# Fluorescence in Erbium Doped Gallium Lanthanum Sulphide: Potential for mid-IR Waveguide Laser

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**Abstract:** Fluorescence is reported in waveguides fabricated via the ultrafast laser inscription technique in Erbium doped Gallium Lanthanum Sulphide ($Er^{3+}$:GLS) for mid-infrared laser applications. The pump wavelength was 980nm leading to mid-infrared transition at 2.75 μm.

## 1. Introduction.

Integrated optics that operate in the mid-IR region of the electromagnetic spectrum (3- 25 μm) are attracting a considerable amount of research interest due to their potential applications such as remote gas sensors[1] and stellar interferometry[2]. Materials such as chalcogenide glasses are suitable host materials for such devices due to their excellent mid-IR transparency[3] which extends beyond 8 μm.

Chalcogenide glasses are based on the chalcogen elements S, Se, and Te[4]. These glasses are formed by the addition of other elements such as Ge, As, Sb, Ga, etc. In addition to their transparency in the mid-IR they also may also offer a high nonlinear refractive index up to ~500 times that of fused silica[5], low-multi-photon absorption and high photosensitivity. Of the chalcogenide glasses, gallium lanthanum sulphide (GLS) is a particularly appealing candidate as it is thermally stable up to 550 ºC, arsenic free and non-hydroscopic.

These glasses have several advantages over other glass materials as rare-earth hosts. The solubility of rare-earth ions is extremely high due to the presence of lanthanum as a glass former, and the emission cross sections of rare-earth levels are enhanced by the high refractive index (n=2.4 at 1.55 μm). Combined with the low phonon energy, this potentially gives access to MIR transitions for lasers.

The non-toxicity, high glass transition temperature, excellent rare-earth solubility, high refractive index (n = 2.3 at 1 μm), low phonon-energy, high non-linearity and photosensitive properties of GLS also make it an interesting candidate for research into planar waveguide devices[6].

## 2. Waveguide fabrication.

GLS glass fabrication is described in detail in reference[7]. In our experiments, GLS glass with a composition of 65 mol% gallium sulphide and 35 mol% lanthanum sulphide were melted and after annealed polished into flats 10 x 10 x 1 mm in size with all six faces polished to λ/4. In this work we utilized the ultrafast laser inscription (ULI) technique[8] to fabricate waveguides embedded in an $Er^{3+}$:GLS substrate. ULI is a powerful fabrication technique which relies on the nonlinear absorption of sub-bandgap photons to induce permanent structural changes to a material. These changes can manifest themselves in multiple ways including a change in refractive index[8]. The induced modification can be localized to the high intensity region at the focus of an ultra-short pulse train. This gives ULI the unique advantage over other waveguide fabrication techniques of being capable of forming three dimensional structures[8].

The waveguides were fabricated using a mode-locked Yb-doped fiber laser which emitted 400 fs pulses with a central wavelength of 1060 nm and a pulse repetition rate of 500 kHz.

The substrate was mounted on air bearing stages and pulses from the fabrication laser were focused inside the substrate to a distance of 360 μm from the top surface using 0.4 NA aspheric lens. The multi-scan writing technique was used. Fabrication pulse energies incident onto the sample were varied from 60-40 nJ in decreasing increments of 4nJ. The translation speeds varied from 0.5 to 20 mms$^{-1}$ with the substrate translation being perpendicular to the laser beam direction.

## 3. Waveguide Characterisation

The $Er^{3+}$ ions in the waveguides were excited at the energy level $^4I_{11/2}$ using a fibre laser operating at 980nm which was collimated with a 10X aspheric lens and then focussed in the sample with another 10X aspheric lens. The fluorescence was imaged over a distance of 83 cm with a $CaF_2$ lens and captured using a FLIR SC7000 camera using a long pass filter which cut off at 2.0 µm in front of the camera in order to block the pump wavelength and the 1550 nm wavelength from the $^4I_{13/2} \rightarrow {}^4I_{15/2}$ transition . Waveguides of heights and widths up to 20×12 µm are shown to exhibit single mode guiding at 2.75 µm with very symmetric mode profiles. Figure 1 shows the facet image of one of the waveguides along with the corresponding mode profile image. In addition the absorption spectrum of 9.7mol% $Er^{3+}$ doped GLS glass and the $Er^{3+}$ energy levels indicating the infrared transitions are also presented in the same figure.

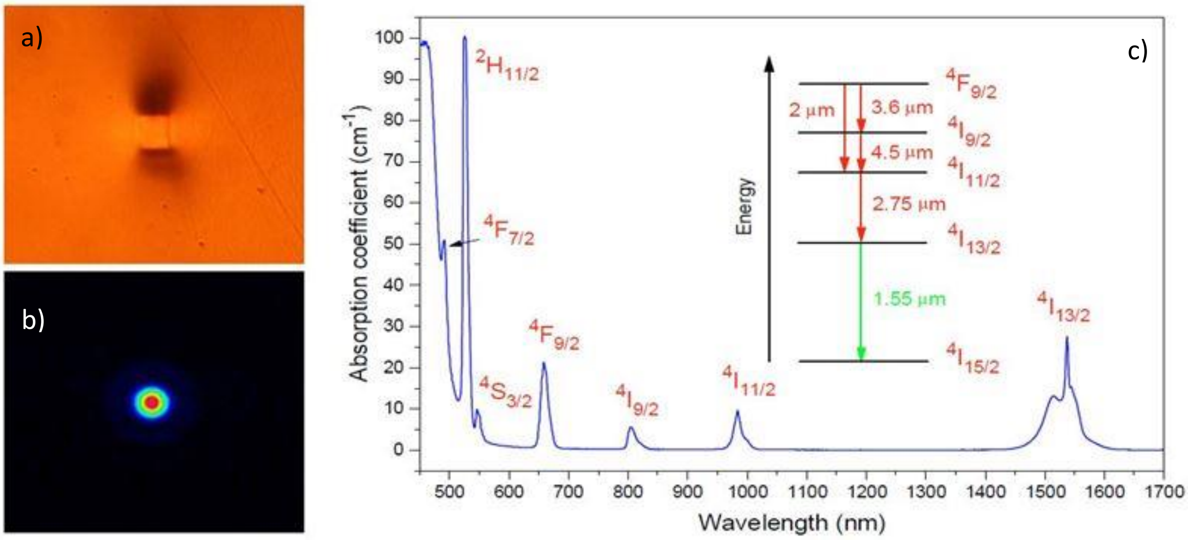


Fig 1. (a) Facet image for a waveguide taken in transmission mode, (b) Corresponding mode profile image of fluorescence at 2.75 µm, (c) Absorption spectrum of 9.7mol% $Er^{3+}$ doped GLS glass and $Er^{3+}$ energy levels indicating the infrared transitions

## 4. Conclusion

In conclusion we present the fabrication of waveguides in $Er^{3+}$ doped gallium lanthanum sulphide by utilizing the ULI technique. We demonstrated fluorescence at 2.75µm with a pump wavelength of 980 nm which enables us to explore the possibilities for an $Er^{3+}$:GLS waveguide laser

## 5. References

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