Invited Contribution

New Glasses for Optical Fibres and Their Applications

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1. Introduction

Over the past three decades, optical fibres based on high-purity silica have established themselves as perhaps the ultimate communications material. These global cobwebs of glass have revolutionized telecommunications, reaching virtually every populated region on earth and providing enormous bandwidth, the full extend of which has yet to be exploited. Passive waveguides are today being spliced together with lengths of fibre doped with the rare-earth ion erbium, providing optical fibre amplifiers which can boost a fading signal by three orders of magnitude. This combination of active and passive waveguides has made possible all-optical networks, with no electrical/optical interfaces except at the signal source and receiver and paved the way for global optical fibre telecommunications.

Although silica has proved to be ideal for low-loss fibres, it is rarely optimal for functional devices in either fibre or planar waveguide configuration. Silica has particularly low acousto-optic merit, small optical nonlinearity and tiny electro- and magneto- optical coefficients. As a rare-earth host for amplifiers and lasers, it has exceptionally high phonon energy, which leads to non-radiative decay of the excited states, giving rise to poor pump efficiency and in many cases rendering a particular transition unusable. The latter is illustrated by the praseodymium-doped 1.3µm fibre amplifier where a low phonon-energy host, (such as ZBLAN) must be used.

A virtually infinite range of compound glasses is available from which to tailor the properties to suit a particular application. This paper gives examples of research into germanate, telluride, sulphide, mixed-halide and chalcohalide glasses which have been developed as substitutes for silica fibres in specific applications. In particular, it concentrates on research for glasses to use in a practical 1.3µm optical fibre amplifier, as a host for erbium in a planar lossiess splitter, as highly nonlinear materials and in acoustically-efficient devices.

2. Low Phonon-Energy Glasses

It transpires that most of the requirements for optimised fibre and planar devices 1 can be met by glasses having a phonon-energy below about 300cm^{-1} (cf. silica with ~1000cm^{-1} and ZBLAN 600cm^{-1}). When doped with rare-earths, such glasses exhibit efficient radiative transitions at wavelengths as long as 4µm (corresponding to closely-spaced energy levels) without serious competition from phonon-mediated de-excitation. Since the transmission of the glass in the infra-red is also usually limited by the multi-phonon absorption edge, low phonon-energy glasses also have excellent infra-red transmission and can thus form the basis of lasers in the commercially-important 3-5µm wavelength region where the applications are for monitoring of gaseous pollutants.

Low phonon-energy glasses are also invariably composed of compounds having a high reduced-mass, e.g. heavy metals, chlorides and sulphides. As a consequence, they have refractive indices in excess of 2.2, which leads to an optical non-linearity up to two orders of magnitude greater than silica. In addition, the acousto-optic merit can be 1000x that of silica, making them attractive for acousto-optic waveguide switches.

It has been shown that praseodymium-doped ZBLAN glass fibre has potential for a 1.3µm fibre amplifier. However, even in this glass which has a relatively low phonon energy compared to that of silica, 96% of the pump power is lost as heat in the glass to the competing process of multi-phonon decay. The correspondingly-high pump power has hampered the emergence of a suitable commercial device. A world-wide effort is therefore aimed at developing a lower phonon-energy glass to increase the pump efficiency to perhaps 1dB/µW (cf. EDFA as high as 11dB/mW). The search for a suitable host has targeted glasses such as the halides and sulphides, all of which offer good transmission in the infra-red, reasonable transparency at the pump wavelength (around 1µm) and good chemical durability. Extensive work based on fluoride glasses modified with indium and gallium show only a 2 slight improvement over the fluorozirconate glasses, while substitution of the heavier chlorine for fluorine (as in the mixed cadmium halide glasses) show efficiencies up to 10%. Unfortunately, these materials are unstable and are rapidly attacked by moisture.

Work has concentrated on the gallium lanthanum sulphide glasses in which quantum efficiencies as high as 60% are indicated. Progress is such that glass batches approaching a kg can now be melted and multi-mode fibres of several hundred metres drawn. Fibre drawing is particularly challenging as these glasses have a very high viscosity at temperatures below the onset of crystallisation.

3. Low Index Glasses

A second candidate for an efficient 1.3µm is Nd-doped low-index glass. Up to now the 1.3µm transition in neodymium has been discarded as having a gain peak at too long a wavelength (1400nm in silica, 1340nm in ZBLAN). Generally, more ionic glasses tend to shift the emission spectrum of neodymium towards shorter wavelengths and these glasses are characterised by having a low index. The glass with lowest known index is a fluoro-beryllate composition, which has the disadvantage of being highly toxic, environmentally unstable and difficult to draw. Recently, however we have found that glasses in the alumino-fluorophosphate system which have gain peaks in the region of 1317nm, which coincides almost exactly with the wavelength of zero dispersion in most installed fibres. These glasses are chemically durable, stable against crystallisation and straightforward to draw.

Nd-doped glasses have a number of advantages for 1.3µm amplifiers. High concentrations (several percent) can be incorporated without fear of upconversion effects, leading to amplifiers of only a centimetre or so long. As well as obviating the need for a low-loss fibre, planar amplifier devices are readily achievable. We hare drawn fibres with losses less than l dB/m and demonstrated gain of several dB in single-mode fibres. The challenge now is to reduce the competing amplified spontaneous-emission from the more-favoured 1.06µm transition by continuous filtering along the length of the amplifier. Computations based on numerous spectroscopic measurements indicate that a pump efficiency of l dB/mW is within reach.

4. Other Glasses

As well as the above examples of the importance of new glasses for guided-wave devices, work on other interesting glass compositions will be reviewed. These include so-called "spaghetti glasses', heavy-metal oxide glasses and chalcohalides. While none of these glasses are expected to compete with silica as a low-loss transmission medium, they have unique properties at longer wavelengths and are expected to find applications in devices where relatively-short lengths are used.

5. Conclusions

Glasses with high-refractive index, high acousto-optic merit, low phonon energy and good solubility of the rare-earth are essential for optical waveguides devices of the future. At the ORC, research on advanced materials for multi-function waveguides is driven by device requirements. A more efficient optical fibre amplifier for 1.3µm requires new glasses of lower vibrational energies to minimise nonradiative decay. Planar lossless splitters rely on a new waveguide material which allows high incorporation of erbium. Modulators need bulk or fibre optics which interact with acousto-optic power. Other new glasses with very high photosensitivity are being developed for fibre Bragg gratings, and highly non-linear glasses for all-optical switches. It is clear that for functions as diverse as amplification, splitting, modulation, switching or filtering the key to these devices is new glass materials.