Measuring of nonlinear properties of spatial light modulator with different wavelengths

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Abstract. The non-linear optical properties of Spatial Light Modulator (SLM) represented by Nonlinear Refractive Index (NLR) and nonlinear Absorption coefficient has been measured in this work using highly sensitive method known as Z-scan technique for different wavelengths (red and green). The capability to do instant measurements of different nonlinear optical parameters lead to consider these techniques as one of the most desired and effective methods that could apply for different materials. The results showed that the NLR were in the same power for the different wavelengths while the nonlinear absorption is higher in case of green laser.

Keyword: SLM; Nematic Liquid Crystal, Z-scan technique

1-Introduction
Liquid Crystals (LC’s) are materials that have one or more intermediate phase(s) between solid and liquid phases. In this intermediate phase, they retain the ability to flow like ordinary liquid, but also possess long-range orientational order. Some liquid crystals may also have positional order as well. Liquid crystalline phases, which classified according to their orientational and positional orders. The nematic phase has only orientational order, while the chiralnematic (cholesteric) phase has orientational order resembling the
nematic phase, but possess a helical layer structure as well. This spontaneous helical director configuration makes it more difficult to reorient a cholesteric than a nematic, liquid crystalline phases are illustrated in 'figure 1' [1, 2]. Liquid crystals are widely employed in display applications (LCDs). They are used to construct Light valves and Spatial Light Modulators (SLMs) utilized in real-time image processing and optical computing applications. They are also used to fabricate optical limiting and optical switching devices, highly sensitive temperature sensors and thermo-graphical devices, among many other usages. Their sensitivity to polarization distribution makes them even more useful for future possible applications [3].

Figure 1. liquid crystalline phases [1].
Nonlinear isotropic materials exhibit nonlinear optical responses when their optical properties are field-dependent. Usually, in order to observe nonlinear responses, high field strength or high optical intensity from a high-power pulsed laser is required. The strong anisotropic and molecular rotation of the LC’s lead to highly nonlinear optical response so, the refractive index of them change under applied stimulate (electric or magnetic field) or low optical intensity from CW laser [3].

S. Bahae et al. [4], were the first group whom introduce the z-scan technique, which could be defined as a highly simple sensitive method compared with interferometric method, from this technique the nonlinear parameters of liquids and sold could behind.

In Z-Scan technique, a sample is scanned along the optical axis in the focal region of a single Gaussian TEM00 beam. The transmission through the sample, with and without an aperture in the far field is then recorded. The transmission with an aperture (closed aperture) characterizes the sign and magnitude of the nonlinear index, while the transmission without an aperture (open aperture) characterizes the nonlinear absorption. This is a simple and sensitive technique for measuring the change in phase induced on a laser beam upon propagation through a nonlinear material. It gives both the sign and magnitude of this phase change, \( \Delta \Phi_o \) which is simply related to the nonlinear refractive index, \( n_2 \) [5, 6].

2-Experimental work

In this work, z-scan technique is used to measure the nonlinear parameters of SLM cell which has an array of 90° nematic LC., Holoeye LC2002 SLM from Sony has been used. This type contains a Sony SVGA (800*600) LC micro display and driver electronics, the wavelength range of this SLM is (400-650) nm, LCD thickness is 20μm, the experiment was carried out at room temperature.

In this work we used two different lasers wavelengths to study the nonlinear properties of SLM the first one is He:Ne laser (\( \lambda = 632.8 \text{nm} \)) and the second one is green semiconductor laser (\( \lambda = 532 \text{ nm} \)). The beam is focused to a small spot by a positive lens with focal length 15 cm. The Z-scan technique, which is a simple experiment, used to measure intensity dependent nonlinear susceptibilities of materials. In this technique, the material sample (SLM) is passed through extensive Gaussian beam along the z-direction, and the far field intensity versus sample position Z-scan curve, predicated on a local response, gives the real and imaginary part of third order susceptibility. In the closed-aperture (window), Z-Scan measures the change in intensity of a beam, focused by lens as the sample passes through the focused area. Photo-detector (or power meter) collects the light that passes through an axially centered aperture in the far field. The change in on axis intensity is caused by self-focusing either self-defocusing by the sample (the SLM in our case) as it travels through the beam waist. A TEM00 Gaussian beam has maximum intensity at the center and will create a change in index of refraction forming a lens in a SLM as shown in ‘figure 2’ [7].

**Figure 2.** Closed aperture Z-Scan, the blue arrow indicate the direction of movement.
While when the aperture is moved we get an open-aperture (window) method, here the Z-Scan measures the change in intensity of the focused beam, as it clear in 'figure 3', in the far-field at detector, which captures the entire beam. Multi-photon absorption in SLM caused changing in output intensity as the SLM travels through the focused beam waist. In the focused area, the intensity is in its maximum value, so we get largest nonlinear absorption. At the “tails” of the Z-scan curve, where |Z| >> Zo, the beam intensity is too weak to elicit nonlinear effects. The higher order of multi-photon absorption present in the measurement depends on the wavelength of the laser source and the energy levels of the SLM [7].

Figure 3. Open-aperture Z-Scan, the blue arrow indicate the direction of movement.

The relative on-axis transmittance of the SLM, which is obtained (at the small aperture of the far-field detector), is given by [8]:

\[ T(Z, \Delta \Phi_0) = 1 - \frac{4 \Delta \Phi_0 Z / Z_0}{[(Z^2 / Z_0^2) + 9][(Z^2 / Z_0^2) + 1]} \] (1)

Where \( T \) is the transmission of laser light through the aperture, which is a function of the sample position \( Z \), and \( Z_0 \) is Rayleigh wavelength and \( \Delta \Phi_0 \) is the on-axis phase shift at the focus zone, and it’s measured through the following equation [8]:

\[ \Delta T_{p-v} \approx 0.406(1 - S)^{0.25} \Delta \Phi_0 \] (2)

The \( \Delta T_{p-v} \) is measured by get the difference between the normalized peak and valley transmittance and \( S \) is linear transmittance of the aperture, which is calculated from the following formula [8]:

\[ S = 1 - \exp \left(-2r_a^2 / w_a^2\right) \] (3)

Where \( r_a \) represent aperture radius and \( w_a \) is the beam radius at the aperture, the nonlinear refractive index could be found through the following equation [9]:
\[ n_2 = \Delta \phi_0 / I_0 L_{\text{eff}} k \] (4)

where, \( k = 2\pi / \lambda \), \( \lambda \) is the laser wavelength, \( I_0 \) is the maximum intensity within the SLM at the focus and the \( L_{\text{eff}} \) Effective thickness, which is given by [10]:

\[ L_{\text{eff}} = [1 - \exp(-\alpha_0 L)]/\alpha_0 \] (5)

Where \( \alpha_0 \) is the linear absorption coefficient of the samples and it is obtained through the, Beer-Lambert law that defines based on \( \alpha = -\left( \frac{1}{l} \right) \ln I/I_0 \)in the linear regime of the experiment. While the nonlinear absorbance coefficient given by the following equation [10]:

\[ \gamma = 2\sqrt{\sum T / I_0 L_{\text{eff}}} \] (6)

3-Experimental results
The spectral absorbance of the SLM was measured by use of an UV-VIS spectrophotometer, which is shown 'figure 4'.

![Figure 4. UV-VIS absorbance spectra of SLM](image-url)
The Rayleigh wavelength ($Z_0$) is equal to 3.1 cm to green laser and 2.7 cm to the red one and they both are greater than the SLM thickness, which is, allows considering the interaction between the laser pulse and the SLM to occur at just one location and not to distribute out over the entire interaction length. The results of typical Z-scan normalized transmittance measurement for the SLM in case of used He:Ne Laser is shown in 'figures 5' and results illustrated in table 1.

![Normalized transmittance curve of SLM for He:Ne laser](image)

**Figure 5.** Normalized transmittance curve of SLM for He:Ne laser

| Case                        | $n_2 \left( \frac{W}{cm^2} \right)$ | $\gamma \left( \frac{cm}{mw} \right)$ | $\alpha (\mu m^{-1})$ |
|-----------------------------|-------------------------------------|----------------------------------------|-----------------------|
| Closed. Aperture            | 12.965*10^-8                        | 0.0249                                 | 0.203                 |
| Closed. aperture/open,aperture | 1.2554*10^-7                       | -                                      | -                     |

While the results of typical z−scan normalized transmittance measurement for the SLM in case of used green semiconductor Laser are shown in figures 6 and results illustrated in Table 2.

![Normalized transmittance curve of SLM for Green semiconductor laser](image)

**Figure 6.** Normalized transmittance curve of SLM for Green semiconductor laser
Table 2. The linear and Nonlinear Optical properties of SLM for green semiconductor laser

| Case                      | n (\(\frac{W}{cm^2}\)) | \(\gamma (\frac{cm}{mW})\) | \(\alpha (\mu m^{-1})\) |
|---------------------------|------------------------|----------------------------|--------------------------|
| Closed aperture           | 9.927 \times 10^{-8}   | 0.286                      | 0.162                    |
| Closed aperture/open      | 2.053 \times 10^{-7}   | -                          | -                        |

The resulted behavior of the SLM shows a positive z-scan profile starting linearly at (z<0) (far from focus) where the laser beam intensity is low and non linear refraction is negligible in this case the transmittance still constant, when the SLM began to move towards the focus the intensity began to increase, self-lensing will occur in the SLM and the laser beam will be collimated on the aperture which is located in front of the detector, so the higher transmission of the laser beam will be passed through the aperture until it reach to its maximum at the focus (z=0) then this maximum intensity began to drop after passing the focus zone and the behavior return to its linearity as the sample moved at (z>0). The non linear absorption of the SLM is calculated utilizing open aperture z-scan measurement, the behavior is changed from linear far from the beam waist (-z) then to nonlinear at (z=0) then return to its linear behavior at (+z) which change its intensity, this change is caused by two photon absorption in the sample travels through beam waist. S. Saadi et al [11], determine the real part of the third order nonlinear susceptibility of SLM utilizing Z-scan technique using He:Ne laser which is in a good agreement with our results related with He: Ne laser.

4-Conclusions

An investigation of the optical nonlinearity of SLM by using two different sources have been carried out in this work. The nonlinear refractive index, \(n_2\) of SLM cell which contains of an array of twisted nematic LC was measured using the single Beam z-scan technique for excitation wavelength, 632.8 nm, and 532 nm in the CW regime. The sign of the nonlinear refractive index was found to be positive so the experiment confirmed that the nonlinear phenomenon was caused by self-focusing process, the value of nonlinear refractive index for two wavelengths were in the same power.

The nonlinear absorption experiments were carried utilizing open aperture z-scan measurements, the value of this coefficient is lower when Red laser was used.

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