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Research Article

Defining Optical Characteristics of Non-linear Materials by Computer-aided Z-scanning

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Abstract **–** The discovery of materials with large yet quick nonlinearities is of tremendous interest. This database needs to be expanded as a result. Techniques for calculating nonlinear coefficients are explained throughout article. This curiosity is mostly driven by Nonlinear absorption (NLA) and nonlinear refraction (NLR) are the two categories that emerge from the search for materials for applications like sensor protection and all-optical switching. The library of nonlinear optical properties of materials, especially organic materials, is frequently insufficient to identify patterns that will direct synthesis efforts. There are many fascinating prospects for both fundamental research and practical applications in organic nonlinear optics. Microelectronics and genetic engineering are two examples, which are similar to other high-tech businesses. Advances in science and technology are likely to have a fundamental interaction that fosters advancements in both fields. For instance, nonlinear optical phenomena are being exploited more and more in laser and optical technologies. Z-Scanning, a method for determining the optical properties of non-linear materials including liquid crystals, semiconductors, and thin films, has been transformed into an original electromagnetic mechanism in this work with the use of a computer. For every signal, the movement resolution of this mechanism has been measured to be 0,002 mm (2.10^{-3} mm). This value is a parameter that significantly increases the amount of obtained data points during the measurement interval. Measurement values can become more solid and sensitive in this way.

Keywords – Optics, laser, nonlinear optics, z scan, opto-mechanics, optical measurement techniques

I. INTRODUCTION

A weighted spring that is susceptible to vibration from effective forces may exhibit non-linear behavior. Similarly, significant non-linear optical effects are predicted to be produced by a powerful beam. The electrical fields of beams from common light sources are not very effective at making such behaviors easily visible. With the discovery of laser beams, non-linear parameters in materials have been realized. A few theoretical assumptions about the topic have been made. However, the 1960's saw the beginning of experimental research. In order to properly characterize the material, non-linear parameters must be provided. Among the methods used in the subject's frame are Z-Scanning, Degenerate Four-Wave Mixing (DFWM), Electric Field Induced Second Harmonic (EFISH), Third Harmonic Generation (THG), Optical Kerr Door, and Non-linear Fabry-Perot Method. Non-linear optics is a very real and active field nowadays, and there are more and more research being done on the topic. From semiconductor technology to izotrop decomposition, non-linear optics is used in many different fields. Additional application areas include photochemistry, high-resolution spectroscopy, optical radar (LIDAR), and the remote description and definition of air contaminants.

II. THEORY

When a powerful light field permeates the material, the relationship between the light field and the force caused by polarization cannot be described using linear electrodynamic equations. Finally, a non-linear binding occurs between P and E.

$$P = \chi^{(1)}E^{(1)} + \chi^{(2)}E^{(2)} + \chi^{(3)}E^{(3)} + \cdots \quad (1)$$

The phrases of the following assertion may be studied in order to determine the numerous non-linear optical facts that correlate to them. Since each subsequent period is smaller than the one before it by E_a times (E_a is the atomic force of the electrical field), the likelihood of a non-linear event occurring in relation to each subsequent term is also reduced. The non-linear polarization coefficients with two or more degrees are represented by $x^{(2)}$ and $x^{(3)}$, where $x^{(1)}$ is the linear coefficient. Like linear coefficients, non-linear coefficients are similar to the medium characteristics. For example, they produce $x^{(4)}$ fourth, $x^{(5)}$ fifth harmonics, parametrical spreading with $x^{(2)}$ single photon and $x^{(3)}$ four photons, and parametrical enchancing of light. Other non-linear optical phenomena are caused by non-linear polarization coefficients as their degree increases [11].

Z-Scanning Technique

ΔT_{pv} is the difference between the permeability change in the material under study using the z approach and the maximum-minimum values of the obtained data; T_p and T_v are the maximum (peak) and minimum (valley) permeability values, respectively. Among these experimentally determined quantities is phase change ($\Delta Ø_0$). The relationship of non-linear reflection between ΔT_{pv} and $\Delta Ø_0$ is: [6][7]

$$\Delta T_{pv} = 0,406(I - S)^{0.27}|\Delta Ø_0| \quad (2)$$

Here $\Delta Ø_0$;

$$\Delta Ø_0 = (2\pi / \lambda)\, n_2\, I_0\, L_{eff} \quad (3)$$

Leff is;

$$L_{eff} = (I - e^{-\alpha L}) / \alpha \quad (4)$$

S is the breach's permeability. The parameters $\Delta Ø_0$ and I_0 represent non-linear phase change (r=0) and radiation force on the focal point (z=0) [5][8][11].

One of the essential strategies is demonstrated in the image below by experimentally comparing nonlinear parameters. Material is created along the z axis utilizing manual or computer-aided processes.

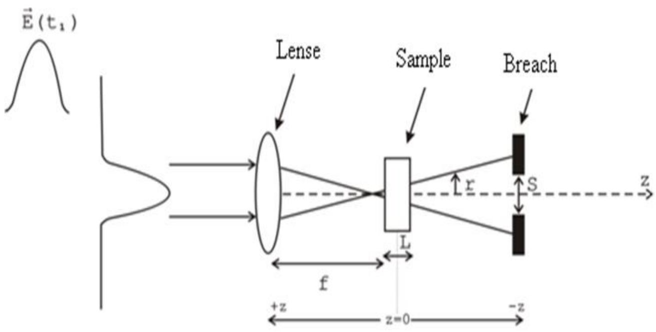

Fig. 1 Specifications for material inspection using Z scanning.

The material that has to be examined is positioned such that the front of it faces the laser beams. The sample holder is positioned above the linear transfer setup, which moves along the laser beams' z axis. Sufficient information for non-linear parameters is provided by the quantity of laser beams that are transferred from the material when it moves. One experimental setup may be utilized to calculate non-linear optical coefficients using the Z-Scanning approach. The benefits of the Z-Scanning approach that set it apart from the others are its versatility and sensitivity for non-linear optical measurements. The effectiveness and suitability of the Z-Scanning technology have been demonstrated through trials and observations [9].

III. EXPERIMENTAL STUDY

Opto-mechanical mechanisms are available in many grades and may be utilized for certain purposes. However, they might be costly to purchase straight from manufacturers. The experimental setup we employed in the investigation is a fully unique system; it differs from all other systems of comparable size and connecting mechanism. The technical schematics of the optomechanical system employed in the experimental setup are presented below.

The New Design Opto-Mechanical System

The newly developed opto-mechanical system, whose design is finished, combines different shafts, carrier systems, bearings, universal plastic clutch adapters (couplings) that lessen the stepper motor's workload, and various servo motor mechanical components.

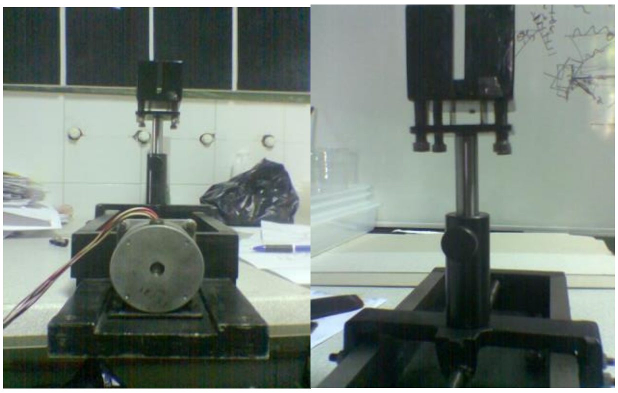

Fig. 2 Front and back photos of the new design opto-mechanical system.

This system may also be employed in academic research, particularly in the z-scan experimental setup, which is a nonlinear optics experimental application that permits measurements with accurate position changes in optics. This system can accomplish precise position adjustments due to its mechanical construction [1][3].

Fig. 3 Photos of the side carrier rail and main body carrier system mechanism of the new design opto-mechanical system.

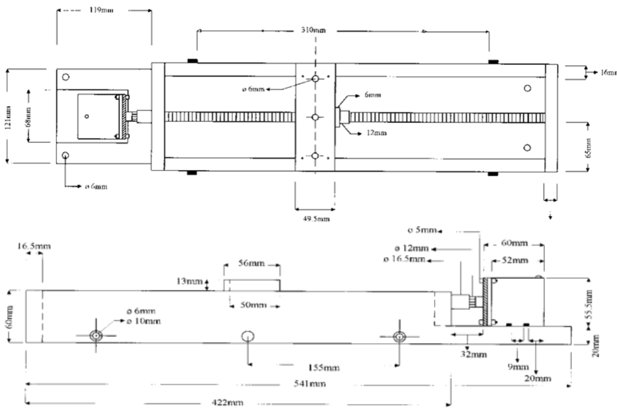

Fig. 4 Top and left side technical drawings of the new design opto-mechanical system (drawn with AutoCAD).

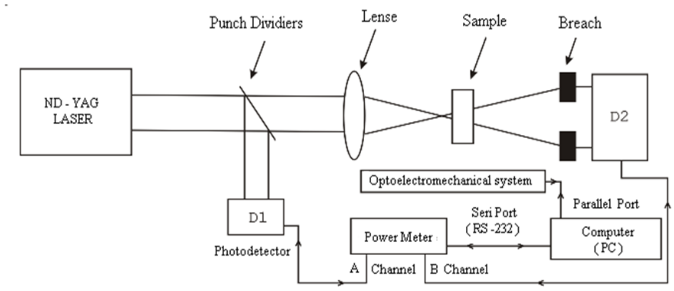

Fig. 5 Diagram of experiment setup.

The fundamentals and standards of motion are crucial factors in mechanical systems. The purpose of a stage is to restrict motion to a certain path. For a linear stage, a straight line is the best path of progress.

The system has a total weight of 8.54 kg. 379 mm is the scanning distance, while 2.12×10^{-3} mm is the motion resolution [3].

The System Setup

Optomechanical components of the experimental device have been incorporated into the step engine, and connection with the computer has been made possible by the use of an electrical circuit parallel port. The power-meter used in the measurements was linked to the computer via a serial connection. One software was built for calibration, and another was written to control the entire system. The schematic of an experimental apparatus used to characterize nonlinear materials is shown below. The dedectors used in the studies to measure light force are of the Ophir brand, and we have thorough descriptions of their features. Using the reference dedector (D1), we may achieve better results. An Ophir optical power-meter coupled to both dedectors provides the permeability value of light power (D2/D1).

The distance-permeability rate for nonlinear materials acknowledged in the literature is shown below for a variety of materials. Curvileniar maxima and minimum points in the figure indicate non-linear effects of the examined materials. All of the diagrams that provide this effect were created using the Z-Scanning method [4].

IV. RESULTS

The experimental and result obtained by moving the CS_2 material [8][10] system with a specially designed holder from -z (-10 cm) to +z (+10 cm) at 3 mm intervals are shown in Figure 6. In this study, the intensity of the light at the focal point was calculated as 1.3 GW/cm^2 [2][3].

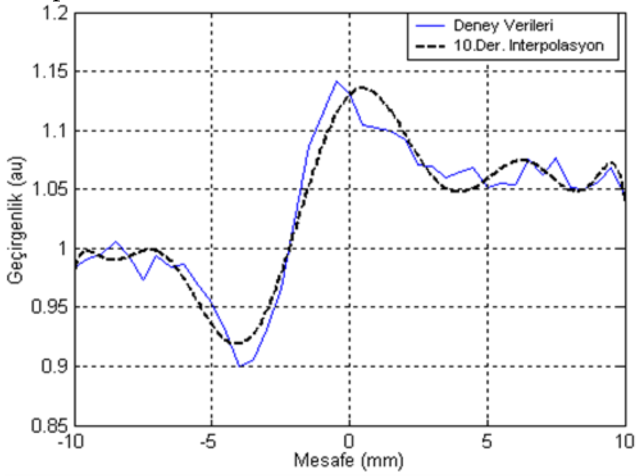

Fig. 6 Permeability Changes in CS_2 as a Result of Z-Scan Measurement [1].

A maximum peak appears after the focal point, and a minimum trough appears before it in the permeability change that we got. The nonlinear refractive index was determined empirically by calculating the difference between the maximum from the graph (Figure 6.) as T_p = 1.09986, T_v = 0.89986 [2]. As we have already discussed, one of the most crucial parameters in the Z-scan approach is thickness. For the intensity *lo* = 1.3 GW/cm^2, our experimental investigation did not provide a nonlinear refractive index change of CS_2. According to the literature, CS_2 is $\Delta n = 5.6\text{x}10^{-5}$ at *lo* = 2.6 GW/cm^2 [6][7][8].

The non-linear effect is seen in the graphs we created using the observations we collected (Figure 6). The interpolation (curve fitting) approach (10th degree) was used to plot the graph that was produced in the Matlab software [2].

V. DISCUSSION]

Among these processes are the most significant devices in the optical sector, which come in a variety of sizes and shapes. The expense of purchasing them directly would be high. Every mechanism that we employed in the experiments was created by myself and is unique. The size and connection configuration of these systems are very different from those of other systems.

VI. CONCLUSION

This paper's experimental setting for the z-scan approach, known as the Opto Electromechanical experimental setup, was created by creating unique optomechanical systems. The thin sample's variations in distance with carbon disulfide (CS_2) permeability were graphically displayed.

The closed slit z-scan experiment showed a 1.3 GW/cm^2 change in the nonlinear refractive index of CS_2 put in a 1 mm thick cell. Using a cell that was 1 mm thick, the material's laser intensity value a 2.6 GW/cm^2 in the literature.

If the full Z-scan system had been purchased ready-made, it would have cost over $3,000 (without software); however, owing to this study, it is now feasible to have this system for about $300. The experimental set includes electrical circuits and controls, stepper motor control, an optomechanical system, and computer applications. This experimental apparatus for the characterisation of nonlinear materials is being used for one of the first time in academic studies for the optics discipline in Turkey.

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