Direct Write Reliefs in Excess of One Micrometer on Chalcogenide Thin-Films Using Electron Beams

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Brillouin scattering has revealed a photo-reversible 50% reduction in the longitudinal elastic modulus in chalcogenide glass (Ge_xSe_{1-x}).[1] Structural changes due to electron beam irradiation have also been observed.[2] 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 with height on the order of 1 μm, thereby enabling flexibility in the realization of direct write optical waveguides.

Thin films of Ge_xSe_{1-x} (x ~0.2) chalcogenide glass where fabricated by pulsed laser deposition. 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, the $Ge_{0.20}Se_{0.80}$ thin film is exposed to electron beams characterized by beam scan rate energy, and current. Atomic force microscopy (AFM) was used for characterization. Here, we expose 1 pixel wide lines 50 μm long on ~400 nm thick films using an aperture of 500 μm diameter and a resolution (i.e. beam step size) of 5 nm. As shown in Fig 1, all lines have a spike at the beginning and a trench at the end. Beams with a fast enough scan rate show a sawtooth pattern which using a DFT has been correlated to the trapezium size of 1.28 μm at this resolution. Fig 2 shows that for extreme exposure counts and a slow enough beam, deformations greater than twice the thickness of the film can be obtained. We conducted finite element waveguide analysis of the deformations to demonstrate capacity for light guiding at telecommunications wavelengths. Fig. 3 illustrates that light can be guided even in a relatively shallow deformation. Fig 4 shows the effective propagation index (guided modal phase constant normalized to free space phase constant) of the fundamental mode and the regions where multiple modes are guided.

1 J. Gump, I. Finkler, H. Xia, R. Sooryakumar, W. J. Bresser, P. Boolchand, Phys. Rev. Lett. **92**, 245501 (2004).
2 G.. B. Hoffman, W. Liu, W. Zhou, R. Sooryakumar, P. Boolchand, R. M. Reano, J. Vac. Sci. Tech. B **26**, 2478 (2008).

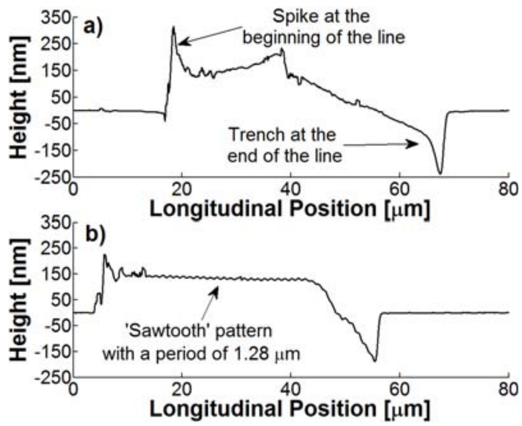

Fig 1: Longitudinal section plots of lines for (a) a beam scan rate of 1.48 x 10^3 μm/s and (b) 3.76 x 10^3 μm/s for a 100 kV beam, 360 nA and 5000 exposures. The slower scan rate removes the sawtooth pattern but exacerbates the spike and trench heights.

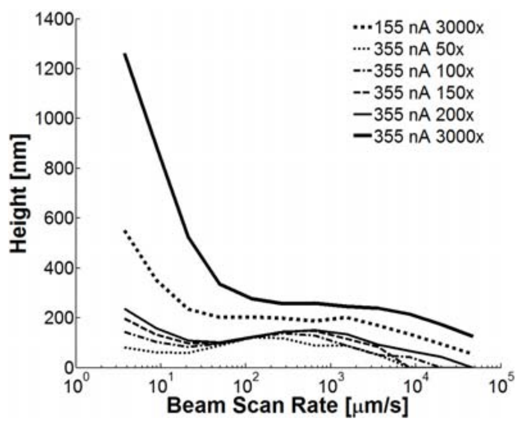

Fig 2: Height versus beam scan rate for a 50 kV beam and different beam currents and exposure counts. Note the swift jump in deformation heights for the slowest beam scan rates, larger currents, and higher exposure counts.

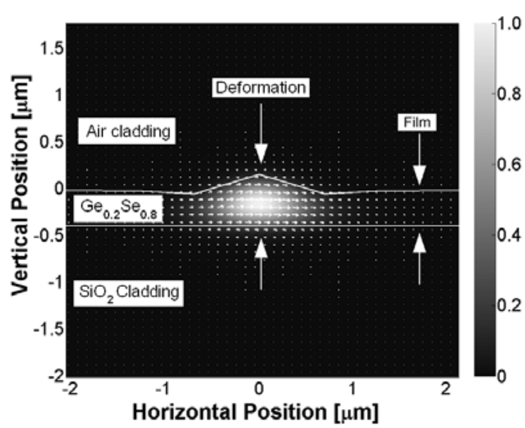

Fig 3: Geometry (solid white lines) of a ridge approximated as triangular. Power density pattern (surface plot) and transverse electric field pattern (white arrows) were obtained using the finite element method; the fundamental mode is shown. This is a 50 kV, 355 nA beam with 3000 exposures and 8.53 x 10^3 μm/s beam scan rate.

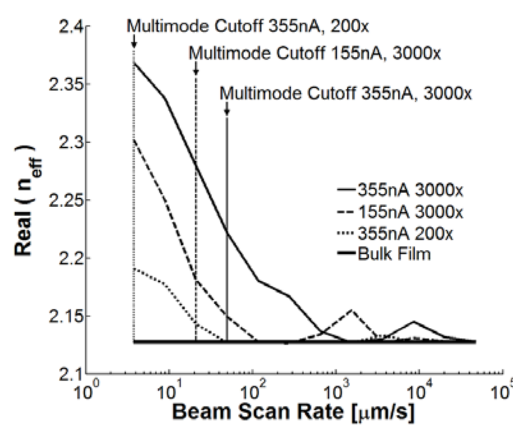

Fig 4: Effective propagation index (n_{eff}) of the fundamental mode versus beam scan rate for a 50 kV beam with beam currents and exposure counts as parameter. The n_{eff} of the bulk film TE_0 slab mode is shown as a reference. Also shown are the lines to the left of which denote regions where more than one mode is guided (Beam is 50 kV).