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Thermal-Induced Non-linearity of Ag Nano-fluid Prepared using γ-Radiation Method

(Induksi-Terma Ketidak-Linearan Nanocecair Ag disedia Menggunakan Kaedah Sinaran-γ)

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ABSTRACT

The non-linear refractive index of Ag nano-fluids prepared by γ-radiation method was investigated using a single beam z-scan technique. Under CW 532 nm laser excitation with power output of 40 mW, the Ag nano-fluids showed a large thermal-induced non-linear refractive index. In the present work it was determined that the non-linear refractive index for Ag nano-fluids is -4.80×10^{-8} cm^2/W. The value of Δn_0 was calculated to be -2.05×10^{-4}. Our measurements also confirmed that the non-linear phenomenon was caused by the self-defocusing process making them good candidates for non linear optical devices.

Keywords: γ-radiation; nanofluid; non-linear refractive index; z-scan

ABSTRAK

Indek biasan taklinear nanocecair Ag yang disediakan dengan kaedah sinaran-γ telah dikaji menggunakan teknik imbasan-z alur laser tunggal. Di bawah pengujaan laser CW 532 nm dengan kuasa sinaran 40 mW, nanocecair Ag telah menunjukkan satu sifat indeks biasan tak-linear yang besar. Dalam kajian ini ditentukan bahawa indek biasan tak-linear untuk Ag adalah -4.80×10^{-8} cm^2/W. Nilai Δn_0 telah dikira dan bernilai 2.05×10^{-4}. Pengukuran kami juga mengesahkan bahawa fenomena tak-linear adalah disebabkan oleh proses nyahfokus-dirian membuatkan ianya calon yang baik untuk reka bentuk optik tak-linear.

Kata kunci: Imbasan-z; indek biasan tak-linear; nanocecair; sinaran-γ

INTRODUCTION

The field of non-linear optics has opened up a new frontier in science and technology. The major requirements for non-linear optical materials are; large non-linear optical (NLO) response, low losses at the wavelength(s) of interest, good optical quality, mechanical stability, easy preparation procedures and low cost. In this context, metallic nanoparticles are known to be among the most suitable and promising materials. Metal nano-fluids has demonstrated a vast range of applications such as the labeling of biological molecules, surface enhanced Raman scattering, optical limiter and optical photonics devices (Jia et al. 2008; Palpant 2006; Sutherland 1996). Z-scan method is one of the simple and accurate methods for measuring the non-linear optical properties such as non-linear refraction and non-linear absorption of solid and liquid samples (Chen et al 1999; Li et al. 2001; Yang et al. 2004). This method also provides the magnitudes of real and imaginary part of non-linear susceptibility and the sign of the real part can be simultaneously determined (Almond & Patel 1996; Moran et al. 1975; Oliveira & Zilio 1994; Yüksek et al. 2008).

The non-linear optical properties measurement of metal Au and Ag colloidal solutions prepared using chemical reaction method has been recently reported by Jia et al. (2008). Under CW 633 nm excitation they found that all open aperture z-scan data show a linear absorption behavior. In the present work we report the non-linear refractive index of Ag nano-fluids prepared using γ (^{60}Co-rays) radiation at 30 kGy level.

METHODOLOGY

To prepare Ag nano-fluid sample, 2 mg of silver nitrate ($AgNO_3$ Aldrich-99%), 1.5 g of polyvinylpyrrolidone (PVP, MW 29,000 Aldrich) and 1 mL isopropanol were used. The PVP and isopropanol were used as a colloidal stabilizer and radical scavenger of hydroxyl radical, respectively. The PVP solution was made by dissolving PVP powder in 50 mL of deionized water at room temperature. The solution was stirred for 2 h and was bubbled with nitrogen gas (99.5%) in order to remove oxygen.

The γ-radiation (^{60}Co-rays) source is an effective tool for polymerization process and reducing agent. Silver nitrate ($AgNO_3$) was added into PVP solution and isopropanol, which acted as a hydroxyl radical scavenger. The concentration of Ag nanoparticles in solution was calculated to be 2.35×10^{-4} M. The sample was then irradiated with γ-radiation at a dose of 30 kGy. In this process, γ-irradiation produces hydrated electrons that reduce the silver ions to silver atoms, which then aggregated in the solution. The average diameter of Ag nanoparticles was measured using nanophox machine (Sympatec GmbH, D-38678) and the particles average size was recorded as 26 nm. The linear absorption spectrum for samples was measured using UV-Vis spectrophotometer (Shimadzu-UV1650PC).

Figure 1 shows the schematic diagram of a single beam z-scan experiment used in the present measurement. The experiments were performed using a 532 nm laser beam from a diode laser (Coherent Compass SDL-532-150T). The beam was focused to a small spot using a lens and the sample was moved along the z-axis by a motorized translational stage. At the focus point the power output of the laser beam measured was 40 mW. The transmitted light in the far field passed through the aperture and the beam intensity was recorded by a photodiode detector, D. The laser beam waist ω_0 at the focus length was measured to be 24.4 μm and the Rayleigh length was found to satisfy the basic criteria of a z-scan experiment. A quartz optical cell containing specimen solution was moved across the focal region along the z-axial direction.

RESULTS AND DISCUSSION

Figure 2 shows the absorption spectrum for Ag nano-fluids with the surface plasmon absorption peaks located at 410 nm. This implies that the thermal induced non-linearity absorption in Ag nano- fluid is small since the surface plasmon peak is far from the wavelength of laser beam used in the present experiment.

Figure 3 shows the transmittance curve obtained for Ag nano-fluids. The laser intensity measured I_0 was as 4.27×10^3 W/cm^2 and the aperture linear transmittance was 0.17. The peak-valley curves indicate that the non-linear refractive index of the medium is negative.

Furthermore, the symmetrical shape shows that the non-linear absorption is very small. Our experimental data were calibrated with data for distilled water in which there is no measurable signals detected. The third order

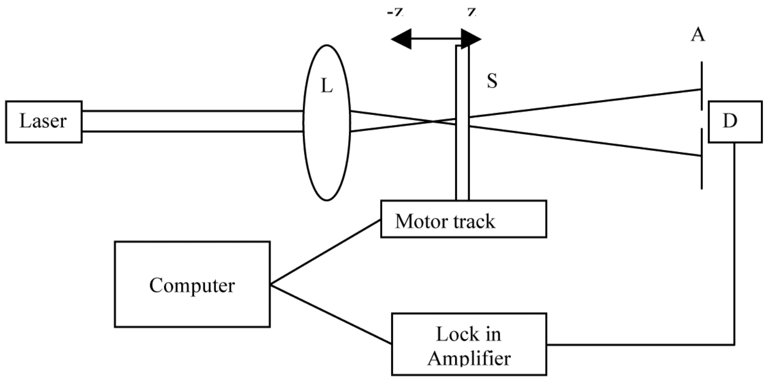

FIGURE 1. Schematic diagram of a single beam z-scan experiment setup: L, Lens; S, Sample; A, Aperture; D, Detector

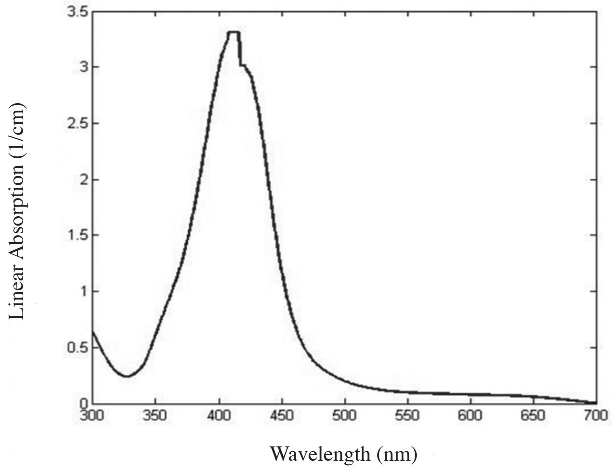

FIGURE 2. Absorption spectrum of (Ag-PVP) nano-fluid at concentration of 2.35×10^{-4} M. The average particle size is 26 nm

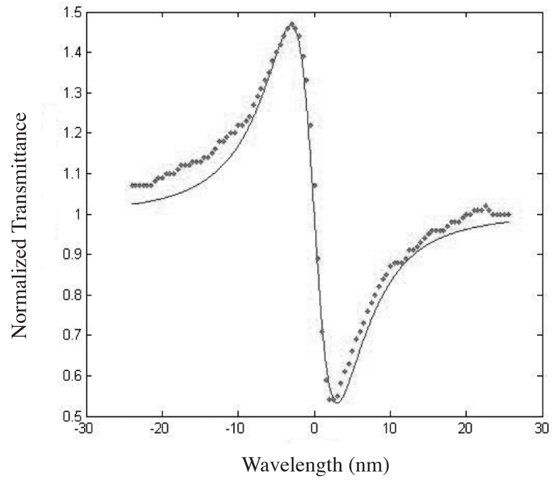

FIGURE 3. Closed aperture z-scan experimental data for (Ag-PVP) nano-fluid under laser excitation at 532 nm wavelength. The solid line is the curve calculated using Equation 3

non-linear refractive index, n_2 was calculated using the expression reported by Sheik-Bahae et al. (1990); Xia et al. (1994) as:

$$n_2 = \frac{\Delta\phi_o}{kL_{eff}I_o}, \qquad (1)$$

where $k = 2\pi/\lambda$. I_o is the beam intensity at focus point, $L_{eff} = (1 - e^{-\alpha L})/\alpha$ is the effective thickness of the sample. In the present work the linear absorption coefficient, α was obtained from the absorption spectrum of Figure 2. The phase change, $\Delta\phi_o$ was calculated from the experimental data of normalized peak to valley transmittance, ΔT_{p-v} expressed as:

$$\Delta T_{p-v} \approx 0.406(1-s)^{0.25}|\Delta\phi_o|, \qquad (2)$$

where s is the aperture linear transmittance. The solid line in Figure 3 is the calculated values using analytical equation proposed by Liao et al. (1997, 1998):

$$T(z,\Delta\phi) = 1 - \frac{4\Delta\phi_o x}{(x^2+1)(x^2+9)}. \qquad (3)$$

The shape of curves calculated using Equation (3) are generally in good agreement with the experimental data obtained for Ag nano-fluid sample. Using the values of I_0 and s measured in the present work, we obtained the value of non-linear refractive index n_2 for Ag nano-fluid sample as -4.80×10^{-8} cm^2/W. Knowing n_2, the change in non-linear refractive index at the focus can be calculated as $\Delta n_0 = n_2 I_0$ where I_0 being the on-axis irradiance at the focus. The value of Δn_0 and linear absorption coefficient for the present sample are -2.05×10^{-4} and 0.115 cm^{-1}, respectively.

Conclusion

Thermal-induced non-linearity of Ag nano-fluid prepared using γ-radiation method was successfully measured using a single beam z-scan technique. The values of non-linear refractive index, n_2 for Ag nano-fluid obtained using CW 532 nm laser excitation was -4.80×10^{-8} cm^2/W. The value of Δn_0 for Ag nano-fluids was also calculated to be -2.05×10^{-4}. The experiment also confirmed that the non-linear phenomenon was caused by the self-defocusing process.

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