Journal of the Optical Society of America B
OPTICAL PHYSICS

Closed aperture CW Z-scan of L-tryptophan for determination of optical nonlinearity in the thermal regime

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Received 11 June 2021; revised 16 July 2021; accepted 1 August 2021; posted 2 August 2021 (Doc. ID 432845); published 7 September 2021

The closed aperture continuous wave Z-scan of L-tryptophan at 661 nm was performed to investigate the variation of on-axis nonlinear phase shift ($\Delta\Phi_0$) with the change of optical field strength. $\Delta\Phi_0$ was found to vary nonlinearly with irradiance (I_0) in the range from 150 to 290 MW/m^2. This nonlinear variation is explained by considering the effect of linear and nonlinear absorption of radiation on the thermo-optical refractive index. Using the quadratic fitting of $\Delta\Phi_0$ with I_0, we have found the thermo-optic coefficient of refractive index dn/dT, thermal coefficient of nonlinear refractive index n_2^T, and the nonlinear absorption coefficient β in the observed power regime.

https://doi.org/10.1364/JOSAB.432845

1. INTRODUCTION

Z-scan is a popular technique for determining the nonlinear refractive index (n_2) and the nonlinear absorption coefficient (β). It is a much simpler technique, in terms of both requirement for experimental apparatus and data analysis, but, on the other hand, it has higher sensitivity as compared to other techniques like third-harmonic generation (THG) [1], degenerate four-wave mixing (DFWM) [2], and Mach–Zehnder interferometry [3]. Z-scan has an advantage in indicating the sign of nonlinearity immediately. Since the proposition of this technique in 1989 by Sheikh Bahae *et al.* [4] and their subsequent works further elucidating the details of this technique [5–8], it has become a widely used method for studying third-order optical nonlinearities in different types of materials. There are several variants of this technique, such as the conventional single-beam transmission Z-scan (TZ-scan) [4], two-color Z-scan [6] eclipsing Z-scan (EZ-scan) [8], time resolved Z-scan [9], reflection Z-scan (RZ-scan) [10], and modified Z-scan method [11]. In our study, the single-beam transmission Z-scan has been utilized in characterizing the third-order nonlinear response of L-tryptophan. In this technique, a sample is translated along the propagation axis of a focused laser beam with Gaussian profile, and the transmitted beam is detected and analyzed at a far-field position. In the case of closed-aperture Z-scan, the on-axis optical field transmitted through a small aperture in the far field position detects the change in refractive index of the medium due to nonlinear optical interaction. On the other hand, the total optical power transmitted through the sample is measured in the case of open-aperture Z-scan, which detects the nonlinear absorption in the material. This technique has been used to study the third-order nonlinearity in semiconductors [12–17], organic- or carbon-based materials [18–24], and biomaterials like total protein and albumin in blood [25–28]. This technique has also been used in quantification of cholesterol and triglycerides in blood [29], in determining nonlinear optical (NLO) response of native and oxidized low-density lipoprotein (LDL) particles as a function of temperature [30,31], fibrillization of amyloid fibrils and insulin fibrils [32], and the nonlinear refractive index of retinal aldehyde [33]. There have been quite a number of investigations on the third-order nonlinearity of amino acids in the femtosecond regime at different wavelengths and under different conditions [34–37]. The nonlinear refractive index of some standard materials like CS_2, SiO_2, H_2O, and tryptophan in water solution in the femtosecond regime were found using EZ technique [38].

The theory of Z-scan was originally developed for describing the third-order nonlinear response at molecular and electronic levels using a femtosecond-pulsed laser at low repetition rate. In this case, the nonlinear refraction is purely Kerr type and the coefficient of refraction n_2 is a constant [1–6]. With a CW or quasi-CW laser, i.e., at megahertz pulse rate, the molecular reorientation and thermal contribution to the nonlinear response becomes significant. Thermal effect dominates the nonlinear effects in the CW laser regime, as the time scale at which other mechanisms ensue is very small (10^{-15} s in the case of electronic polarization to 10^{-8} s in the case of saturated