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Physical origin of observed nonlinearities in Poly (1-naphthyl methacrylate): Using a single transistor-transistor logic modulated laser beam

Qusay M. A. Hassan, Hussain A. Badran†, Alaa Y. AL-Ahmad, and Chassib A. Emshary

Department of Physics, College of Education, University of Basrah, Basrah, Iraq

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A thermal lens technique is adopted using a single modulated continuous wave (cw) 532-nm laser beam to evaluate the nonlinear refractive index n_2, and the thermo-optic coefficient $\mathrm{d}n/\mathrm{d}T$, in polymer Poly (1-naphthyl methacrylate) (P-1-NM) dissolved in chloroform, tetrahydrofuran (THF), and dimethyl sulfoxide (DMSO) solvents. The results are compared with Z-scan and diffraction ring techniques. The comparison reveals the effectiveness and the simplicity of the TTL modulation technique. The physical origin is discussed for the obtained results.

Keywords: nonlinear refractive index, thermo-optic coefficient, self-phase modulation, nonlinear optics

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1. Introduction

It is well recognized that measurements of thermophysical properties are important for the researchers interested in the optical materials area. The interaction between lasers and matter can result in thermal loading causing degradation and/or reduction of the thermal performance. The changes in properties such as thermal conductivity, thermal diffusivity, and temperature coefficient of optical length with the sample temperature rise define the figure of merit for a given material. The measurements of these properties as a function of temperature with traditional methods are always a challenging goal since it requires high cost devices and an appropriate excitation regime to obtain the data, especially when performed in the temperature interval where the material is submitted to a phase modification.[1,2]

The thermal lens (TL) spectroscopy is one of the most sensitive absorbance methods used in the measurement of a temperature rise following the conversion of the absorbed optical radiation into heat through non-radiative relaxation process.[1] Absorption of a laser beam generates thermal energy in the medium through non-radiative de-excitation resulting in an increase of the temperature of the irradiated region. The temperature distribution of the irradiated region will be the same as the intensity distribution across the beam cross section which is usually Gaussian. Since most liquids have a positive coefficient of thermal expansion, the thermo-optic coefficient, $\mathrm{d}n/\mathrm{d}T$, is negative and consequently the thermal lens generated is a divergent one. The formation of the thermal lens can be probed either by the same pumping beam[3] or by a dual beam.[4] The thermal lens generated by the refractive index when a sample is placed beyond the beam waist ω_0, by one confocal length, $\pi\omega_0^2/\lambda$, is detected by its effect on the intensity at the center of the probe laser beam measured through a pinhole aperture with a photodiode, where λ is the light wave length.

Thermal lens spectroscopy has drawn attention due to its application in measurements of the thermo-optical properties in an optical material. In addition, it was used in two different techniques, the mode matched thermal lens[5,6] and the mode mismatched thermal lens spectropies.[7] It was used in a variety of applications such as scanning microscopy,[8] food analysis, and environmental research,[9,10] realization of optical logical gates,[11] measurements in microchips,[12] microchemical chips,[13] complex fluids,[14] investigation of the quantum yield,[15,16] ion chromatography,[17] and determination of iodine.[18]

Changes in refractive index induced by an optical field can give rise to various nonlinear phenomena in optical materials.[19] In the spatial dimension, the interplay between the divergence of the propagating beam and the nonlinear optical response of the medium can give rise to a wide range of self-action ranging from optical self-trapping to spontaneous formation of ring patterns due to the modulation instability.[20] A related phenomenon is the spatial self-modulation of a coherent beam which generates concentric intensity rings in the far field. The diffraction rings have been observed in nematic liquid crystals by Zolotko *et al.*,[21] in thermally dependent refractive index,[22] polymer films,[23] in Kerr media[24,25] and liquid crystals.[26,27]

The diffraction ring pattern is understood from the spatial self-modulation effect. A pump beam with a Gaussian intensity profile should induce a phase shift $\Delta\Phi$, with a bell-shaped transverse profile. For each point y_1, on the Gaussian distribution of the beam, another point profile y_2 exists, with the

†Corresponding author. E-mail: badran_hussein@yahoo.com

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