Relief and Trench Formation on Chalcogenide Thin-Films Using Electron Beams

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Glasses are tremendously varied and complex materials consisting of networks of characteristic building blocks (pyramids, tetrahedral) whose relaxation can be arrested to varying degrees. Recently the role of network connectivity on light induced effects has been elucidated in Raman scattering, and Brillouin scattering has revealed a photo-reversible 50% reduction in the longitudinal elastic modulus in chalcogenide glass (Ge_xSe_{1-x}). Structural changes due to electron beam irradiation have also been observed. These findings offer unique opportunities to exploit their photon- and electron-response to advance and develop devices for photonic integrated circuits with nano-scale control. In this paper, we present experimental results of electron beam induced reliefs in amorphous Ge_xSe_{1-x} films deposited on silicon dioxide cladding layers.

Thin films of Ge_xSe_{1-x} (x ~0.2) chalcogenide glass where fabricated by pulsed laser deposition. Such a laser based fabrication process has the advantages of nearly stoichiometric transfer of target material to deposited films, short processing times, and possibility of process control through laser operating parameters. The films were fabricated using rotating targets of chalcogenide glasses that were prepared by conventional direct synthesis from elements in evacuated silica ampoules followed by melt quenching.

Employing an electron beam lithography instrument, as shown in Fig. 1, the $Ge_{0.20}Se_{0.80}$ thin film is exposed to electron beams characterized by dose, energy, and current. A 400 µm aperture was used, yielding a beam with a spot size on the order of 100 nm. For light guiding structures, the focus is on the fabrication of ridge waveguide reliefs, the goal being to obtain structures that operate in the single mode regime. Atomic force microscopy (AFM) was used for characterization, avoiding scanning electron microscopy (SEM) which could induce undesirable deformations. Fig. 2 shows an AFM measurement of one of the reliefs formed by linearly scanning the electron beam a distance of 30 µm on a 1.36 µm thick $Ge_{0.20}Se_{0.80}$ film at a dose of 7.2×10^6 µC/cm^2, beam current of 150 nA, and beam energy of 100 kV. The beam step size was 5 nm. The line is 40 nm high, and the deformation is 1 µm wide.

The electron beam induced reliefs are observed to be strongly dependent on the electron beam dose. Fig. 3 is AFM data showing the cross-sectional profile as a function of dose. At relatively large dose values, a transition region is observed where the reliefs become trenches in the film. The trenches are accompanied with slightly raised edges that slowly decrease in height away from the center of the trench. Both of these types of deformations could be used in optical gratings, waveguides, and waveguide-cavity coupled structures. Relief height versus electron beam dose is shown in Fig. 4. At a dose of 2.13×10^6 µC/cm^2, a height of 85 nm is observed. The observation that an electron beam can induce a mound and a trench in Ge_xSe_{1-x} glass that lies near its rigidity transition opens up new directions in the development of novel devices for photonic integrated circuits exploiting mask-less lithography techniques.

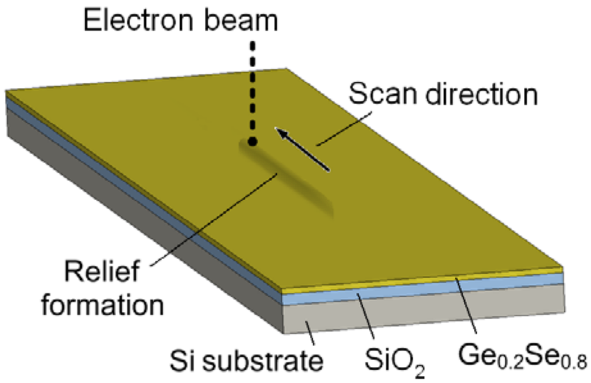

Fig. 1. Schematic of electron beam induced reliefs in $Ge_{0.20}Se_{0.80}$.

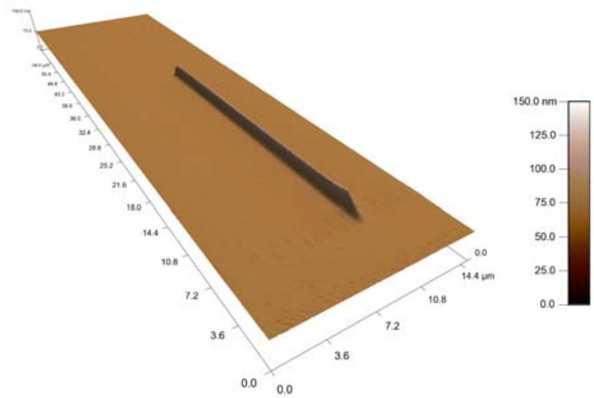

Fig. 2. AFM measurements of reliefs in $Ge_{0.20}Se_{0.80}$ when exposed to a dose of 7.2×10^7 µC/cm^2 (relief is 30 µm long, 1 µm wide, and 40 nm in height).

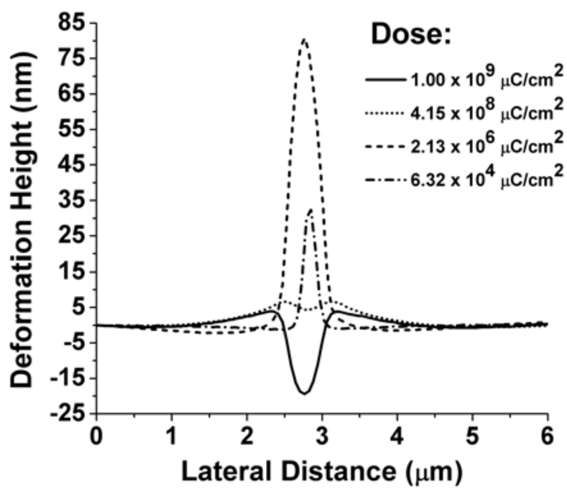

Fig. 3. AFM measurements of cross-sectional profiles of electron beam induced reliefs show the presence of a transition dosage between trenches and reliefs.

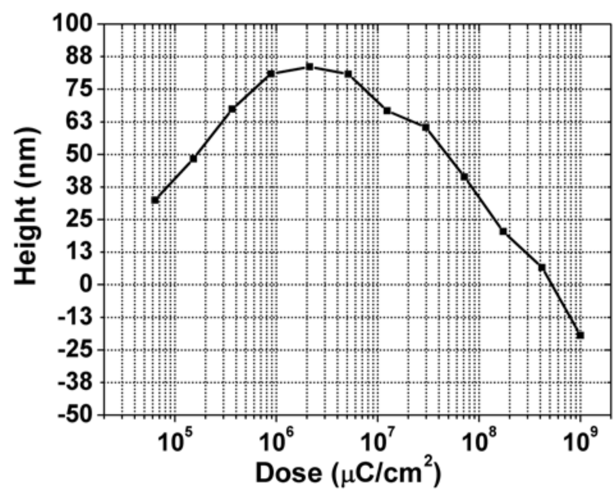

Fig. 4. AFM measurements of relief height, relative to original film surface, versus electron beam dose.