

2D Chalcogenide Thin Films for Super-Resolved Laser Structuring

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Abstract: The saturable absorption behaviour associated with chalcogenide thin films has been investigated and optimized using Z-Scan Technique. Huge saturable absorption responses (of the order of 10^{-7} m/W) were observed for the Bismuth Selenide thin films, which depend on material characteristics and the laser parameters. An approach in which the application of the saturable absorber thin films for super-resolved laser inscriptions has been discussed and a theoretical analysis of the super-resolution efficiency of the thin films has been made.

1 INTRODUCTION

Surpassing the diffraction limit is a question that's been puzzling the researchers for many years. Any conventional lens that is perfected by its design would be diffraction limited. Hence, the need for a technique to surpass the diffraction limit, with minimal complexity, is of great importance for super-resolution applications. Currently, there are several techniques and proposals to achieve super-resolution by surpassing the diffraction limit [1-3]. Even though there are efficient techniques, the high cost and lack of versatility makes them inappropriate for certain applications such as super-resolved laser inscription.

The use of saturable absorbers for achieving super-resolution has been widely investigated for improving the efficiency of optical data storage, laser inscriptions and other similar applications [4-6]. In this regard, the chalcogenide materials such as Sb_2Te_3 , Bi_2Se_3 and Bi_2Te_3 hold great importance as saturable absorbers. The saturable absorption in such material arises due to the bleaching of light when the absorption saturates while the sample is irradiated with intense laser pulses [7].

The chalcogenide saturable absorbers belong to the category of topological insulators. They have an insulating bandgap in the bulk with conducting surface states [7]. The complex nature of topological insulator calls for the precise optimisation of the saturable absorption behaviour associated with respect to the material properties such as thickness and crystalline structure and laser excitation parameters such as wavelength and pulse duration.

In this work we propose a technique to optimise the optical nonlinearities associated with chalcogenide materials and theoretically study the efficiency in terms of super-resolution.

2 EXPERIMENTAL TECHNIQUES

2.1.1 Material Preparation

The Bismuth Selenide thin films were prepared by means of electron beam deposition [8]. A quartz microbalance with a precision of ± 0.2 nm allows the preparation of Bismuth Selenide thin films ranging from 1 nm to 100 nm. All the films were subjected to identical deposition conditions such as the deposition rate (0.5 nm.s^{-1}), room temperature and chamber pressure (10^{-6} mbar). To prevent the thin films from oxidation, a 2 nm SiO_2 layer was also added. The films were annealed in an oven at 150°C to 200°C for 1 hour. The morphological analysis was carried out by using SEM and XRD techniques.

2.1.2 Investigation of Nonlinear Optical Properties

The optical nonlinearities associated with Bismuth Selenide were analysed using the Z-Scan technique. A 1030 nm wavelength, 400 fs Ti: Sapphire Laser, operating at 100 Hz, has been employed for the Z-Scan measurements. The laser has been focused using a 100 mm plano-convex lens. The thin films were translated along the focal axis of the lens to expose the thin films to an intensity gradient. The transmitted light through the thin films is then split in two parts with a beam splitter. One part of the beam is detected by a photo detector using a lens ("open" aperture Z-scan), whereas the other part is detected after passing through a small aperture ("closed" aperture Z-scan) as mentioned elsewhere [8].

3 RESULTS AND DISCUSSIONS

The Open aperture Z-Scan analysis of Bismuth Selenide thin films yielded a response where the transmission has

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increased when the sample was closer to the focus and the transmission peaked when the sample was at the focal plane of the lens. This is a characteristic of saturable absorption behaviour. No response was recorded in the “closed” aperture Z-Scan arm indicating that the thin film holds only a strong saturable absorption behaviour. From the analysis of the Z-Scan curves a nonlinear absorption coefficient of the order of 10^{-7} m/W has been determined.

When a gaussian beam is passing through a saturable absorber, the low-intensity region of the gaussian pulse suffers higher absorption and the high-intensity central region is less absorbed. This results in the size reduction of the gaussian pulse spatially. Fig. 1. represents the beam size reduction simulated using the nonlinear beer-Lambert’s Law [9], that results in a 15% of beam size reduction after passing through a Bi_2Se_3 saturable absorber.

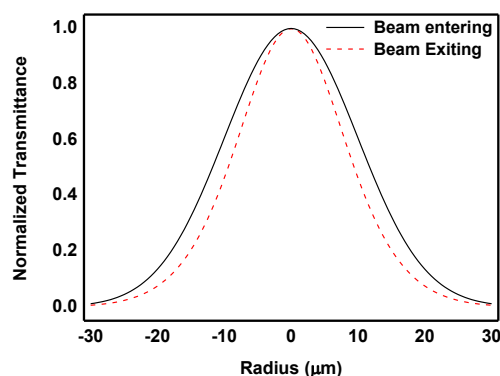


Fig. 1. Simulation of the gaussian beam size reduction after passing through a Bi_2Se_3 saturable absorber.

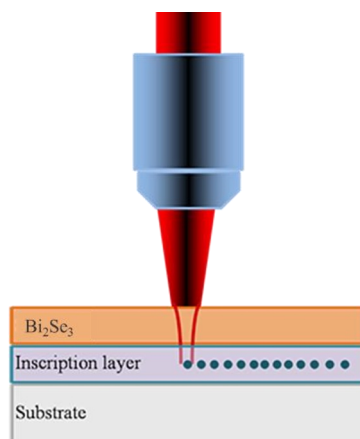


Fig. 2. Super-Resolved Inscription using Bi_2Se_3 saturable absorber.

Our group is currently aiming to make experimental demonstrations of the super-resolution efficiency using multilayer structures as the one shown in Figure 2.

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