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The Application of Ga:La:S-based glass for Optical Amplification at 1.3μm

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ABSTRACT

The optical properties of praseodymium-doped low-phonon energy glasses have recently attracted considerable attention for their potential application as a 1.3μm Pr^{+3} -doped optical fibre amplifier. Sulphide glasses based on Ga_2S_3 and La_2S_3 are amongst the lowest phonon energy glass which are suitable for this application, with quantum efficiencies exceeding 50 % currently measured on bulk samples in our laboratory. The purpose of this paper is to describe the thermal, optical and spectroscopic properties of Pr^{+3} -doped sulphide based glasses and report on progress to date in achievement of a Pr^{+3} -doped sulphide based fibre.

1 - Introduction

Driven by the quest for a practical and efficient 1.3 micron amplifier, praseodymium-doped low-phonon energy glasses have recently attracted considerable attention[1,4]. Initial interest in fluoride glass optical fibres doped with praseodymium, the PDFA, was generated in 1991 with the announcement of a 1.3μm amplifier operating with a gain of over 10 dB. This host was extremely inefficient however, with a gain coefficient of less that 0.1 dB/mW, compared to the 11 dB/mW achieved with an erbium-doped amplifier operating at 1.55μm[5]. Extensive development of Pr^{+3}-doped fluoride-glass fibre amplifiers has resulted in 20 dB gain from approximately 100mW of pump power at 1.02 microns, and diode-pumped modules have been demonstrated[6].

The quantum efficiency of the Pr^{+3}-doped ZBLAN fibre amplifier is low (typically 3-4%) as a result of the high rate of non-radiative multiphonon decay from the metastable $^1G_4$ state to the underlying $^3F_4$ level, which dominates over the radiative emission of 1.3 μm to the $^3H_5$ level. However, higher gain coefficients can be obtained by decreasing the non-radiative rate

of the $^1G_4$ level and also through a large emission cross section for the $^1G_4$ to $^3H_5$ transition, conditions met by many low phonon energy glass, in particular for sulphide glasses based on Ga_2S_3 and La_2S_3. In fibre form, such glass would provide the potential for highly efficient amplification[4,5] which can be lead to a practical device. The purpose of this paper is to describe the thermal, optical and spectroscopic properties of Pr^{+3} -doped sulphide based glasses and report on progress to date in achievement of a Pr^{+3} -doped sulphide based fibre.

2 - GLS Glass

2.1 Melting Procedure

The gallium-lanthanum sulphide glasses (GLS) were originally reported by Lozac'h et al[7] and the extend of the glass formation domain has been discussed by Flahaut et al[8]. Bulk-glass samples were prepared by melting the starting materials in an vitreous carbon crucible within an evacuate silica ampoule in a electric furnace. Melting is undertaken for several hours at 1170°C and then quenched in water or liquid nitrogen. For evaluation of bulk properties, samples of thickness 5mm were routinely fabricated and with adequate choice of the carbon crucible, samples up to 10mm in diameter and 90mm in length were achieved, a size which is suitable for rod in tube preform preparation and fibre drawing.

2.2 - Thermal Properties

Differential thermal analyses (DTA) and thermal mechanical analysis (TMA) for GLS glasses doped with different levels of Pr^{+3} were undertaken to establish the thermal properties of this glass system with regard to fibre fabrication. All samples analyzed showed a relatively high glass transition temperature (T_g) of about 550°C compared to halide glasses. We note also that the crystallization onset temperature (T_x) was more sensitive to the level of Pr^{+3}, with the T_x-T_g gap, which measures the stability against devitrification during fibre fabrication, varying between 116°C to 130°C, with the coefficient of thermal expansion (CTE) of 90 $^0C^{-1}$ x 10^{-7}.

2.3 - Spectroscopic Properties

A fundamental understanding of the radiative and non-radiative properties of the GLS glasses is obtained through a series of spectroscopic measurements. Absorption spectroscopy of heavily doped samples reveals the position and the integrated absorption cross-section for each energy level of the ion in the host. Subsequent application of Judd-Ofelt theory predicts the associated radiative rates, branching ratios and emission cross-sections. Emission spectroscopy completes the analysis, providing fluorescence spectra and lifetimes.

Transmission measurements provide the indication of the suitability of the host for

application in the visible and near infrared. Figure 1 shows the transmission spectrum for doped GLS glass over the useful wavelength range.

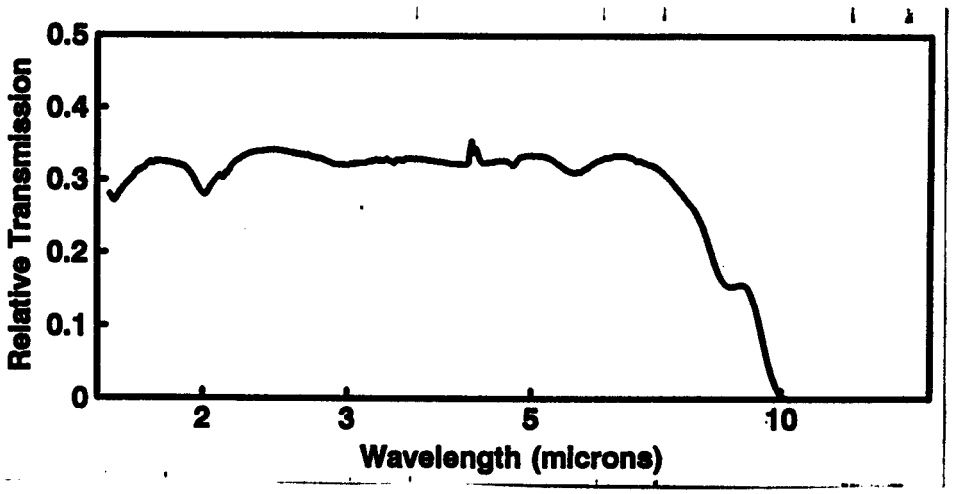

Fig.2 Transmission Spectrum of doped GLS glass by FTIR spectroscopy

Figure 2 shows the results of transmission measurements through a bulk glass sample which are extrapolated to yield the minimum or intrinsic loss. Thus GLS glass provides a transmission range from the visible to about 6 microns with a loss minimum at about 5 microns. The intrinsic loss at the pump wavelength of 1.0 microns is estimated to be about 0.01 dB/m. An absorption of less than 0.1 dB/m is considered necessary for a useful device. In practice, losses are higher than the intrinsic minimum due to absorption by impurities and by scattering. However, these extrinsic mechanisms can be minimized by purification of the starting materials, as well a precise experimental procedure in the glass

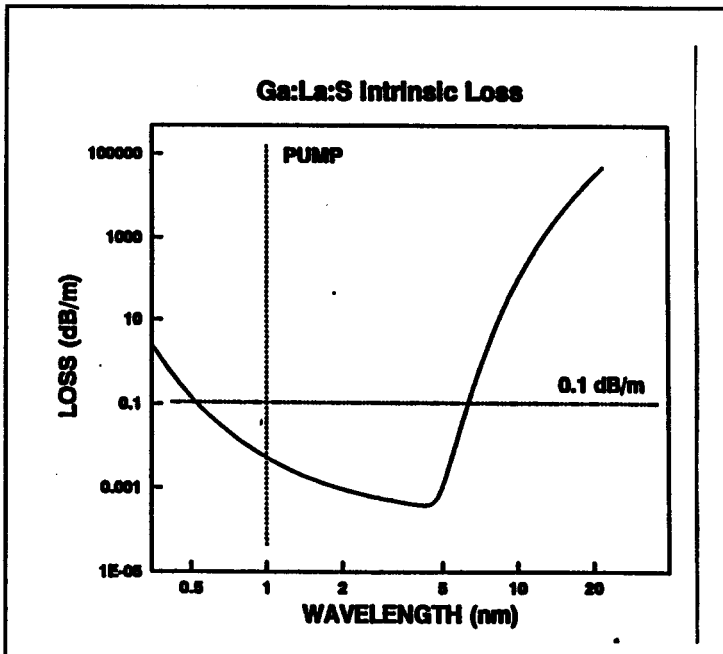

Fig.2 Intrinsic absorption and scattering loss of GLS glass extrapolated from transmission measurements.

melting to avoid bubbles and inclusions.

The fluorescence spectrum of a Pr^{+3}-doped glass sample was obtained by pumping with a Ti:Sapphire laser tuned to the peak of the $^1G_4$ ground state absorption, at about 1.0 micron, and then analyzing the emission on an optical spectrum analyzer. By chopping the signal with an acousto-optic modulator and directly detecting the decay of the fluorescence intensity, the lifetime of this level could be determined. Fig.3 provide the fluorescence spectrum. We note that for the bulk sample, the peak of the emission is at about 1.34 microns, slightly outside the telecommunication range of 1.28 to 1.32 microns. Measured lifetimes of the excited state were found to be on the order of 280μsec. Long lifetimes indicate a greater probability of radiative decay and we have shown that the maximum lifetimes are critically dependent on the elimination of all hydroxyl impurities from the glass. Figure 4 shows the influence of OH^- content on measured lifetime for GLS glass. Through a Judd-Ofelt analysis, the total radiative decay rates can be calculated. The total radiative lifetime of a GLS sample doped with 500ppm of P^{+3} obtained was 520μsec. The measured and calculated lifetimes

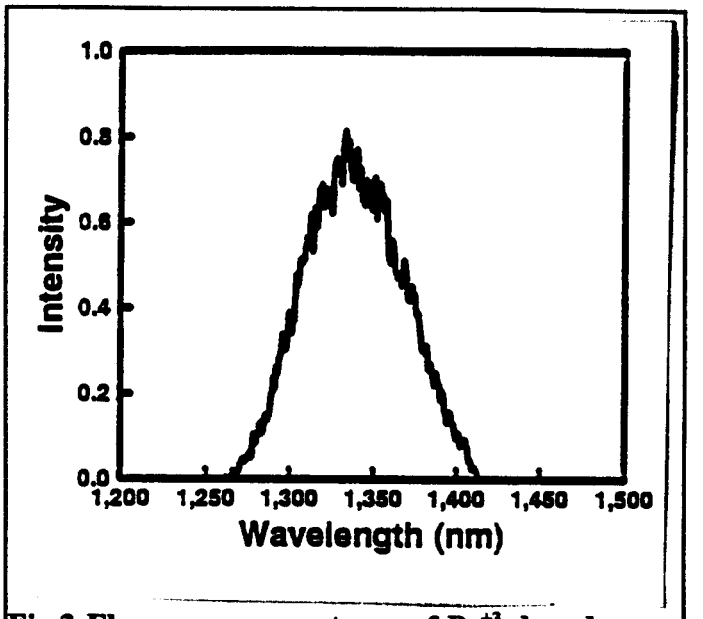

Fig.3 Fluorescence spectrum of Pr^{+3}-doped GLS glass pumped at 1.02 microns.

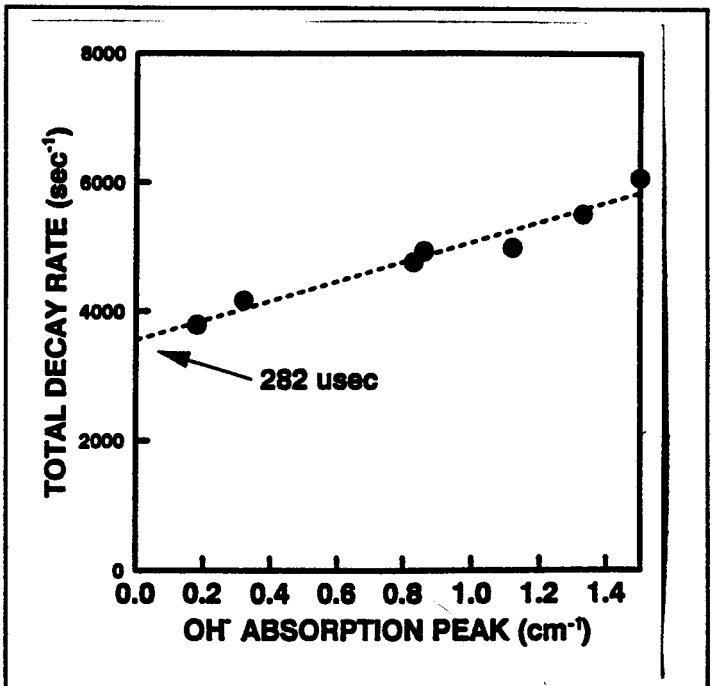

Fig.4 Influence of OH^- on measured lifetime for GLS glass

for the $^1G_4$ level allow a prediction of the quantum efficiency of an amplifier, defined by the number of photons emitted at 1.3 μm over the number of pump photons absorbed. From the ratio of the calculated total and radiative decay rates, given by the reciprocal of the corresponding lifetimes, we predict a radiative quantum efficiency for GLS glass 80%, while a value of 53% is presently measured. These values represent over an order of magnitude increase in the performance over that of current 1.3 microns devices.

2.4 - device Modelling

A numerical model has been developed which describes the principle performance features of a 1.3μm optical fibre amplifier, including the effects of ground state absorption (GSA), excited state absorption (ESA) and amplified spontaneous emission (ASE). The equations for the relevant Pr^{+3} energy levels are solved describing the propagation of the pump, signal and ASE (both forward and backward propagating) using routines developed for the erbium doped fibre amplifier. Figure 5 shows the calculated gain spectrum for a single-mode GLS fibre of length 13 m and numerical aperture 0.4. When pumped at a wavelength of 1.02 microns, this fibre will provide a small-signal gain of approximately 30 dB, ie. a factor of 1000 increase in signal strength for a pump energy of 50 to 75 mW. This performance far exceeds that of current Pr^{+3} -doped fluoride fibres.

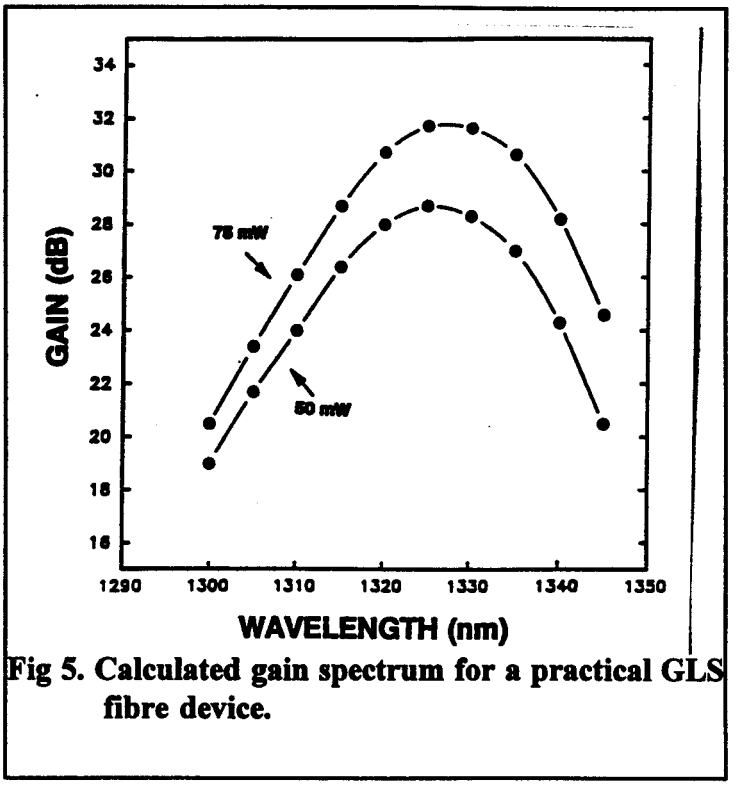

Fig 5. Calculated gain spectrum for a practical GLS fibre device.

3 - Conclusion

In conclusion as a candidate material for a practical 1.3μm optical fibre amplifier the GLS glass system remains a leading particularly with regard to quantum efficiency.

Acknowledgements

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