PC-Based systems for experiments in optical characterization of materials

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Abstract. An automatic control for applications of optical characterization of materials using the optical Z-Scan technique is presented in this work. The emphasis is placed in the design of the graphical user interface (GUI) and the automation process. For this purpose, we use a USB data acquisition module with programmable I/O ports for control and signals acquisition for the complete system. The control software was developed using the graphical programming language LabVIEW® and compiled in order to obtain a portable system with the hardware used in this work.

1. Introduction

Since the apparition of the laser in the 1960’s, the study of nonlinear optical properties of materials has become readily accessible. Nonlinear optics and photonics are important disciplines for research and development of high technology applications in many research fields and advanced industries [1, 2]. A large number of photonics applications have been development based on the nonlinear optical properties of materials. Nonlinear optical processes, resulting from the light-matter interaction are particularly relevant since they offer not only the possibility of new proposals for photonic applications, but the opportunity to understand physical process at fundamental level [1]. In this context, the z-scan technique is a relatively simple, but powerful method that has been used to obtain both the sign and magnitude of the complex nonlinear refractive index of some optical materials. The technique is based on the principle that spatial variations of the incident intensity distribution can photoinduce a lens in the nonlinear material which affects the posterior propagation of the beam and intensity changes at far field are obtained. The on axis intensity normalized to that without nonlinear material is called the transmittance. If the transmittance of the nonlinear material is measured as a function of the sample position \( z \) a characteristic \( z \)-scan curve can be obtained. The magnitude and sign of the nonlinearity can be evaluated from the difference between the maximum and minimum transmittance and the shape of the curve, respectively [3].

Originally, a pulsed Gaussian beam incident to a thin Kerr nonlinear sample was considered to obtain simple analytical formulas relating the \( z \)-scan curve obtained from the on-axis intensity at the far field [6]. The aim of this work was to establish an automatic implementation of the Z-Scan technique, which would
enable the measurement of the nonlinear absorption and the nonlinear indices of refraction of a host of materials.

2. The Z-scan technique
The Z-scan technique works on the principle of moving the sample under investigation through the focus of a tightly focussed Gaussian laser beam. The interaction of the medium with the laser light changes as the sample is moved along z-axis. This is because the sample experiences different intensities, dependent on the sample position \( z \) relative to the focus \( z=0 \). By measuring the transmitted power (transmittance) through open aperture \( z \)-scan measurements make it possible to locate the position of maximum absorption even in the presence of nonlinear refraction effects (e.g., thermal lensing) [5]. Such changes can be due to local mechanism, such as reversible alterations in the molecular structure, and nonlocal mechanism where the absorbed energy can be diffused as heat producing a thermal lens effect or a molecular thermal agitation, and consequently a density change via the thermelastic coupling or the electrostrictive effect [1]. The basic experimental setup is shown in figure 1, where BS is a beamsplitter, D1 is the reference detector, D2 the probe detector and the sample is at position \( z \).

![Figure 1. Basic Z-scan setup.](image)

A sample with nonlinear refraction will act like a lens with variable focal length as it is moved along the \( z \)-axis. The result of a typical sample scan is a transmittance versus position graph. This is illustrated in figure 2. A pre-focal valley and post-focal peak is observed for a positive change in refraction and a pre-focal peak and a post-focal valley is observed for a negative change in refraction. The sign of the nonlinear index of refraction of a sample is thus immediately clear from the shape of the graph.

![Figure 2. Transmittance through a sample with a positive or a negative nonlinear index of refraction \( n_2(\gamma) \).](image)
3. Experimental setup
The implemented experimental z-scan setup is schematically shown in figure 4. We use an CW Ar-ion laser system working at 514 nm (Coherent®), this energy was monitored during z-scan measurements. The laser beam was then focused on the sample by means of a positive lens (f=12 cm). The sample was attached to a translation stage from Newport® with a travel range of 150 mm and a resolution of 0.5 μm in order to perform z-scan experiments, controlled using a SMC100 motion controller driver from Newport®. A large area Si-photodetector (918-SL) was used like probe detector with an identical photodiode for the reference signal. An aperture was placed in front of the probe detector for the nonlinear index of refraction measurements (closed aperture z-scans). All signals captured from photodetectors were conditioned using an instrumentation amplifier and collected using a data acquisition system NI 9215 from National Instruments™, this is a four channel system and 16 bit simultaneous analog input mounted on a hi-speed USB carrier NI 9162. All the system and the administration of the setup were automated via a LabView® control program.

![Z-scan experimental setup](image)

**Figure 4.** Z-scan experimental setup developed.

4. Experimental results
Implementing our z-scan device, the nonlinear optical response of an ionic liquid sample was used for a preliminary characterization. In figure 5, we show the graphical user interface developed in LabView® programming system used for the control of the system.
Figure 5. Graphical user interface developed for z-scan experiments.

The interest about nonlinear ionic liquids is the result of the huge potential of organic materials in optical applications. Among the myriad of organic materials, a new class of molten salts called ionic liquids has been intensively studied owing to their interesting physicochemical properties [7-11]. They present an ionic-covalent molecular structure and different molecular architecture [7]. In this work, we show the preliminary results of one ionic liquid of [BMI] family: 1-buthyl-3-methylimidazolium tetrafluoroborate [BMI][BF₄]. The obtained normalized transmittance curves, as a function of the sample position, are presented in figure 6.
Figure 6. Z-scan curves for a sample of ionic liquid 1-buthyl-3methylimidazolium tetrafluoroborate [BMIM][BF₄].

The normalized transmittance can be obtained as function of the dimensionless sample position \(x=z/z_0\), where \(z_0\) is the Rayleigh range and \(z\) is the z-scan sample position according to [12]:

\[
T_N = 1 + \Delta \Phi_0 \left[ \frac{4x}{(1 + x^2)(9 + x^2)} \right]
\]  

(1)

The phase shift can be obtained from the \(\Delta T_{p-v}\) peak to valley experimental transmittance and the diaphragm aperture (S) according to:

\[
\Delta \Phi_{p-v} = \frac{\Delta T_{p-v}}{0.404(1-S)^{1/25}}
\]  

(2)

For the nonlinear refractive index was employed:

\[
n_2 = \frac{\lambda \Delta \Phi_0}{2\pi I_o L_{eff}}
\]  

(3)

Where \(\Delta \Phi_0\) is the phase shift, \(\lambda\) is the wavelength, \(L_{eff}\) is the effective thickness of the sample, and \(I_o\) is the input beam intensity (at \(z=0\), focal point). The experiments were carried out using a CW argon laser at 514 nm, the [BMI][BF₄] presented an nonlinear refractive index \(n_2\) equal to \(-2.88459 \times 10^{-13}\) m²/W [11].

In summary, we have developed a useful laboratory facility with which practically any optical sample can be investigated. Moreover, the preliminary results obtained suggest that ionic liquids are a class of very promising materials for optical applications with large nonlinear refractive indexes. The results indicate that the photothermal lens effect gives the most important contribution for the large nonlinearity that this medium presents by the ionic liquid structure, determined by the anion, influence the nonlinear refractive index and thermo-optical coefficient dispersion.
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