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Research Article

Applications of the Z-Scan and I-Scan Methods in Nonlinear Optics

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Abstract – There is great interest in discovering materials with substantial yet quick nonlinearities. Therefore, there is a need to extend this database. This interest, which stems largely from the quest for materials for all-optical switching and sensor protection applications, includes both nonlinear absorption (NLA) and nonlinear refraction (NLR). The database for nonlinear optical characteristics of materials, particularly organics, is sometimes insufficient for identifying patterns to guide synthesis efforts. In this study, we warn that the Z-scan technique's results on the active nonlinear processes of a particular reference are frequently disputed. NLA and NLR in solids, liquids, and liquid solutions may be quickly measured using the Z-scan approach. The nonlinear optics community has quickly adopted the Z-scan approach as a standard method for identifying the nonlinear changes in absorption and index independently. It should always be noted, nevertheless, that this approach is susceptible to any nonlinear optical mechanism that results in a change in the refractive index and/or absorption coefficient, making it generally impossible to identify the underlying physical processes from a Z-scan. It is worth noting that nonlinear absorption, such as two-photon absorption, can have an effect on the measured signal. This, however, may be assessed separately by noting the total power of the transmitted beam. The nonlinearity measurement may be adjusted using this data.As a result, several variants of the z-scanning approach will be tested in this study.

Keywords – Optics, laser, nonlinear optics, z scan, ı scan, optical measurement techniques

I. INTRODUCTION

The non-linear index n_2 Kerr nonlinearity and the non-linear absorption coefficient $\Delta\alpha$ are measured in nonlinear optics using the "open" and "closed" approaches, respectively, using a z-scan measurement. In order to rectify the computed result, the open technique is usually employed in conjunction with the closed approach.

A hole is positioned in this experiment to keep part of the light from getting to the detector. The equipment is set up as the diagram shows. A laser is focused by a lens to a certain point, after which the beam naturally defocuses. After a longer distance, a detector is positioned behind an aperture. The aperture causes only the central region of the cone of light to reach the detector.

II. THEORY

In a nonlinear sample, a beam causes a change in the total refractive index that is proportional to both the nonlinear refractive index of the material and the beam intensity. In the most basic scenario, with just third-order nonlinearities present, this leads to the following modification:

$$n = n_0 + n_2 I \qquad (1)$$

In this case, I is the excitation intensity, n is the total refractive index, n_0 is the linear refractive index, and n_2 is the third-order nonlinear refractive index. Due to its intensity profile, a Gaussian incoming beam will cause a nonlinear refractive index change profile when a lens is applied to the beam. Consequently, a refractive index lens is being induced in the nonlinear medium by the beam propagation.

Originally presented by [5][6], the transmission Z-scan method is a straightforward and sensitive. Based on scanning the sample in relation to a lens's focal plane in Fig. 1., this technique works. A closed aperture Z-scan detector, which is positioned behind the sample in the far field and has an aperture in front of it, is used to track the refractive index lens effect as the sample is being displaced. Therefore, it is assessed how much the light-induced lens inside the sample causes focusing and defocusing.

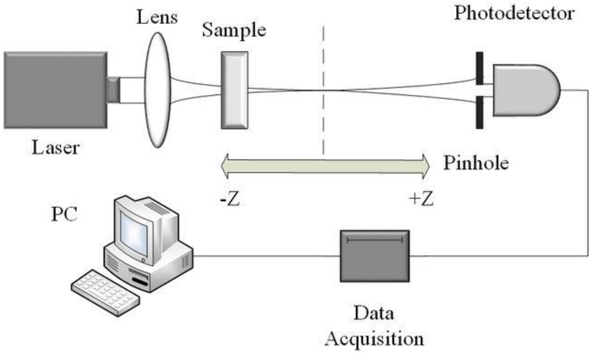

Fig. 1 Configuration for the Z-Scan method experiment [4].

The experimental setup for transmission Z-scan experiments is presented in Fig. 1 and its basic elements are the focusing lens, the translation stage and the detector [1].

III. I-SCANNING METHOD

The importance of I-scan development stems from its benefits. To begin, the Z-scan approach results in various lighted portions of the sample according to the scan's position relative to the focus plane. This might be a problem with inhomogeneous samples, as each scan distance will measure a different portion of the sample, resulting in extremely inconsistent data. The fact that the sample is no longer going through the focus and that the likelihood of damage is reduced is another significant benefit of this approach. An further significant benefit of this approach is that it makes it simpler to detect high-order effects in a single trial.

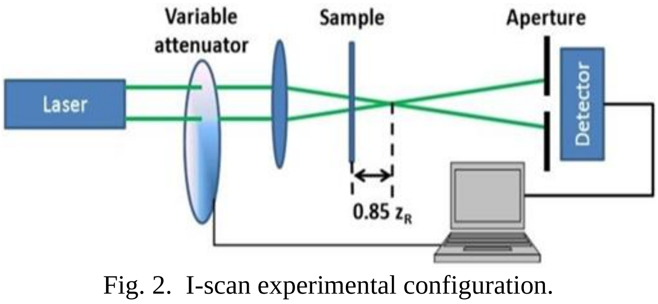

Fig. 2. I-scan experimental configuration.

In a closed-aperture I-scan experiment, the transmission is described by the following theoretical function:

$$T_{closed}\,(I)_{z=-0,85z0} \cong 1 - 0.2k\Delta n = 1 - 0.2kn_2 I \qquad (2)$$

A linear dependency of the transmission on the incident intensity is observed when $\Delta n = n_2 I$ and only third-order nonlinearities are present. According to Figure 3, this function's slope is proportional to the nonlinear refractive index.

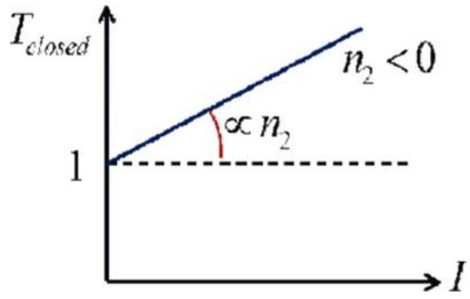

Fig. 3. The closed aperture I-scan's theoretical nonlinear refractive index is derived from the transmission vs. intensity curve.

IV. Z SCANNING MEASUREMENTS

The intensity of the Kerr nonlinearity, or the value of the nonlinear index n_2, of an optical material is frequently measured using the z-scan measurement technique [5][6]. In essence, the beam radius (also known as the on-axis intensity) is determined at a location behind the focus as a function of the sample position after a sample of the material being studied is passed through the focus of a laser beam.

The self-focusing effect has an impact on these numbers. Self-focusing lowers the beam divergence and raises the detector signal if the nonlinear index is positive and the sample is positioned behind the focus (as shown in Fig. 3) [8].

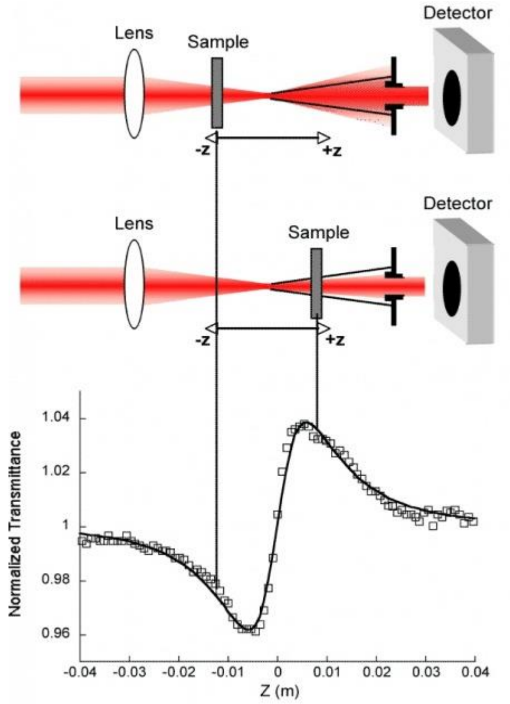

Fig. 3. The closed aperture z-scan is based on the self-focusing effect [8].

The solid line in Fig. (4) is a typical closed aperture Z-scan result for a thin sample displaying nonlinear refraction. For instance, when the sample is moved away from the lens, a self-focusing nonlinearity, $\Delta n>0$, causes the normalized transmittance to fall and then rise (raising Z). When normalizing is done, the transmittance is set to unity for the sample that is distant from focus and has very little nonlinearity (i.e., for |Z| >> Z0) [9].

The focal location is brought closer to the sample by the positive lensing in the sample that is positioned before the focus, which increases the far field divergence and decreases the aperture transmittance. On the other side, the same positive lensing lowers the far field divergence when the sample is positioned after focus, enabling a higher aperture transmittance. A self-defocusing nonlinearity, $\Delta n<0$, has the opposite effect. Dashed line in Fig. 4. [3].

The Z-scan technique's ease of use and simplicity in determining the nonlinear optical coefficients with a high degree of precision is one of its appealing aspects. The observed values, however, are the nonlinearly induced $<\Delta n>$ and/or $<\Delta\alpha>$, as is the case with the majority of nonlinear optical measuring techniques. The time-average over a time equivalent to the temporal resolution of the detection system is indicated by < > [9][3].

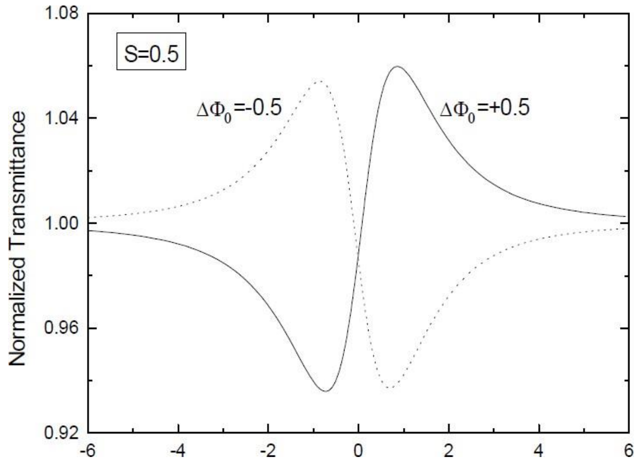

Fig. 4. A typical Z-scan for third-order nonlinear refraction that is positive (solid line) and negative (dashed line) [9].

In the field of dual wavelength all optical switching applications, where cross phase modulation is crucial, research into non-degenerate nonlinearity is technologically significant [10]. An obscuration disk [11] is used in place of the far field aperture in the eclipsing Z-scan method, blocking the majority of the beam. Sensitivity to generated wave front distortion is increased by an order of $\lambda/10^4$ with this modification of the Z-scan approach. Additionally, two color eclipsing Z-scan techniques have been proposed [12]. The single beam open aperture Z-scan method was used to make the measurements reported in this thesis. The Z-scan method is extremely sensitive to both the sample thickness and the beam profile [5][6]. Any departure from the beam's Gaussian profile and the thin sample approximation will result in inaccurate findings.

Consequently, certain changes have been proposed to get around these drawbacks. The non-apertured multi-channel Z-scan approach is one such adaptation, in which a two-dimensional CCD camera is used to capture the entire far field beam profile distortion [13][14]. Through image processing, the distorted beam at a certain cell position is contrasted with the undistorted beam (i.e., without nonlinearity). Total profile distortion signal (TPDS), which is proportional to nonlinear phase shift, is then defined by adding the module of intensity variation across each pixel of the CCD camera.

This method has some advantages [14], such as: (a) the entire far field; (b) the image recorded can be digitized and stored in a computer, and the image is ready for further processing and analysis; and (c) a CCD detector has a very high dynamic range. Astigmatic Gaussian beams [15] and top-hat beams [16] can also be used to do Z-scan measurements. A slit is utilized instead of a (round) aperture for an astigmatic Gaussian beam [15]. It has also been proposed to use Z-scan measurement for non-Gaussian beams with arbitrary sample thickness [17] and aperture [18]. In the case of the former, nonlinear parameters are measured in comparison with a standard sample, mostly CS_2 [16].

Advantages and Disadvantages of Z-Scan

Some of advantages of Z-Scan; The only complex scenario is directing the laser toward the slut. Nonlinearity's sign and magnitude can be assessed at the same time. The nonlinearity components of refractivity and absorptivity can be separated. Nevertheless, the DFWM approach cannot be used to do this. Display a great level of sensitivity. A good optical quality sample may readily decompose even a λ/300 phase distortion. The geometry that restricts optical power is closely related to Z-scan.

Some of disadvantages of Z-Scan; Due to its difficulty in acquiring, the requirement for high quality Gaussian TEM_{00} beams for certain experiments is a drawback. The non-Gaussian beams are entirely different in terms of analysis. Because of the sample's imperfections, the beam may get warped.

V. DISCUSSION

In this study, I scanning and Z scanning techniques were examined together with their applications. A compilation article was prepared by giving sample results from various publications, explaining their advantages and disadvantages.

VI. CONCLUSION

Z-scan method is characterized with simplicity and good accuracy. Open aperture Z-scan method of studying optical nonlinearity of materials is appropriate for studying of materials; Closed aperture Z-scan method is appropriate for studying the nonlinear refraction of materials. The aperture stop should be located in the far-field range of the focused beam. The size of the aperture should be in accordance with the required aperture transmittance. Applying the both open and closed Z-scan method allows elimination of influence of nonlinear absorption on the results for nonlinear refraction. To eliminate/minimize the influence of radiation it is preferably regulation of the information signal, i.e. using a two- channel system with two receivers - measurement and reference receiver to measure the laser power.

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