Z-SCAN TECHNIQUE AND ENGINEERING APPLICATIONS FOR NONLINEAR OPTICAL MEASUREMENTS

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Introduction

There are many intriguing possibilities for both basic research and real-world application presented by organic nonlinear optics. Similar to other high-tech industries like microelectronics and genetic engineering, technological and scientific developments will probably interact fundamentally in a way that fosters advancements in the other. For instance, optical and laser technologies are increasingly using nonlinear optical phenomena.

Since photonics has such a wide range of potential application technologies and each has its own specific requirements, the process of optimizing materials for third-order nonlinear optical applications is difficult, and no single solution is likely to emerge as dominant. For instance, nonlinear optical phenomena-based optical systems are increasingly utilised in practical applications.

It necessity in order to evaluate the nonlinearity of the optical characteristics of freshly created materials is growing as nanotechnology develops and new nano-materials with specific attributes are created. The operation of optical components in systems with powerful laser sources requires nonlinear refraction and absorption of optical materials, including biological materials.

This, as well as the advancement and enhancement of laser technology, necessitates an increase in the precision and automation of techniques for studying optical nonlinearity in materials.

In practice, certain approaches are employed to investigate one or more nonlinear effects. One of these approaches, Z-scan methods, is particularly well adapted for the simultaneous study of two nonlinear processes, nonlinear absorption and nonlinear refraction, both of which relate to the dielectric permeability of materials. This technology is modified in two ways: open aperture Z-scan for studying optical nonlinear absorption and closed Z-scan for studying material nonlinear refraction.

Specifications of the Z-scan Technique

The sign and size of third order nonlinear susceptibility's real and imaginary components may be determined using the Z-scan method. In the first single beam in the set-up, the sample's transmittance along the direction of a concentrated Gaussian laser beam can be measured. The size and direction of a laser beam will alter as it travels through a nonlinear substance. To determine the ratio of the amount of light passed through an aperture in the far field to the focus region, closed aperture Z-scan experiments (M. Sheik-Bahae et al., 1989, 1990) are used.

In this situation, nonlinear refraction and nonlinear absorption are both affecting the transmitted light. The phase distortion that the beam experiences as

it travels through the nonlinear material is transformed into matching amplitude changes in a closed aperture Z-scan experiment.

Contrarily, if light transmission is assessed without the use of an aperture (i.e., when all of the light is collected), the measurement method is known as open aperture Z-scan (M. Sheik-Bahae et al., 1989). Nonlinear absorption is the sole factor in this case that influences throughput. Z-scan graphs for both closed and open apertures are always standardized to linear transmittance, or transmittance at high |z| values. The genuine and fictitious components of it are provided by experiments using Z-scans with closed and open apertures (M. Sheik-Bahae et al., 1989).

The aperture is typically shut. Open aperture data is separated into Z-scan data to reduce the impact of nonlinear absorption present in the closed aperture measurement (M. Sheik-Bahae et al., 1989). The split Z-scan graph, a novel graph, solely offers details on nonlinear refraction.

In a Z-scan measurement, a tiny sample is assumed, meaning that the sample length is significantly smaller than Rayleigh's range. $z_0 = k\omega_0^2/2$, where k is the wave vector and W_0 is the beam waist]. This is necessary to guarantee that the beam profile does not fluctuate significantly inside the sample. Figure 1 depicts the experimental setup for the single beam Z-scan approach. The photodetector (PDl) monitors the laser energy input. Open and closed aperture measurements are provided by PD2 and PD3, respectively.

Additionally, this strategy has been changed to incorporate eclipse Z-scan (T Xia et al., 1994) and two-color Z-scan (M. S. Bahae et al., 1992, H. Ma et al., 1995). The impact of nonlinear refraction and absorption caused by a strong excitation beam at a frequency ω_e on a weak probe beam at a different frequency

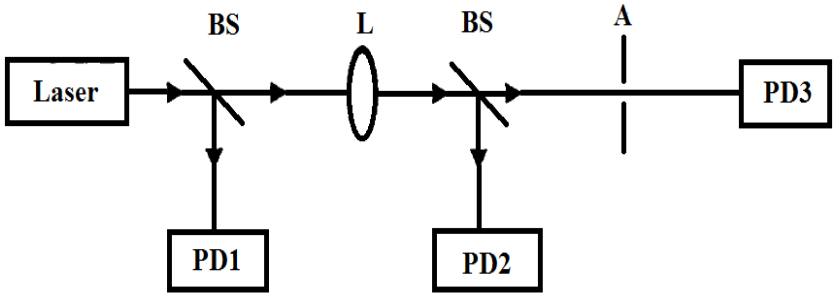

Figure 1. A: aperture; L: lens; BS: beam splitters; schematic design of Z-scan setup.

ω_p i.e, $\Delta n(\omega_e, \omega_p)$ and $\Delta\alpha(\omega_e, \omega_p)$ is measured in non-degenerate (two color) Z-scan. [Δn denotes a change in refractive index, whereas $\Delta\alpha$ denotes a change in absorption coefficient]. The non-degenerate Z-scan approach offers certain benefits over the traditional single beam technique (M. S. Bahae et al., 1992). The

frequency difference ($\omega_P - \omega_e$) can be utilized to learn more about the nonlinear response's dynamics. at considerably lower time resolution than the laser pulse width (Artkin F., 2014).

The two-color Z-scan method enables time-resolved observations by delaying the probe pulse. In the dual wavelength optical switching, cross phase modulation is vital in all applications is key, non-degenerate nonlinearity research is essential (M. S. Bahae et al., 1992). In the eclipsing Z-scan method, the far field aperture is switched out for an obscuration disk (T Xia et al., 1994), which completely blocks the beam. By an order of magnitude, this Z-scan technique change enhances sensitivity to produced wave front distortion (A Marcano et al., 1997). Additionally, a two-color eclipsing Z-scan strategy has been suggested. This thesis' measurements were created with the Z-scan single beam open aperture method. By delaying the beam, the two-color Z-scan approach permits time resolved measurements and imaging front distortion is decreased by an order of magnitude. Non-degenerate nonlinearity research is crucial in the field applications involving dual wavelength optical switching, Additionally, a two-color eclipsing Z-scan strategy has been suggested. This book chapter measurements were made using the single beam open aperture Z-scan technique. Beam profile and sample thickness have a significant impact on the Z-scan method (M. Sheik-Bahae et al., 1989, 1990, F. E. Hernandez et al., 1997). Any deviation from the thin sample approximation and the beam's Gaussian profile will provide inaccurate results. As a result, a number of modifications have been suggested to fix these flaws. One such modification is the adoption of a non-apertured multi-channel Z-scan method, in which the whole far field beam profile distortion is collected using a two-dimensional CCD camera (A. Marcano et al., 1996, P. Chen et al., 1999). The distorted beam at a certain cell point is compared to the undistorted beam during image processing (That is, when there is no nonlinearity). The module of intensity change across, the total profile distortion signal (TPDS), which is proportional to the nonlinear phase shift, is defined by adding each pixel from the CCD camera. There are several advantages to employing this method. including the simultaneously capture the whole far field dispersion of the signal and reference beams (P. Chen et al., 1999); (b) after data collection The collected image might be turned into a digital file and saved on a computer, making it ready for additional processing and analysis; (c) a CCD detector has a very large dynamic range. Z-scan measurements can also be performed using top hat beams (Robert E. Bridges et al, 1995) and astigmatic Gaussian beams (Yong-Liang Huang et al, 2000). For an using a slit instead of a gap, an astigmatic Gaussian beam is employed (Yong-Liang Huang et al., 2000). There have also been suggestions for non-Gaussian beam Z-scan measurements

with arbitrary sample thickness (P. B. Chapple et al., 1994) and arbitrary aperture (J. A. Herman 1998). In the first case, a standard sample, frequently CS_2, is used to evaluate nonlinear properties (Robert E. Bridges et al., 1995).

Open Aperture Z-scan

The figures below illustrates a sample's nonlinear absorption open aperture Z-scan measurements. Measurements of nonlinear absorption, such two-photon absorption (TPA), for instance, result in a focus point with a transmission minimum (M. Sheik-Bahae et al., 1990). As opposed to that, the sample is a saturable absorber, there is a transmission maximum in the focused region and the transmission rises with increasing incoming intensity (K. P. Unnikrishnan et al., 2002, M. Samoc et al., 1998). The idea initially advanced by Bahae et al for pure TPA has been demonstrated to be compatible with excited state absorption (ESA) (S. Couris et al., 1995). In the ESA TPA approach, two photons are gradually absorbed (T. Xia et al., 1997).

Closed Aperture Z-scan

Self-refraction or self-phase modulation in space is demonstrated using a closed aperture Z-scan. A well-defined peak and valley are found in the absence of nonlinear absorption (M. Sheik-Bahae et al., 1989, 1990). If the sample's nonlinear refractive index n_2 is negative, the beam will converge in the pre-focal area and focus closer to the aperture. Due to the shrinkage of the beam as it approaches the aperture, the detector experiences high throughput. As a result, the pre-focal area peaks. The same mechanism causes beam divergence in the post focal zone, which lowers transmission through the aperture. In the aftermath, a valley forms in the post-focal region. The outcome is the exact reverse if the sample has positive nonlinear refraction (pre-focal valley and post-focal peak.). Self-defocusing refers to the first, whereas self-focusing refers to the second. The optical Kerr effect is one of the self-focusing processes because of its fast reaction (Artkin F., 2014, T. Hattori et al., 1991). In this case, an electric field connected to a laser beam causes torque to be applied to anisotropic molecules. A transparent liquid's optical nonlinearity is mostly caused by light-induced molecular reorientation. With inceasing light intensity, the nonlinear refractive index changes linearly. The outcome is closed aperture measurements in the current experimental settings can only provide thermal response (S. J. Bentley et al., 2000, M. D. I. Castillo et al., 1995).

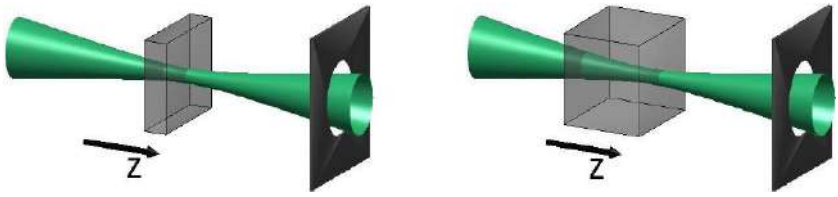

Figure 2. Z-scan: open aperture geometry, determining the function of integrated light intensity crystal location. Thin sample (z_0 of the Gaussian beam) on the left, thick sample (> z_0) on the right.

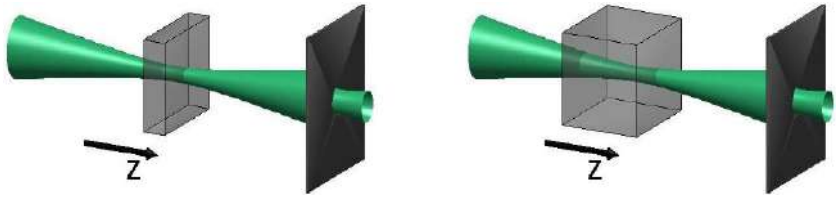

Figure 3. Z-scan: closed aperture geometry with light monitoring of intensity in relation to crystal position.

As a result, detailed closed aperture Z-scan measurements were not undertaken. Furthermore, the closed aperture Z-scan experiment hypothesis proposed for Kerr type nonlinearity does not applicable to thermal nonlinear refraction. Figures 2. and 3. show common geometries for Z-scan measurements. The focused Gaussian beam moves in the z direction as the crystal is pushed through the focus. The integrated intensity will be mainly impacted by nonlinear absorption, although both nonlinear absorption and refraction will have an impact on the intensity's angular distribution. In this way, nonlinear refraction may be measured in a closed aperture geometry and nonlinear absorption can be recorded in an open aperture geometry.

Identifying the sample's thickness or thinness is crucial (compared to z_0 of the Gaussian beams). Comprehensive mathematical formulations (P. P. Banerjee et al., 1991, J. A. Hermann et al., 1993) that have been created for both scenarios that might be utilized to examine Z-scan findings.

Two-photon absorption is one type of nonlinear absorption that might affect the measured signal.

However, by documenting the entire the transmission beam may be measured separately from the power. The use of this knowledge can aid in the the measurement of nonlinearity.

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