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Obtaining Nonlinear Optical Transmittance Parameters of CS_2 Using Z-Scan Experimental Setup

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Abstract: In a linear medium, the index of refraction and the absorption coefficient are independent of the intensity of light, the frequency of the light does not change in the medium, the frequency depends only on the source, the principle of overlap applies, Light and light cannot be controlled (photon-photon interaction does not occur). In the non-linear environment; The refractive index depends on the intensity of the light, the frequency changes, the overlap principle does not apply, the light can be controlled by light. Non-linear optics has many applications and these applications are becoming more common every day. Some of these applications are optical switching, hologram, laser physics, optical communication. The differences can be explained by the shape of the laser pulse and its deviation from the theoretical form, which is often difficult to determine. Another factor affecting the accuracy of measurements of nonlinear parameters of materials is the uncertainty of laser power measurements and the waist size of the focused beam, deviations from the Gaussian distribution, inhomogeneity of the studied material, etc. Linearity is a property of the medium, not the light. It cannot be observed in the absence of nonlinear optical matter (empty space). By changing the properties of the medium, the light causes the properties of the light passing through this medium to change, even its own properties. A high-power light source may have different energy (frequency) values as it passes through the material it passes through. If the value of the applied external electric field (E) is large enough (high energy intensity light is used), the polarization vector will also include non-linear effects. CS_2 is accepted standard test material for non-linear measurements by scientists interested in nonlinear optics. Some applications of CS_2 is fumigation, insecticide, solvent, manufacturing, health effects.

Keywords: Optics, Laser, Nonlinear optics, Measurement techniques, Z-Scan, Mechanical engineering.

Introduction

Improvement of nanotechnology and creation of new nano-materials with specific properties lead to a growing need to study the nonlinearity of the optical characteristics of the newly created materials. Nonlinear refraction and nonlinear absorption of optical materials, including the organic materials, are essential for the operation of the optical elements in systems using powerful laser sources. That, as well as the development and improvement of laser technology, requires increasing the accuracy and automation of the processes of a study of the optical nonlinearity of the materials.

There are some methods used in practice for investigation of one or another nonlinear effect. One of these methods Z-scan methods is particularly suitable for the simultaneous study of two of nonlinear effects nonlinear absorption and nonlinear refraction which are related with the dielectric permeability of matertials. Two modifications of this method are in use: open aperture Z-scan method for study of optical nonlinear absorption and closed Z-scan for study of nonlinear refraction of materials.

The field of organic nonlinear optics offers many exciting opportunities for both fundamental research and technological application. As in other high-tech areas, such as microelectronics and genetic engineering, science and technology can be expected to share a vital interplay where advances on one front enable advances and

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present new challenges on the other. For example, optical devices based on nonlinear optical effects are becoming more and more widely used in practice.

The process of optimizing materials for third-order nonlinear optical applications is a complex one and no single approach is likely to emerge as dominant, due to the range of potential applications in photonics technologies and their particular requirements. Optical devices, for example, based on nonlinear optical effects are becoming more and more widely used in practice.

Non-Linear Optics Measurements

The first nonlinear optics experiment of the laser era was performed in 1961 by a team whose leader was Peter Franken (Franken et al., 1961). As shown in Figure 1., a ruby laser was focused into a slab of crystalline quartz to discover as the nonlinear reaction of the medium to the intense optical frequency radiation at 694.3 nm was strong enough to create a detectable second harmonic component at a wavelength of 347.15 nm. (The vacuum wavelength of the second harmonic component is of course half that of the fundamental).

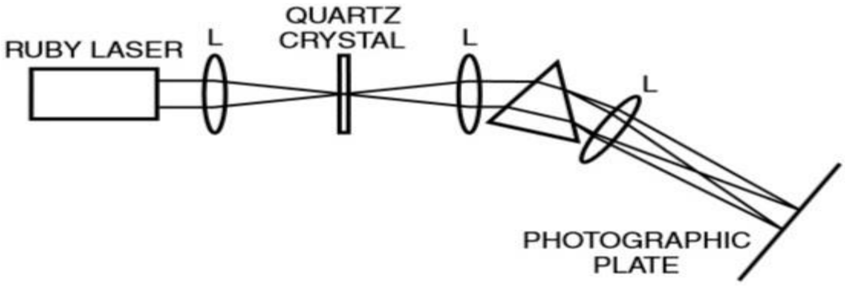

Figure 1. Schematic diagram of the first second harmonic generation experiment by Peter Franken's group at the Michigan University in 1961.

The way to think about this experiment is diagrammed in Figure 1. Consider the electrons response in the quartz to the stimulus of the optical frequency electric field of the laser beam formula becomes $E = A.cosw\omega_t$. The displacement of the electrons generates a dipole moment p per atom, or $P = N_p$ per unit volume where 'N' is accepted as the atomic number density.

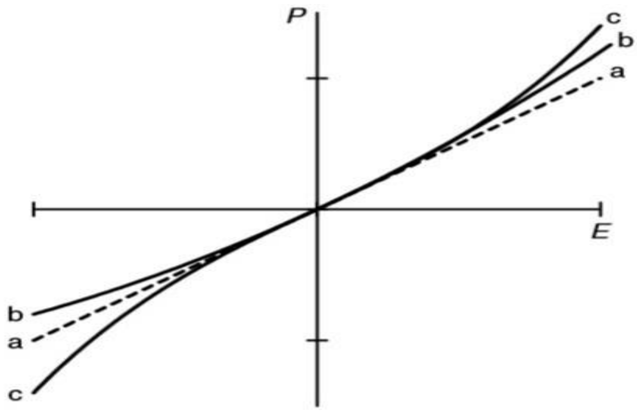

Figure 2. Linear and nonlinear response of polarization P to applied electric field E: (a) linear case (dotted), (b) quadratic nonlinearity, (c) cubic nonlinearity.

It is permitted to write the possibility of a nonlinear response

$$P = \varepsilon_0 (\chi^{(1)} E + \chi^{(2)} E^2 + \ldots) \quad (1)$$

For , $\chi^{(2)} > 0$, the dependence of 'P' on 'E' is represented while in the void of the nonlinear term, Equation (1) reverts to Equation (2), and the linear relationship between E and P represented by the dotted straight line (a) in the figure is recovered.

If $E = A\cos\omega_t$ is substituted into equation, the polarization now reads

$$P = \varepsilon_0 \underbrace{(\chi^{(1)} A \cos \omega t}_{\text{Linear Term}} + \underbrace{\frac{1}{2}\chi^{(2)} A^2 (1 + \cos 2\omega t))}_{\text{Nonlinear Term}} \qquad (2)$$

Nonlinear optics (NLO) is the understudy of optics that defines the actions of light in nonlinear media where the dielectric polarization **P** corresponding nonlinearly to the electric field **E** of the light which is possible to be seen in commonly at very high light densities (values of the electric field can be compared to interatomic electric fields, typically 10^8 V/m) like those provided by pulsed lasers. In the field of nonlinear optics, the superposition principle is not held any longer. Nonlinear optics kept unexplored till the discovery of Second harmonic generation right after demonstration of the first laser (P.A. Franken et al., 1961).

In the early 1980s nonlinear optical materials was extended with a new production of semiconductor materials. For example, multi-quantum well is produced by the amplification of two different semiconductor layers (GaAs and AlGaAs). That let the formation of consecutive hills and valleys of variable potential, for electrons and holes. It is regarded that the carriers are within these potential walls. Hence, they display a semi two-dimensional behavior and large optical nonlinearity.

It can be an useful instrument for network communication for Photonic information and communication systems. It has developed very fast in last years. However, using only fiber optical systems has not ability to meet the necessity on carrying the information flow in future of communication systems. Fast optical switches which can verify (process) large scale of data should be developed so as to remove the gateways caused by optoelectronic return throughout the network. Large and fast nonlinear optical (NLO) materials are appropriate tool for photo-dynamic therapy to treat serious diseases like cancer, and other biomedical applications in the near future soon (L. W. Tutt et al., 1993), (B. G. Maiya et al., 1989) for optical switches, optical correction and optical power limiting applications (T. D. Mody and J. L.Sessler, 2001).

Methods for Studying of Optical Nonlinearity of Materials Applications

There is considerable interest in finding materials having large yet fast nonlinearities. Thus, there is a need to expand this database. Methods to determine nonlinear coefficients are discussed throughout many publications.. This interest, that is driven primarily by the search for materials for all-optical switching and sensor protection applications, concerns both nonlinear absorption (NLA) and nonlinear refraction (NLR). The database for nonlinear optical properties of materials, particularly organic, is in many cases inadequate for determining trends to guide synthesis efforts.

Degenerate Four Wave Mixing, DFWM: Used for measuring third order nonlinear reaction and magnitude of this reaction. Third Harmonic Generation: Used only for measuring third order nonlinearity. Z-Scan: Used for measuring magnitude of third order nonlinearity and its sign. Electro-absorption technique: Third order nonlinearity dispersion studies are carried out with this technique. Time-Resolved Optical Kerr Effect and Transient Absorption Techniques: Used for presenting photophysical processes that determine nonlinearity (Paras N. Prasad, David J. Williams, 1991).

Z Scan Technique

In this experimental setup an aperture is placed to prevent some of the light from reaching the detector. The equipment is arranged as can be seen in the diagram. A lens focuses a laser to a certain point, and after this point the beam naturally defocuses. After a further distance an aperture is placed with a detector behind it. The aperture causes only the central region of the cone of light to reach the detector. Typically values of the normalized transmittance are between

$$0{,}1 < S < 0{,}5 \qquad (3)$$

The detector is now sensitive to any focusing or defocusing that a sample may induce. The sample is typically placed at the focus point of the lens, and then moved along the z axis a distance of which is given by the Rayleigh length z_0:

$$z_0 = \frac{\pi W_0^2}{\lambda} \quad (4)$$

The thin sample approximation states that the thickness of the sample *L* must be less than the Rayleigh length $L < z_0$. The z-scan measurement technique (M. Sheik-Bahae et al., 1990), (M. Sheik-Bahae et al., 1989), is often used for measuring the strength of the Kerr nonlinearity (i.e. the magnitude of the nonlinear index n_2) of an optical material. Essentially, a sample of the material under investigation is moved through the focus of a laser beam, and the beam radius (or the on-axis intensity) is measured at some point behind the focus as a function of the sample position.

These quantities are affected by the self-focusing effect. If the nonlinear index is positive, and the sample is placed behind the focus, self-focusing reduces the beam divergence and thus increases the detector signal. If the sample is moved to the left-hand side of the focus, the focus is moved to the left, and the stronger divergence after the focus decreases the detector signal. From the measured dependence of the detector signal on the sample position, it is possible to calculate the magnitude of the nonlinear index.

The Z-scan technique is a method which can rapidly measure both NLA and NLR in solids, liquids and liquid solutions. The Z-scan method has gained rapid acceptance by the nonlinear optics community as a standard technique for separately determining the nonlinear changes in index and changes in absorption. However, it must always be recognized that this method is sensitive to all nonlinear optical mechanisms that give rise to a change of the refractive index and/or absorption coefficient (Paras N. Prasad, David J. Williams, 1991).

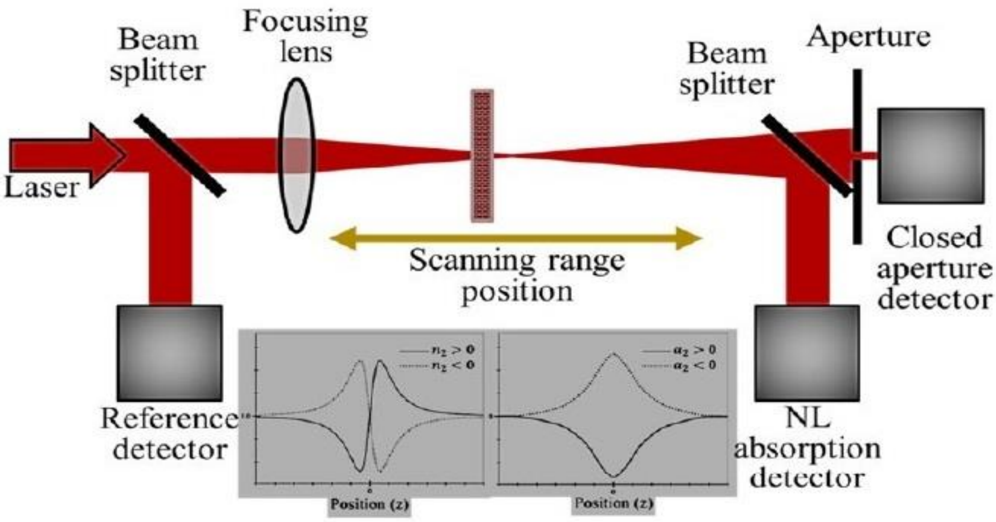

Figure 3. Typical single beam Z-Scan setup. The inset shows the characterictic Z-Scan curves for open and closed apertures (Cid B de Araujo et al., 2016).

Result and Conclusion

CS_2 is accepted standard test material for non-linear measurements by scientists interested in nonlinear optics. We used a quartz cell of 1 mm thickness with CS_2 in the experimental measurements. This information is about the chemical substance CS_2. It is accepted standart test material for non-linear measurements by scientists interesting optics. We used thickness of 1 mm quartz cell with CS_2 in the experimental measurements (Holleman &Wiberg, 2001). CS_2 polymerizes upon photolysis or under high pressure to give an insoluble material called "Bridgman's black", named after the discoverer of the polymer, P. W. Bridgman. Trithiocarbonate (-S-C(S)-S-) linkages comprise, in part, the backbone of the polymer, which is a semiconductor (Ochiai, Bungo, 2005).

Table 1. Nonlinear parameters of CS_2 (Carbon disulfide) (Breitzer, 1999).

Nonlinear Parameters	
n_2^I (Third-order nonlinear refractive index)	$3.0 \pm 0.1 \times 10^{-18}$ m^2 W^{-1}
$\chi_R^{(3)}$ (Third-order refractive nonlinear electric susceptibility)	370×10^{-33} C m V^{-3}
γ_R (Nonlinear refractive index)	0.0065×10^{-57} C m^4 V^{-3}
α_2 (Third-order absorption coefficient)	0.8×10^{-12} m W^{-1}
$\chi_I^{(3)}$ (Third-order nonlinear electric susceptibility)	84×10^{-33} C m V^{-3}
γ_I (Intensity of nonlinear refractive index)	0.0015×10^{-57} C m V^{-3}

Some applications of CS_2 are fumigation; used for fumigation in airtight storage warehouses, airtight flat storages, bins, grain elevators, railroad box cars, shipholds, barges and cereal mills (Greenwood, 1997). Insecticide: Carbon disulfide is used as an insecticide for the fumigation of grains, nursery stock, in fresh fruit conservation and as a soil disinfectant against insects and nematodes (Worthing,1991). Solvent**:** Carbon disulfide is a solvent for phosphorus, sulfur, selenium, bromine, iodine, fats, resins, rubber, and asphalt. It has been used in the purification of single-walled carbon nanotubes (Park, 2006). Manufacturing: The principal industrial uses of carbon disulfide are the manufacture of viscose rayon, cellophane film, carbon tetrachloride and xanthogenates and electronic vacuum tubes, health effects; at high levels, carbon disulfide may be life-threatening because it affects the nervous system. Significant safety data comes from the viscose rayon industry, where both carbon disulfide as well as small amounts of H_2S may be present (Artkin, 2018, 2021).

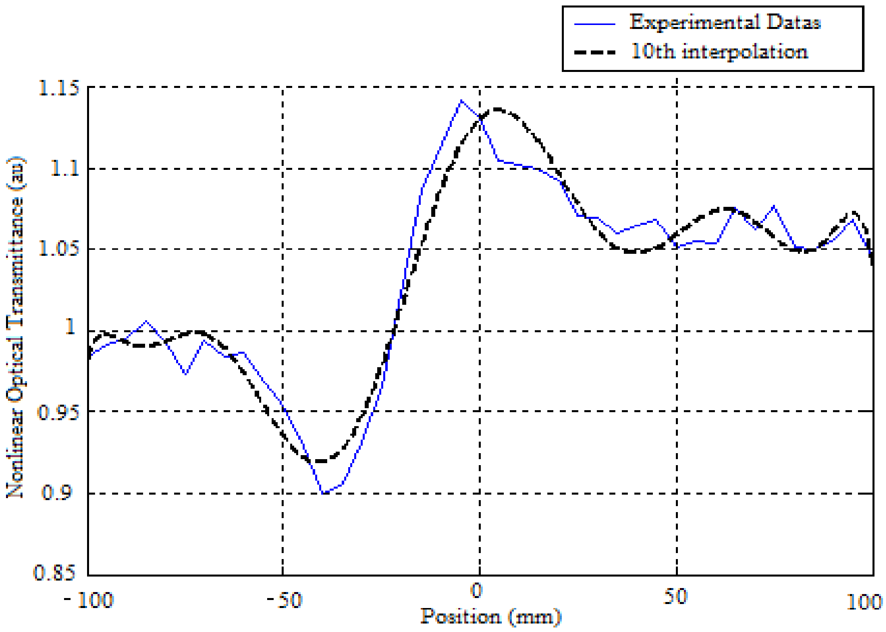

Figure 4. Position-nonlinear optical transmittance changes of CS_2 as a result of Z scan measurement.

The experimental and theoretical results obtained as a result of the movement of the CS_2 from -z (-100 mm) to +z (+100 mm) at 3 mm intervals are shown in Figure 4. In this study, the intensity of the light at the focal point was calculated as 1.3 GW/cm^2.

In the permeability change we have obtained, the minimum trough is seen before the focal point and the maximum peak after the focal point. In order to find the nonlinear refractive index, the difference between the maximum was calculated experimentally as Tp = 1.09986, Tv = 0.89986, from the graph (Fig. 4). As we mentioned before, the thickness is a very important parameter in the Z-scan technique. The graph shows the nonlinear transmittance parameters from the graphs we have drawn with the measurements we have obtained (Figure 4). The graph obtained in Matlab R 2020 b environment was drawn using the interpolation (Curve fitting) technique (10th order) (Artkin, 2005, 2014).

This study establishes the basis of my Phd studies at Sofia Technical University. My Phd studies are developed version of this study. Some of the information and data used in this article were used in the PhD study of Computer-aided Z-Scan Testing Apparatus Integrated Apparatus Integrated into Servo Motor and PLC for Investigation of Non-linear Materials' Permeability. I would like to thank Prof. Dr. Fevzi Necati Ecevit from Gebze Technical University and Associate Professor Dr. Ivanka Kalimanova from Technical University of Sofia.

Scientific Ethics Declaration

The author declares that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the author.

Acknowledgements or Notes

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