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ARTICLE

Thermal-induced nonlinearities in rose, linseed, and chamomile oils using continuous wave visible laser beam

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Abstract: Self-diffraction rings or spatial self-phase modulation were observed in rose, linseed, and chamomile oils under 473 nm continuous wave laser irradiation. The measurements were performed by propagating the laser beam through a cell containing each sample. The number of rings as well as diameter of the outer-most ring in each pattern obtained increases monotonically with increasing input power. The diffraction ring patterns are theoretically simulated using Fresnel–Kirchhoff diffraction integral in the case of an optically thin medium. The experimental and simulation results show that when a laser beam with Gaussian profile is transmitted through an oil medium, a series of circular diffraction rings forms in the intensity distribution pattern in the far-field. The nonlinear refractive index, n_2, was determined from the number of observed rings and by the Z-scan technique. The results obtained from self-diffraction rings experiment and Z-scan are compared and analyzed for the three different oils. A large value was obtained of the order of $n_2 = 1.32 \times 10^{-6}$ cm^2/W for chamomile oil using the diffraction ring pattern technique. This large nonlinearity is attributed to a thermal effect resulting from linear absorption. Moreover, the optical limiting characteristics of rose, linseed, and chamomile oils were investigated.

Key words: self-phase modulation, thermal nonlinearity, diffraction ring pattern, nonlinear refractive index, Z-scan technique.

Résumé : Nous observons des anneaux d'auto-diffraction ou une modulation d'auto-phase spatiale dans des huiles de rose, de lin et de camomille sous irradiation laser en continu à 473 nm. Les mesures s'effectuent en propageant le faisceau laser à travers une cellule contenant chaque échantillon. Le nombre d'anneaux, ainsi que le diamètre de l'anneau extérieur croissent de façon monotone avec l'augmentation de la puissance laser. Les patrons d'anneaux de diffraction sont simulés théoriquement en utilisant l'intégrale de Fresnel–Kirchhoff dans le cas d'un milieu optique mince. Les résultats expérimentaux et théoriques montrent que lorsque un faisceau laser avec un profil gaussien est transmis à travers le medium huile, une série d'anneaux de diffraction circulaire se forme dans le patron de distribution d'intensité dans le champ lointain. L'indice de diffraction non linéaire n_2 est déterminé à partir du nombre d'anneaux observés et de la technique de Z scan. Les résultats obtenus de l'expérience des anneaux d'auto-diffraction sont comparés et analysés pour les trois huiles. On obtient une grande valeur de $n_2 = 1{,}32 \times 10^{-6}$ cm^2/W pour l'huile de camomille utilisant la technique du patron d'anneaux de diffraction. Cette importante non linéarité est attribuée à un effet thermique résultant de l'absorption linéaire. De plus, nous étudions les caractéristiques optiques limitatives des trois huiles. [Traduit par la Rédaction]

Mots-clés : modulation d'auto-phase, non linéarité thermique, patron d'anneaux de diffraction, indice de réfraction non linéaire, technique Z-scan.

1. Introduction

Owing to the needs for new optical devices, the search for new materials is an ongoing matter. These materials should behave nonlinearly with input laser light intensity and respond in very short times. To examine the existence of nonlinearities in any material, there exist a number of methods, the most important of which are diffraction ring pattern [1], thermal lens [2], and the Z-scan technique [3]. Each of these methods is easily carried out; they require a laser source with low variable output power, <1 W, working in the lowest transverse mode, TEM_{00} (i.e., having Gaussian extent). Many materials have been tested for nonlinearities [4–14] for various objects using these three techniques [15–23].

To our knowledge, no attempts have been carried out to investigate any types of nonlinearities in vegetable oils except one experiment that studied the nonlinear properties of palm oil via diffraction ring technique doped by the addition of silver nanoparticles by Zamiri et al. [24] and another experiment by Al-Dergazly et al. [25] to calculate olive oil Kerr constant for electro-optical applications.

In the present work, we present the study of nonlinear optical properties (i.e., estimation of the nonlinear refractive index, n_2) in rose oil, linseed oil, and chamomile oil via diffraction ring technique using a visible laser beam. A theoretical model is adopted to reproduce the ring pattern obtained experimentally [26]. Also, we report the measurements of nonlinear refractive index of the samples using Z-scan technique and analyzed on the basis of the thermal lens model. The results indicate that oils exhibit strong nonlinear refractive index properties. Moreover, we studied the optical limiting behavior of these samples. The mechanisms leading to the observed diffraction ring patterns and optical nonlinearities properties have also been investigated.

2. Experimental

2.1. Samples

The rose oil, linseed oil, and chamomile oil used in the experiments are available in the local markets, their chemical structures are not available because each of them is made of a number of

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