

## Direct laser written channel and spin-coated thin film waveguides in an amorphous chalcogenide (Ga:La:S)

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**Abstract** Chalcogenide glasses are emerging as interesting and useful materials for planar technologies. Recently, we have laser ( $\lambda=244$  nm) written uniform channel structures into neodymium-doped gallium lanthanum sulphide glass. A typical channel waveguide, with refractive index change  $\Delta n \approx +10^{-3}$ , has attenuation  $< 0.5$  dB cm $^{-1}$  and is spatially single-mode at 1  $\mu\text{m}$  with measured fluorescence decay of 73  $\mu\text{s}$  for the  $^4\text{F}_{3/2}$  lifetime at 1075 nm. In addition, high quality thin films of this undoped glass were successfully spin-coated onto an expansion coefficient matched substrate. The interface quality between the substrate and guiding layer was observed to be excellent with uniformity in the spun layer and no observed crystallisation.

Chalcogenide glasses (ChGs) have unique optical properties that make them very interesting for integrated optical (IO) devices. These properties include low phonon energies (325 - 425 cm $^{-1}$ ), high IR transparency and a high non-linear refractive index. In addition, ChGs and amorphous films undergo remarkable structural changes when exposed to radiation and can potentially provide an interesting route to developing passive and active devices [1].

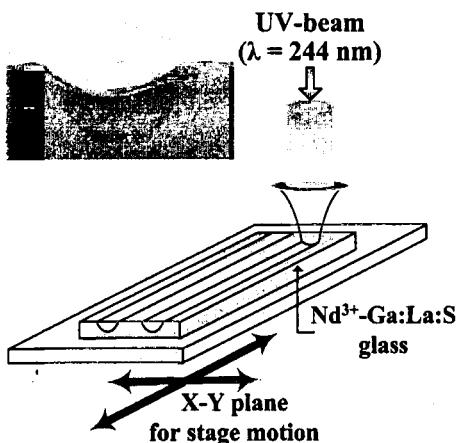


Figure 1. Set-up used to directly write channel waveguides into Nd<sup>3+</sup>-Ga:La:S. Micrograph of a channel is shown inset.

We have previously reported the development of channel waveguides in gallium lanthanum sulphide (Ga:La:S) glass [2]. The channel geometry can be beneficial for achieving low laser thresholds, circular spatial outputs and compatibility with optical fibre. The set-up shown in figure 1 consists of a frequency-doubled UV laser (Coherent FRED Sabre 500) with 200 mW of CW output at 244 nm. The UV beam spot size ( $1/e^2$  radius of intensity) is approximately 3.1 mm and the measured spot size of the focused waist is 3.3  $\mu\text{m}$ . The sample was attached to a computer controlled translation stage, which provided the 2D movement of the sample, has a maximum scan velocity of up to 5 cm/s and relative position resolution of 0.1  $\mu\text{m}$ . The quality

and dimensions of a channel waveguide was determined by both the intensity of the focused laser beam and the scan velocity. For our experiments, the UV spot size was varied between 25 – 50  $\mu\text{m}$  by adjusting the sample to focus distance and this, together with adjustment of the power, provides a controllable intensity in the range of  $I_{UV} = 1.5 - 10.2$  kW/cm $^2$ . The scan velocity was varied between 0.17 – 5 cm/s, and hence a fluence in the range of 1.5 – 150 J/cm $^2$  was applied to the glass surface. Micrographs were obtained using an analytical scanning electron microscope (SEM, JEOL 6400) to which an energy dispersive X-ray microscope (EDX), allowing compositional analysis, was attached. The micrograph shown inset in figure 1 shows a representative channel directly written into Ga:La:S glass with UV-laser fluence of 10.8 J/cm $^2$ . In this case photostructural changes in

the form of giant-photocompaction ( $1.2 \mu\text{m}$ ) and a region of refractive index change, with physical channel dimensions of  $13 \mu\text{m}$  by  $6 \mu\text{m}$ , were observed. Measurements within the photomodified region revealed variations in elemental ratios, with a decrease in gallium and sulphur and a relative increase in lanthanum content. This photochemical modification contributes to densification by creating a region of raised refractive index, which forms the waveguide core. A Ti:sapphire laser, tuned to  $814 \text{ nm}$ , was used to measure the room temperature fluorescence spectrum of a Ga:La:S sample doped with  $0.5 \text{ wt\% Nd}_2\text{S}_3$ . The measured fluorescence decay, of  $73 \mu\text{s}$  for the  $^4\text{F}_{3/2}$  lifetime, and  $^4\text{F}_{3/2} \rightarrow ^4\text{I}_{11/2}$  emission cross-section at  $1075 \text{ nm}$  were in good agreement with previous works [3]. A typical channel waveguide, with refractive index change  $\Delta n \approx +10^{-3}$ , has attenuation  $< 0.5 \text{ dB cm}^{-1}$  and is spatially single-mode at  $1 \mu\text{m}$ .

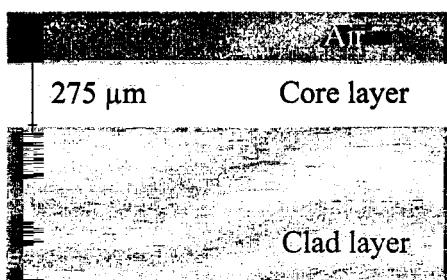


Figure 2. Core layer of Ga:La:S glass on clad layer of same material obtained through the spin-coat process.

Spin coating has been applied with great success in the fabrication of optical waveguides for IO applications [4]. The fabrication process as applied to Ga:La:S glass involves three steps. First, a heated ( $500^\circ\text{C}$ ) Ga:La:S substrate,  $2 \text{ mm}$  thick, was used as the clad layer and was dipped into molten ( $1100^\circ\text{C}$ ) core Ga:La:S glass. Next, the substrate was withdrawn from the molten glass and finally was spun at a chosen speed ( $1000 - 6000 \text{ rpm}$ ) to obtain a film of desired thickness. It was generally observed that with increased spin speed there was reduced

uniformity of film thickness. The micrograph shown in figure 2 is that of a  $\sim 275 \mu\text{m}$  Ga:La:S thin film as fabricated through the spin coating process. It can be seen that film uniformity is excellent without the formation of bubbles or similar defects. Furthermore, it was also observed that there was no crystallisation in the core/clad interface or in the core layer as a result of the process. Initial experiments revealed that disparate thermal expansion coefficients between the clad and core glass resulted in both macro and micro cracking of films. Modification of both the clad ( $\alpha = 10.5 \times 10^{-6} \text{ K}^{-1}$ ) and core ( $\alpha = 10 \times 10^{-6} \text{ K}^{-1}$ ) compositions was critical to obtain defect free thin films. Further investigation into the fabrication of multiple layers, for example an overclad layer, reduction of film thickness and improving film uniformity is still required for optimisation of the waveguide optical properties. Utilising laser writing to form channel waveguides within the core layer would serve as an extension of the spin coating technique. The relative ease of fabricating high quality waveguides presents Ga:La:S glass as an exciting candidate for development of passive and active IO devices for near-mid infrared sources.

## REFERENCES

1. L.B. Shaw, B. Cole, P.A. Thielen, J.S. Sanghera and I.D. Aggarwal, "Mid-wave IR and long-wave IR laser potential of rare-earth doped chalcogenide fiber", *IEEE J. Quantum Electron.*, vol. 37, pp 1127-1137, 2001.
2. A.K. Mairaj, A. Fu, H.N. Rutt and D.W. Hewak, "Optical channel waveguide in chalcogenide (Ga:La:S) glass", *Electron. Lett.*, vol. 37, pp. 1160-1161, 2001.
3. T. Schweizer, D.W. Hewak, D.N. Payne, T. Jensen and G. Huber, "Rare-earth doped chalcogenide glass laser", *Electron. Lett.*, vol. 32, pp. 666-667, 1996.
4. D.W.J. Harwood, A. Fu, E.R. Taylor, R.C. Moore, Y.D. West and D.N. Payne, "A  $1317 \text{ nm}$  neodymium doped fluoride glass waveguide laser," *ECOC*, vol. 2, pp 191-192, Berlin Germany, 2000.