2101

Application of Novel Glass for the Next Generation of Optical Fibre Devices

Daniel W. Hewak, A.K. Mairaj, M.N. Petrovich and Y.W. West,
Optoelectronics Research Centre, University of Southampton, Southampton SO17 1BJ UK
phone: +44 2380 593164, fax: +44 2380 593142
email of corresponding author: dh@orc.soton.ac.uk

Abstract

Our work has focussed on gallium lanthanum glass and fibre, for both active and passive applications. As part of our ongoing programme, optical, thermal and mechanical properties of these glasses are under study. In parallel with this, fibre drawing is being refined in a quest for practical fibres. Over the past year, improvements have been made in understanding and eliminating the sources of loss in these glasses. In this paper, we describe the current specifications of fibres based on this material group.

Keywords: Chalcogenide, Fabrication, Optical Fibre, Planar Channel Waveguides

Introduction

Glass fibres based on silica have forever revolutionized the way we communicate. This glass provides low transmission loss in a stable and easily fabricated material providing perhaps the ultimate passive optical waveguide. This very inertness however makes active applications, direct manipulation of the light within the fibre, difficult. The erbium doped fibre amplifer is the exception rather than the rule. There are a whole range of laser transitions and the possiblity for amplifiers, across the telecommunications transmission windows, which cannot be achieved in a silica glass host [1]. Moreover, by virtue of its inherent stability, electro-optic, acousto-optic and magneto-optic interactions, nonlinear and photorefractive effects are weak. To fully exploit the active properties of an optical fibre, research must turn to new optical fibre materials [2].

For the past decade, we have worked with a sulphide based glass, gallium lanthanum sulphide(GLS), for optical fibre applications. This glass provides a range of important properties in particular a nonlinearity two orders of magnitude greater than silica. It is readily doped with rare earth ions, at concentrations exceeding 10 weight percent of the glass, and provides amplification at wavelengths around include 1.3, 1.4 and 1.6 microns to name only a few. However, GLS glass is difficult to form into optical fibre mainly due to the different physical properties of the core and cladding materials and problems with impurities [3]. This paper presents our efforts in novel glass work and presents the important material properties of this glass along with a description of the first fibre structures.

Glass Properties

Table 1 summarizes the optical, thermal and mechanical properties of GLS glass. The promise of this glass as an optically active material has already been demonstrated. First, with a composition based on lanthanum sulphide, it can be readily doped to high levels of any of the lanthanides ions simply by substitution. Unlike a silica glass host where rare earth ion clustering limits concentrations to a few hundred parts per million, we have prepared glasses with concentrations of hundreds of thousands of parts per million. It is possible to obtain a glass with even 40% by weight erbium sulphide [4]. The ease of doping with rare earth ions combined with it low phonon energy make this glass an ideal candidates for many for laser sources and optical fibre amplifiers. The high refractive index, 2.48 compared to 1.46 in silica boosts the radiative rates of rare earth transitions providing enhanced efficiency for many transitions. Researchers are pursuing optical amplifiers in the 1.3 micron region from this family of glasses [5]. Measurements of the third order non-linear index show that among optical glasses, GLS offers the highest reported nonlinearity reported to date demonstrated in a glass [6]. This index, two order of magnitude stronger than that in silica glass, provides the possibility of shorter, more efficient switching devices. As in all the chalcogenide glasses, GLS shows a number of interesting photoeffects. Its linear index is easily modified, either temporarily with visible light or perhaps permanently with higher intensity illumination [7]. Also, the high index, density and low phonon energy suggest that GLS offers enhanced acousto-optic properties. Measurements which have been performed in bulk glass confirm this possibility [8] and work is progressing to fibre.

Table 1: Key Properties of GLS and Silica Glasses

	Silica	**Sulphide**
Composition	SiO_2	Ga_2S_3:La_2S_3
Optical Properties		
Refractive Index at 0.589 µm	1.458	2.4833
Abbe Number	68	13.7
Non-linear index (esu x 10^{-13})	1	280
Approximate transmission range (µm)	0.16 - 2.0	0.53 - 5.0
Thermal Properties		
Glass Transition (°C)	1175	560
Melting Temperature (°C)	>2200	842
Specific Heat (cal/g-°C)	0.179	0.109^a
Mechanical		
Expansion Coefficient (°C^{-1} x 10^{-6})	0.55	10.6
Density (g/cm^3)	2.2	4.04
Poisson's Ratio	0.17	0.24
Elastic moduli (Gpa): Youngs	73.1	59
Shear	31.2	23
Bulk	36.7	24.5
Knoop Hardness (kg/mm^2)	600	206

a. approximated by value for As_2S_3 glass

Mechanical properties of the glass are typical for non-silica compound glasses. The coefficient of thermal expansion is not neglible as it is with silica, however relatively low for non-silica glasses. Density is high as expected for a heavy metal based glass. Elastic moduli are comparable to silica, and inherently strong fibre can thus be achieved. The Knoop hardness is relatively low, again characteristic of non-silica glasses. This has greatly facilitated the cutting and polishing of rods and tubes of the glass.

Fabrication of Glass and Fibre

Traditionally, the chalcogenide glasses are prepared by melting and compounding the elemental constituents of the glass, for example arsenic sulphide glasses are prepared by melting together elemental arsenic and pure sulphur to form the compound As_2S_3 [9]. However, while other chalcogenides are melted in sealed ampoules containing the required amounts of elemental precursors, gallium lanthanum sulphides are melted from prepared batches of Ga_2S_3, La_2S_3 and La_2O_3 . The binary gallium lanthanum sulphide system has a maximum stability for a gallium to lanthanum ratio 70:30 [10]. It is this composition that has been the focus of our work. Batches of powders are placed in a vitreous carbon crucible and melted in a tube furnace at 1150°C for typically 24 hrs depending on the batch size. The molten Ga_2S_3 fluxes the lanthanum precursors incorporating them into the liquid at temperatures much lower than their melting point. The resulting melts are then rapidly cooled to form the glass. After quenching the resulting glass ingots glasses are then annealed near the glass transition temperature and can then be formed into the desired rods and tubes from which an optical fibre preform is assembled.

Figure 1 shows the lowest loss fibre drawn to date, drawn from a polished GLS glass rod. Absorptive losses arise from infrared-absorbing impurities in the starting materials and glass; the main contaminants are OH^- and transition metals. The OH^- infrared absorption peak at 3 microns has a magnitude of 10 dB/m and covers a substantial part of the spectrum stretching from 2.8 to 3.4 microns, and the tail of the absorption will extend further as the background loss of the fibre is reduced. The peak height we have measured indicates there is less typically than 1 ppm of OH^-. There is some evidence that OH^- impurity can lead to scattering losses in the fibre. Little SH^- impurity, characterized by a peak at 4 microns, can be seen in our glasses compared to other chalcogenides [9].

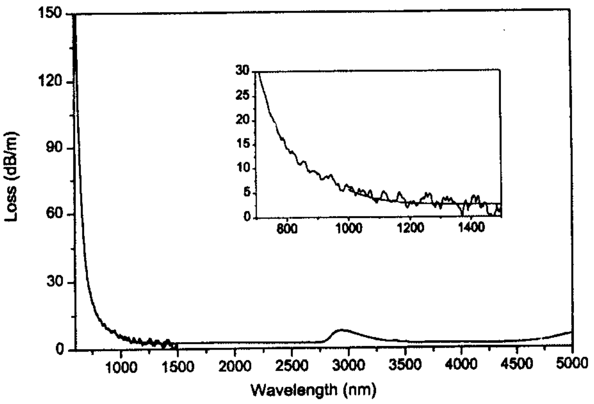

Figure 1 Loss spectrum of typical GLS fibre

Low-loss single-mode compound glass optical fibres are difficult to fabricate, because of the inherent physical and mechanical properties of compound glasses. In particular, to provide the necessary refractive index difference between the core and the clad glasses, changes in the glass composition need to be made. However, different compositions also have different physical behaviour, such as thermal expansion coefficient, glass transition temperature T_g and crystallisation temperature T_x which have to be taken account of in the fabrication process. In particular, the thermal mismatch between the core and clad glasses must be kept to a minimum and needs to be accommodated by the preform design. It is not straightforward to produce small core preforms in a single step.

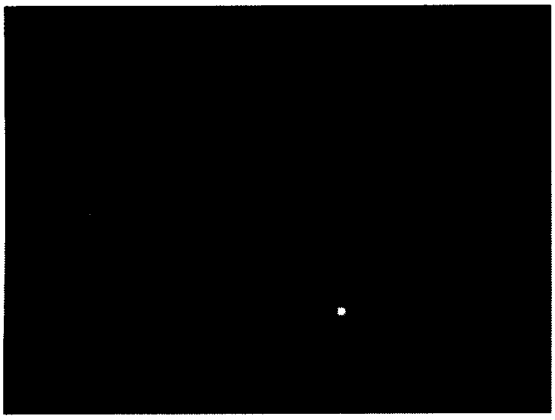

Figure 2 Cross section of a single mode GLS fibre

Figure 2 shows a cross-section of a GLS fibre. This fibre was drawn from the preform in a single step, and this preform was constructed in a manner similar to fluoride fibre preforms [11].

Discussion and Conclusions

The advantages, and potential of working with Ga:La:S, currently outweigh the difficulties in fibre drawing. The causes of loss are now well known, and steps can now be taken to remove them. This will involve a purification scheme which will have a twofold effect: firstly it will remove the absorption losses from transition metals, and secondly it will go some way to eliminating scattering from impurities. Ga:La:S glass is therefore the material of choice for several emerging applications.

Acknowledgements

This work was supported in part by a DTI./EPSRC grant through the Link Photonics Program. Thanks to Mr. John Tucknott, Mr. Neil Fagan, Mr. Ben Hudson, Mr. Edwin Weatherby and Mr. Roger Moore for their technical contributions to this work. Also to Thorsten Schweizer and Dominic Brady for their valuable discussions.

References

1. D. W. Hewak, R. C. Moore, T. Schweizer, J. Wang, B. Samson, W. S. Brocklesby, D. N. Payne and E. J. Tarbox, “Gallium lanthanum sulphide optical fibre for active and passive applications”, *Electron. Lett.* **32** 384-385, 1996.
2. D.W. Hewak, editor, Properties, Processing and Application of Glass and Rare Earth-Doped Glasses for Optical Fibres', Parts B, C and D, Published by IEE, Stevenage, UK.
3. Y.D. West, T. Schweizer, D.J. Brady and D.W. Hewak, Fibre and Integrated Optics, 19, 229 (2000).
4. M. Guittard, A.M. Loireaulozach, F. Berguer, S. Barnier, J. Flahaut, “Glasses of the La_2S_3-La_2O_3-Ga_2S_3-Ga_2O_3 System”, *J. Solid State Chemistry* **62** 191-198, 1986.
5. H. Tawarayama, E. Ishikawa, K. Itoh, H. Yanagita, K. Okada, K. Yamanaka, Y. Matsuoka, H. Toratani, “Pr^{3+}-doped Ga-Na-S glasses for optical fibre amplifiers at 1.3 microns”, *Proc. OAA '97*, postdeadline paper PD1, Victoria, BC Canada, 1997
6. I. Kang, T.D. Krauss, F.W. Wise, B.G. Aitken, N.F. Borrelli, “Femtosecond measurement of enhanced optical nonlinearities of sulfide glasses and heavy-metal-doped oxide glasses”, *J. Opt. Soc. Am. B*, **12** 2053-2059, 1995.
7. K. Tanaka, “Photoinduced processes in chalcogenide glasses”, *Current Opinion in Solid State and Materials Science: Amorphous Materials*, **1** 567-571, 1996.
8. I.Abdulhalim, R.S.Deol, C.N.Pannell, G.Wylangowski and D.N.Payne, “High performance acousto-optic chalcogenide glass based on Ga2S3-La2S3 systems”, *J. Non-Cryst. Solids* **166** 1251-1254, 1994.
9. J. S. Sanghera and I.D. Aggarwal, editors “*Infrared Fiber Optics*”, CRC Press, 1998
10. D. J. Brady, T. Schweizer, J. Wang and D.W. Hewak, ‘Minimum loss predictions and measurements in gallium lanthanum sulphide based glasses and fibre”, *J. Non. Crystal. Solids*, **242** 92-98, 1998.
11. P.W. France, editor, *“Fluoride Glass Optical Fibres”*, Blackie, London, 1989.