Abstract

The study of nature of Optical fiber materials is required for efficient telecommunications. The Z–Scan technique proposed by Sheik Bahae (1989) was used with both CW and pulsed lasers ranging from nanosecond to femtoseconds to measure non-linear optical properties of various class of materials including bulk semiconductors, dielectrics and semiconductor doped glasses, organic molecules, and liquid crystals.

1. Introduction

Wave-guided nonlinear optics \(^{(7,8)}\) had grown rapidly after the advent of laser technology. Wave guided optics changed several aspects of nonlinear optics Firstly; there was the immediate possibility of confined optical power, which produced the very large optical intensities required for nonlinear interactions using sources of modest power. Secondly, weak effects could be easily magnified since optical confinement was maintained over very long interaction lengths. Thirdly, the ensured long interaction length also meant that lower power densities could be used when optical damage was a problem. Fourthly, there was a possibility of compensating for phase mismatch by using dispersion of the guided modes.

The propagation of light in a nonlinear medium is governed by the wave equation derived from Maxwell’s equations for an arbitrary homogeneous, isotropic dielectric medium.\(^{(9,10)}\) The isotropy of the medium ensures that the vectors \(P\) and \(E\) are always parallel so that they may be examined on a component-by-component basis,

\[ \nabla^2E - 1/c_o^2 \frac{\partial^2E}{\partial t^2} = \mu_o \frac{\partial^2P}{\partial t^2} \]  

(1)

It is convenient to write the polarization density as a sum of linear \((\varepsilon_0 \chi E)\) and nonlinear \((P_{nl})\) contributions,

\[ P = (\varepsilon_0 \chi E) + (P_{nl}) \]  

(2)

On further solving the above equation by using the relations such as \(c = c_0/n\), \(n^2 = 1 + \chi\) and \(c_0 = 1/(\varepsilon_0 \mu_o)^{1/2}\)
We can write,

\[ \nabla^2 E - \left\{ \frac{1}{c_0^2} \right\} \frac{\partial^2 E}{\partial t^2} = -\delta \]  

(3)

Where; \( \delta = \mu_0 \frac{\partial^2 P_{nl}}{\partial t^2} \)  

(4)

The above equation represents a wave equation for a nonlinear medium.

A wave equation in which the term \( \delta \) is regarded as a source that radiates in a linear medium of refractive index \( n \). Because \( P \) (and therefore \( \delta \)) is a nonlinear function of \( E \), equation (3) is a nonlinear partial differential equation in \( E \). This is the basic equation that underlies the theory of nonlinear optics. There are two approximate approaches to solve this nonlinear wave equation. The first simple iterative approach is known as the Born approximation \((11, 12)\). The second approach is a coupled-wave theory in which the nonlinear wave equation is used to derive linear coupled partial differential equations that govern the interacting waves. This approach is the basis of the more advanced study of wave interactions in nonlinear media.

2. Experimental Details

Z–Scan setup shown in the figure (1) was used to study Z–Scans. The laser pulses from amplified femtosecond Ti: sapphire (TIS) laser system that delivered 100 fs pulses centered on 800nm operating at 1 KHz repetition rate, the thermal nonlinearity does not contribute to the nonlinearity. Incident beam was focused by lens (L) onto the sample (S). Sample kept on the translating stage was moved from –Z to +Z direction across the focal region.

The light beam transmitted through the sample was detected at two places, one through an aperture (A) placed in the far field by a detector D3 to collect closed aperture Z–Scan data and other D2 using the beam splitter BS2. The entire reflected light from BS2 was collected on the photo detector D2 to simultaneously record open aperture Z–Scan data. A small portion of the incident beam reflected from the beam splitter BS1 was collected by the photo detector D1. The photo detectors \((13, 14)\) D1, D2, and D3 are large area photodiodes designed to monitor the incident pulse energy of the single femtosecond pulse. Neutral density filters are also used in high precision laser
experiments because the power of the laser cannot be adjusted without changing the other properties of the laser light like collimation of beam. They are usually kept in the path of laser beam and can reduce or modify the intensity of all wavelengths equally or to achieve desired light attenuation. It can be colorless or grey filter having greater ability to change aperture, exposure time of the sample. The fractional transmittance is given as \( \frac{I}{I_0} = 10^{-t} \) or
\[
t = -\log_{10} \left( \frac{I}{I_0} \right)
\]
Where \( I_0 \) is the incident intensity and \( I \) is the measurable intensity.

3. Nonlinear Optical Studies In Semiconductor Doped Glasses (SDG’s)

Semiconductor doped glasses\(^{15}\) possess nonlinear properties and they are used for all optical data processing applications\(^{16, 17}\). In SDG’s, semiconductor nano-particles are embedded in the glass matrix. Colored glass filters have the capability to transmit a very broad band of light signals. They are used for order sorting, light attenuation and spectral selection of a broad band source. The long wave pass type filter is used as wavelength sorting filters, transmitting longer wavelengths. Band pass filter is used to improve signal to noise ratio of illumination systems used in optical communication systems\(^{18}\). Color glass filters are available in circular or square shapes and in various colors and sizes. The commercially available Schott color glass filters contain CdS\(_x\)Se\(_{1-x}\) and CdSe,Te\(_{1-x}\) nano-particles. Nonlinear optical properties, such as nonlinear refractive index (\( n_{nl} \)) and two photon absorption (TPA) coefficient were studied in color glass filter. Most of the studies in SDG’s were carried out in the transparency region, \( 2\hbar\omega > E_g > \hbar\omega \), where \( E_g \) represents the energy band gap of the semiconductor and \( \hbar\omega \) is the excitation photon energy. The semiconductor doped glasses (SDG’s) used for analysis have band gap energies ranging between resonance and transparency regions with the excitation photon energy.

![Figure 2: Open aperture z-scan profile \( \{Z (\text{mm}) \text{ Vs. normalized transmission } (T_x)\} \) of RG850 performed at different intensities.](image)

Z–Scan experiment was performed at different intensities. At low intensity or energy the sample exhibits saturable absorption only in the open aperture Z–Scan, but for an open aperture performed at high intensity or energy, the sample showed transition from saturable absorption (SA) to reverse saturable absorption (RSA) at \( z = 0 \).
4. Results And Discussion

At peak intensity of $650 \text{GW/cm}^2$ generated free carrier density increases and starts absorbing the excitation pulse itself, resulting in reduction of transmission through the sample. Dip in the transmission at $Z=0$, may be due to TPA process. The Gaussian beam behind the sample may be assumed to be a thin temporal lens has the same beam radius and a different radius of curvature due to which the position of beam waist and the intensity distribution in the far field get changed during the pulse. The intensity of the Gaussian beam is given by the relation

$$I(z, t) = \frac{2 P(t)}{\pi \omega^2(z,t)} \exp\left(-\frac{2r^2}{\omega^2(z,t)}\right)$$

(6)

Where $P(t)$ is the momentary power of the beam, $\omega(z,t)$ is the beam width in the position $(z)$ of the aperture.

If the aperture $(a) < \omega(z,t)$, then

$$\exp[-2r^2/\omega^2(z,t)] \approx 1$$

(7)

(8)

And the above equation (6) gets modified and the power pulse behind the aperture is given by the relation

$$P_a(t) = \frac{2 P(t)}{\pi \omega^2(z,t)}$$

(9)

When the sample is located away from the beam waist that means in a region of low beam intensity the transmission through the aperture is normalized to unity. As the sample is shifted closer to the beam waist the induced nonlinear absorption and refraction exerts stronger influence on the beam and the normalized transmittance curve takes the characteristic shape. The phenomenon of transition from saturable absorption to reverse saturable absorption is observed in organic molecules and nano-particles.

5. Limitation Of Z-Scan Method

The z-scan curves are dependent on intensity or wavelength of the laser beam used. Therefore the analysis requires utmost care. A novel composition can be observed under different input intensities using z–scan technique and the transformation of open aperture z-scan curves from reverse saturable absorption to saturable absorption.

6. References

Dr. Rakesh Sharma :: Study Of Nonlinear Optical Behavior In Semiconductor Doped Glasses (S.D.G's) Material Of Optical Waveguide


