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Investigation on thermally-induced optical nonlinearity of alcohols

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ABSTRACT

In this work, we studied the thermally-induced optical nonlinearity of alcohols by analyzing the far-filed diffraction rings patterns, which are generated when the alcohols are illuminated by a laser beam resonant to their overtones. We deduced the nonlinear refractive index coefficient n_2 generated by thermal nonlinear optical effect to be $-(20.53 \pm 00.03) \times 10^{-8}\ \mathrm{cm}^2/\mathrm{W}$, which is much higher than that of Kerr effect ($7.7 \times 10^{-16}\ \mathrm{cm}^2/\mathrm{W}$). The results also demonstrated that the thermally-induced optical nonlinearity increased with the laser power and sample concentration increasing. The notable nonlinearity suggests that thermal effect has potentials in many applications such as optical spatial modulation, and trapping and guiding of atoms.

1. Introduction

A number of nonlinear optical phenomena occur due to the light intensity dependent nonlinear refraction index. Taking advantages of those phenomena, people have developed many novel applications, such as all-optical modulation [1,2], optical switching [3–6], optical limiting [7–9], optical delays [10,11]. In mostly reported cases, nonlinear refraction indexes are obtained based on the optical Kerr effect. In fact, thermal nonlinear optical effect can also generate intensity dependent nonlinear refraction index [12–15]. Because it has similar properties as Kerr effect, it is also named as "Kerr-like effect" [16]. The principle of the thermal nonlinear optical effect is that: when the laser beam passes through a medium, the medium is heated and a temperature gradient is formed at the local area, which would result in thermal expansion. Then the acoustic wave propagating in a medium changes the density distribution of the medium, which finally changes the refractive index. As the temperature gradient is closely related to the light intensity, the thermally-induced refractive index is light intensity dependent. Thermal nonlinearities are commonly larger than the electronic nonlinearities of the same material by several orders of magnitude [17]. Nevertheless, there are relatively fewer researches.

In this work, we report the observation of far-field diffraction rings pattern of O-H bond based on thermal nonlinear optical effect. Experimentally, we take ethanol, methanol, propanol and butanol as the nonlinear mediums and obtain the far-field diffraction rings patterns around the overtone region of the vibration of O—H bond at the range from 720 nm to 830 nm. The characteristics of far-field diffraction rings patterns regarding to the laser power, the concentration and position of sample are demonstrated. To illustrate the results, thermal nonlinear optical effect is considered theoretically. Finally, the nonlinear refractive indexes are approximated by the number of the diffraction rings, which are further confirmed by the z-scan method. The notable nonlinearity (8 orders higher than Kerr effect) suggests that thermal nonlinear optical effect has potentials in many applications. For example, people can achieve a continuous lateral phase modulation of incident light by changing the laser power, the concentration and the position of sample [18]. Such a phase modulation method is of particular advantage for the intense laser beam because of the high damage threshold. Moreover, hollow laser beam of tunable size can be obtained, which is of particular importance in trapping the particles of various sizes [19].

2. Experiment

A Gaussian beam is obtained from a tunable Titanium sapphire laser (Spectra-Physics, Matisse TR, CW, tunable from 740–850 nm) and focused into nonlinear medium by a lens with a focal length of 200 mm. The radius of laser beam at output is 0.7 mm and the beam waist at focus is estimated to be 70 µm or so. The wavelength of the laser was set at 765 nm during the experiments.

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The samples (methanol, ethanol, propanol, butanol and acetone) were kept in quartz cuvettes, of which the optical path length is 1 cm. The images of the beams at the output side of the samples were received directly by a screen.

Firstly, we find the diffraction rings patterns only appear from alcohols (methanol, ethanol, propanol and butanol), not from acetone. Typical images of the diffraction rings patterns are shown in Fig. 1(a)–(d), which were obtained with the laser power fixed at 75 mW, the laser wavelength fixed at 765 nm, and the purities of the samples were all 99%. Two diffraction rings with a bright central spot were observed with all the alcohols. However, there is no diffraction ring obtained with the acetone.

Secondly, we took ethanol as an example and studied the effect of concentration on the diffraction rings pattern. We changed the volume ratio of ethanol over deionized water and observed different diffraction rings pattern on the screen (shown in Fig. 2). The laser power was fixed at 120 mW. It is seen that the number of diffraction rings decreases with the concentration of ethanol decreasing. However, there is no diffraction ring obtained without ethanol. In addition, the diffraction pattern is asymmetry when concentration of sample is high.

Thirdly, we investigated the influence of the laser power on the diffraction rings pattern. The volume ratio of ethanol over deionized water was set as 4:1. Fig. 3(a) shows the images of the diffraction rings patterns obtained at the laser power of 60 mW, 75 mW, 90 mW, 105 mW and 120 mW respectively. It is seen that the number of diffraction rings increases with the laser power increasing and the size of the central spot decreases at the same time.

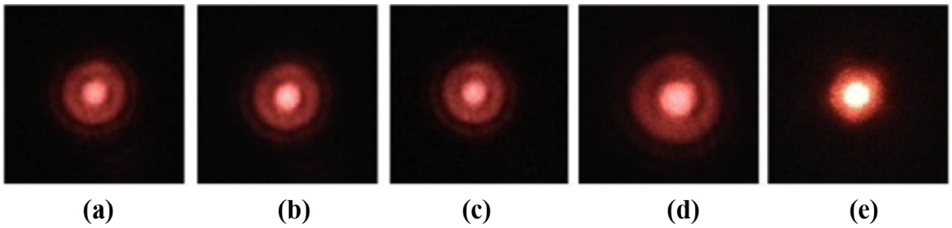

Fig. 1. Diffraction rings patterns of a laser beam passing through quartz cuvettes with various samples: (a) methanol, (b) ethanol, (c) propanol, (d) butanol, (e) acetone. The wavelength of the laser was set at 765 nm, laser power was fixed at 75 mW, and the purities of sample were 99%.

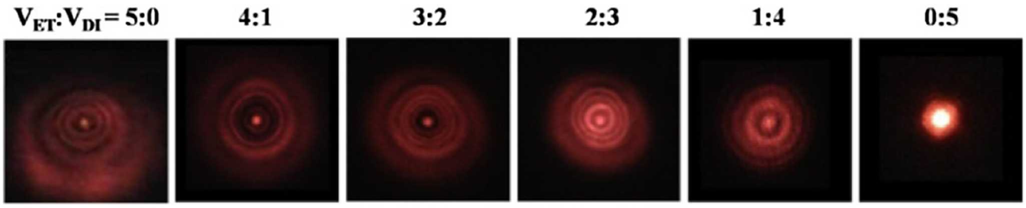

Fig. 2. The influence of the concentration of ethanol on diffraction rings pattern in experiment. The wavelength of the laser was set at 765 nm, laser power fixed at 120 mW.

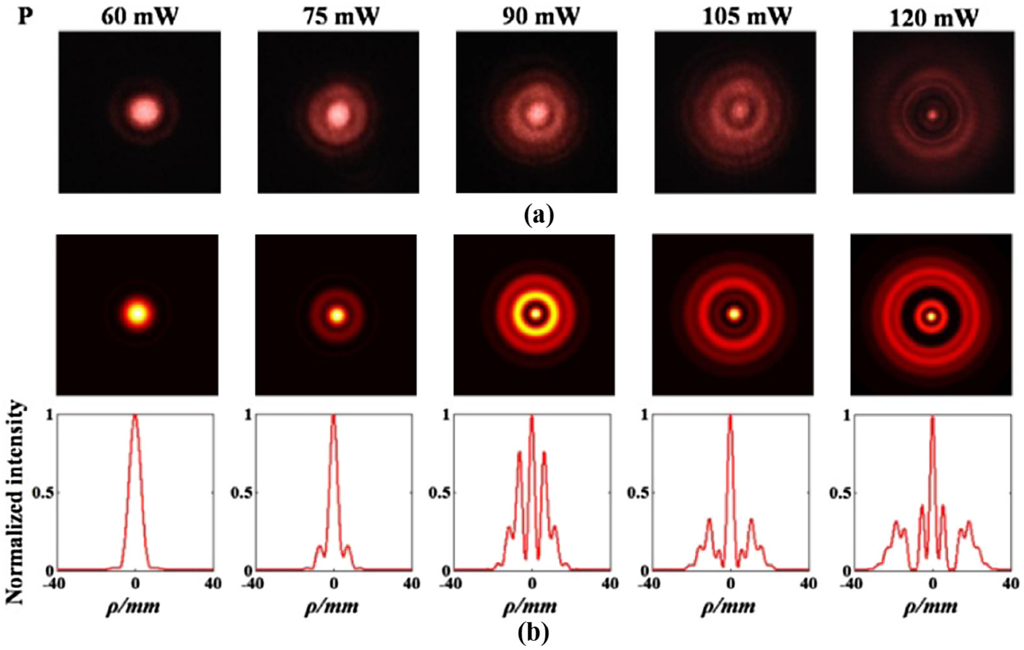

Fig. 3. (a) The experimental graphs of the far-field diffraction rings patterns with four different laser powers. (b) The simulation graphs of the diffraction patterns on x-y plane and the radial intensity distribution according to the experimental conditions. The wavelength of the laser was set at 765 nm, and the volume ratio of ethanol over deionized water was kept as 4:1.