Fabrication Process Development and Characterisation of Compact Chalcogenide Planar Waveguides Having Low Loss

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Abstract
We present the fabrication process development and the characterisation of sub-micron thick As$_2$S$_3$ waveguides. Thin PMMA and BARC were employed as protective layers prior to photo-resist patterning in order to prevent the attack of alkaline developer. The propagation losses of $-0.2$ and $0.6$ dB/cm were measured from 4 micron and 2 micron wide waveguides in 0.85 micron thick film. Slight higher loss in TM mode may be resulted from the etched, rough sidewalls. Compactness and low attenuation of the waveguides strongly support their application in planar integrated nonlinear optical devices.

Keywords: chalcogenide; planar waveguides; fabrication; nonlinear optic devices

Introduction
Chalcogenide glasses (ChGs) represent a wide range of inorganic glasses that contain one or more of the chalcogen elements: S, Se or Te. These glasses typically exhibit low phonon energies due to higher atomic mass, and have an optical window extending far into the infrared (IR). This property has made them good candidates for a number of applications, including thermal and medical imaging, bio-sensing or telecommunications. ChGs are also emerging as excellent materials for integrated nonlinear optic (NLO) devices because they offer ultrafast broadband optical response time (below picosecond), high optical nonlinearity (two to three order of magnitude greater than that of silica) and low linear and nonlinear losses at telecom window. Arsenic tri-sulphur (As$_2$S$_3$), a representative ChG, has been studied in various forms – bulk glass, optical fibre, and recently planar waveguide. Our research group (CUDOS) already reported the development of As$_2$S$_3$ planar waveguides employing thin film deposition and plasma etching [Madden et al.] and demonstrated several NLO devices using these waveguides [Ta’eed et al.]. For more compact photonic integrated circuits, however, the device length reduction has to be compensated by boosting the waveguide nonlinearity coefficient, $\gamma = (2\pi/\lambda)(n_2/\alpha)$. The nonlinear refractive index, $n_2$, is inherent to a material; hence the effective area of the light in the guide ($A_{eff}$) should be shrunk. This means the propagating light is to be tightly confined in the structure. The aim of this study, therefore, was to fabricate sub-micron thick, compact waveguides having low propagation loss.

Devices Fabrication and Characterisation
As$_2$S$_3$ films were deposited by thermal evaporation on thermally oxidized silicon wafers in a chamber evacuated to $2 \times 10^{-4}$ torr. Deposition occurred with the source to substrate distance of $-40$ cm at a rate typically of $0.2-0.3$ nm/s. The photolithography on As$_2$S$_3$ film is not straightforward owing to the attack of alkaline developer solution on the film. Therefore, we covered the film with a thin foreign material (e.g., bottom anti-reflective coat-BARC) as a protective layer [Choi et al.]. After photo-resist patterns were produced on the protective layer by Karl Suss MA6 mask aligner using i-line ($\lambda = 365$ nm) and wet development, the waveguides were etched in an inductively coupled plasma reactive ion etcher (Plasmaplab100, Oxford) with CHF$_3$ gas. The As$_2$S$_3$ guides were cladding with 15 micron thick film of inorganic polymer glass (RPO Pty Ltd, IPG™) and UV cured. Measurements of the insertion loss for the waveguides were made using a tunable laser source, a polarisation controller/scrambler, and an InGaAs power meter.

When we applied the conventional fabrication method [Madden et al.] to 0.85 $\mu$m thick waveguides, the devices produced showed $-0.5$ dB/cm loss, which was 10 times higher than that from 2.5 $\mu$m thick guides. We found that the wet stripping of BARC made the top surface rough so that the light scattering from this surface rose significantly. To overcome this problem we developed a new protective layer exploiting transparent polymers. This approach could eliminate the BARC wet etching process so that the surface degradation was avoided. We have tested poly(methyl methacrylate) (PMMA) as a protective layer. When PMMA was spin-coated on the film, however, lots of pinholes were present. We used BARC to cover up these holes and removed it by plasma etching after As$_2$S$_3$ patterning. Figure 1 shows the cross sectional view of photo-resist pattern on the protective layer and
the finished $\text{As}_2\text{S}_3$ waveguide. We measured the propagation loss of fabricated waveguides by the cut back method. The propagation losses of 0.2 and 0.6 dB/cm were measured from 4 micron and 2 micron wide waveguides in 0.85 micron thick film. (figure 2) Slightly higher loss was found in TM mode, especially from narrower guide. Figure 3 compares the TE1 and TM1 mode field in 2 micron wide, 0.85 micron thick guide. Even though TM is confined more tightly in the core, its shape is more elongated along the film plane; hence more light can see the etched, rough walls, rather than relatively smooth top and bottom interfaces. This can explain the reason of the higher TM loss. Recently we have demonstrated that these sub-micron thick, low loss waveguides can be a promising platform for a parametric amplifier [Lamont et al. (2008a)], super-continuum generation [Lamont et al. (2008b)] and radio-frequency spectrum analyser with terahertz bandwidth [Pelusi et al.].

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References

Figure 1 Scanning electron microscope images showing the cross sectional view of photo-resist pattern on the protective layer (a) and the finished $\text{As}_2\text{S}_3$ waveguide (b).

Figure 2 The insertion losses of fabricated waveguides and the estimated propagation losses by the least square fit.

Figure 3 The TE1 and TM1 mode fields in 2 micron wide, 0.85 micron thick guide.
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