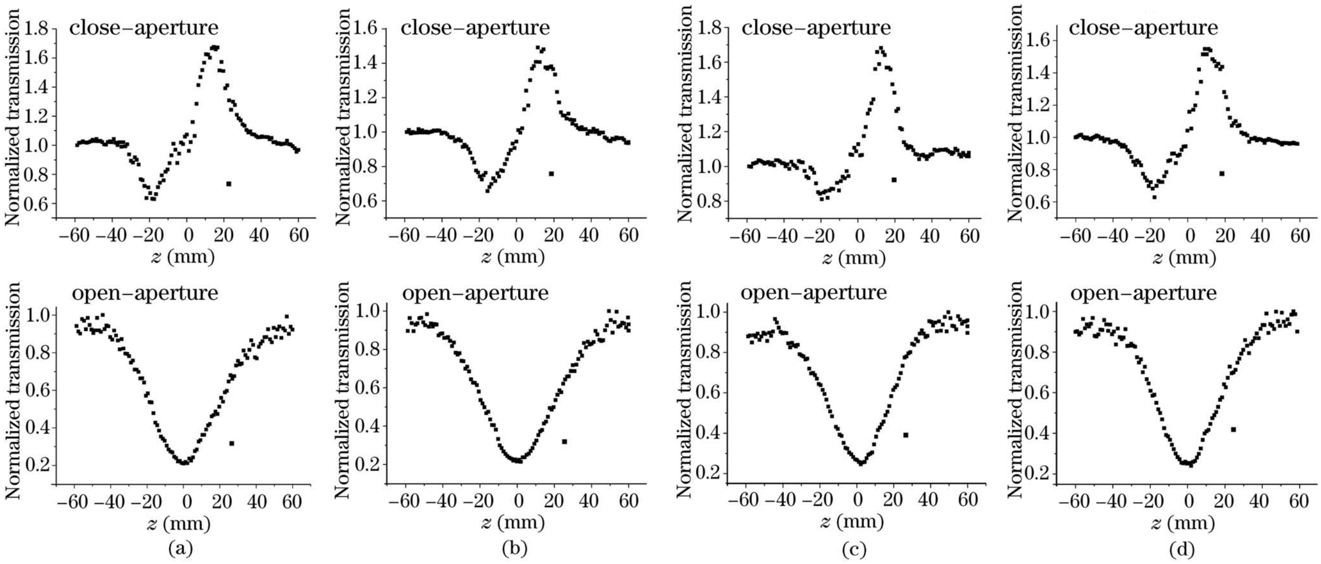

Fig. 3. Z-scan data of the PbS nano-belts with 8 ns at 532 nm. The incident peak intensity is 0.19 GM/cm^2. (a) 0515, (b) 0514, (c) 0520, (d) 0504.

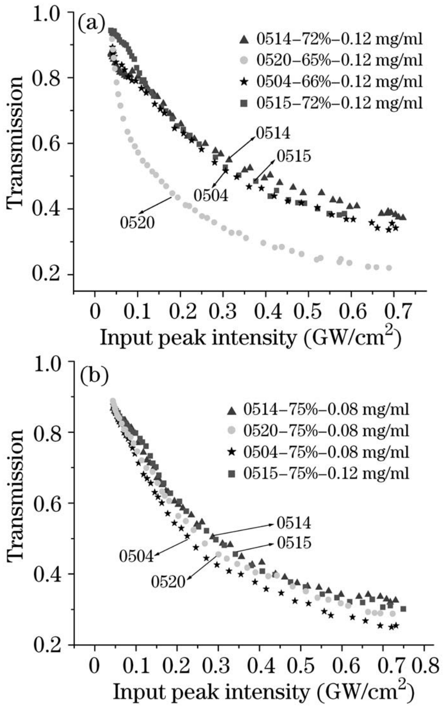

Fig. 4. Optical limiting in four kinds of PbS semiconductor nano-belts with the same concentration and the same linear transmittance.

from the sample was measured simultaneously with and without an aperture in the far-field of lens by detectors (Newport Corp. 818 J). The data were collected by a computer at real time. We measured the optical limiting curves under the same experimental condition by nonlinear transmission method. All the experiments were carried out at room temperature.

The open-aperture and closed-aperture Z-scan results are shown in Fig. 3 with the same linear transmission. We can obtain the nonlinear refraction index n_2 and nonlinear absorption coefficient β by simulating and fitting to these Z-scan curves, respectively, as listed in Table 1. But, we found that the difference of nonlinear index is small between different nano-belt sizes from the experimental results. In order to investigate the physical mechanisms of optical limiting, we measured the limiting curves at the same concentration and the same linear transmittance. It is obvious that the behaviors of optical limiting are different, as shown in Fig. 4. The reason for the difference of optical limiting may be due to the nano-belt size and spatial forms. Some information can be obtained from these results. First, the sign of the refraction index is positive, and the nonlinear refraction is self-focusing effect. Second, it is distinct that the shape of open-aperture Z-scan shows the nonlinear absorption is two-photon absorption, but we should take into account free-carrier-absorption processes in the nanosecond time domain. Third, the bigger is the size of the nano-belts, the stronger is the behavior of optical limiting. The optical limiting properties of PbS nano-belts are mainly relevant to third-order optical nonlinearities. The experimental results indicate that the PbS nano-belts are practical materials for application in optical devices.

The results of experiment show that the nonlinear absorption and nonlinear refraction do not depend critically on the nano-belts size in our investigated size range, but the optical limiting behavior is related to nano-belt size. It is necessary to take into account free-carrier-absorption processes in the nanosecond time domain. The main optical limiting mechanisms with the PbS nano-belts come from the contributions of the two photon absorption and free carrier process at 532 nm.

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