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FABRICATION OF OPTICAL FIBRES CONTAINING LOW LEVELS OF RARE-EARTH IONS

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Abstract

Fibres containing rare-earths have been produced with high absorption levels in the visible and near infra-red regions. This has been achieved without significantly compromising the low-loss characteristics at wavelengths between 900 and 1400 nm.

Introduction

One of the requirements of an optical fibre amplifier or laser is that it should have a high absorption at the pump wavelength and a low loss at the laser wavelength. Conventionally, this is achieved by the use of a high dopant concentration in a short length of neodymium-doped silica rod(1). The same result could, however, be obtained using lower Nd^{3+} levels and exploiting the long interaction lengths and low losses inherent in optical fibres. Thus we hope to dope the fibre core with low concentrations of rare earth ions, e.g. neodymium,to obtain substantial pump absorbtion bands, without significantly affecting the low-loss characteristics of the fibre at other wavelengths. Such a fibre would also be of interest as a distributed temperature sensor utilising changes in either the absorption(2) or fluorescence lifetime(3).

We report here a novel extension of the MCVD fabrication process which has permitted the fabrication of both mono- and multi-mode optical fibres containing rare earth ions at concentrations of up to 0.25% wt in the core region. The technique is unique in that it allows the use of starting materials, e.g. rare earth halides, which have hitherto been unusable since they have a high melting point (>580°C). Consequently, they exhibit a very low vapour pressure at the temperatures commonly encountered in reactant delivery systems for optical fibre fabrication.

Initial work has concentrated on the dopants neodymium and erbium, as these are of interest for both lasers and sensors. We have produced fibres with very high-loss absorption bands (>3000 dB/km) in the visible/near infra-red region, while maintaining low losses (<2 dB/km) in the "second-window" for optical communications around 1300 nm. The technique may also be used to incorporate many other rare earth and transition metals into optical fibres.

Fibre Fabrication

The preform is fabricated using an extension of the MCVD technique, with a number of important modifications to permit the incorporation of the additional dopants into the core glass. Prior to the normal deposition, the required dopant, in this case neodymium in the form of $NdCl_3.6H_2O$ (99.9% pure, melting point=758°C), is inserted into a dopant carrier chamber (Fig.1.) where it is heated under a chlorine atmosphere. This step dehydrates the $NdCl_3$ and fuses the anhydrous crystals to the chamber wall, thus preventing them from passing down the tube and forming bubbles in the glass subsequently deposited. The inside of the deposition tube is then cleaned by gas-phase etching using SF_6 to remove any dopant deposited during the drying process, following which the cladding glass is deposited in the usual manner. During the core deposition the dopant carrier chamber is heated to around 1000°C by a stationary second burner to produce small quantities of $NdCl_3$ vapour. The vapour produced is carried downstream by the reactant flow, where it is oxidised to Nd_2O_3 in the hot zone formed by the deposition burner and incorporated into the core.

Initial measurements showed that the first drying stage did not dehydrate the $NdCl_3$ sufficiently to produce low-loss fibres. Consequently, a second drying process was introduced in which, the core, consisting of SiO_2, GeO_2 and a small amount of Nd_2O_3, is deposited unfused at a low temperature. The porous core layer on the inside of the deposition tube is then dried by passing chlorine over it and heating, after which it is fused to form a clear non-porous layer. The tube is then conventionally collapsed to form a solid rod.

The process is simple to implement on existing MCVD fabrication equipment and gives reproducible fibres in terms of both refractive index profile and dopant concentration. In addition, it may be adapted to incorporate almost any dopant into the core of single- or multi-mode fibres.

Results and Discussion

As expected, absorption measurements on mono- and multi-mode fibres show that the neodymium is incorporated into the glass matrix as the trivalent Nd^{3+} ion. Fibres with absorption levels (at 590nm) ranging from 40 dB/km to 30,000 dB/km (corresponding to dopant levels of 0.3 to 300 ppm of Nd^{3+}) have been fabricated. Fig.2 shows the plot of absorption versus wavelength for a 500m length of neodymium doped fibre having a dopant level of ~ 30 ppm. The very high absorbtion levels in the visible and near infra-red regions of up to 3000 dB/km can be clearly seen. Despite this high loss, it is remarkable to observe the existence of a low-loss window between 950 and 1350 nm of <2 dB/km, a figure not very different from that observed in conventional fibres. Moreover, we believe this excess loss is due to increased scattering in the fibre, rather than to the absorption band tails.

The low OH^- peak at 1390 nm indicates the success of the techniques used to dry the neodymium compounds both before and during the deposition. Furthermore, the consistency of the dopant incorporation along the fibre length has been resolved using an OTDR technique at a wavelength near the 590 nm absorption band. The results show excellent uniformity and indicate the high degree of control in the process.

It is believed that almost any dopant can be incorporated by the above technique. As an indication of this, the absorption spectrum of a fibre heavily-doped with Er^{3+} is shown in Fig.3. The fibre contains ~0.25 % wt Er^{3+} and again shows regions of remarkably low loss, despite heavy absorptions elsewhere.

As part of a continuing programme of investigation into the properties of low concentrations of rare earth ions in ultra-pure glasses, the 1/e fluorescence lifetime of the Nd^{3+} ion has been measured using a pump wavelength of 590 nm. At the peak fluorescence wavelength of 1.07 μm a lifetime of 450 μS was found, which is in good agreement with previously published data(4).

Conclusion

We have developed a simple, reproducible technique for the incorporation of low concentrations of rare earth ions into the core of multi- and mono-mode optical fibres. The fibres have high absorption levels in the visible and near infra-red regions without significantly compromising the low loss characteristics at wavelengths between 900 and 1400 nm. These properties are ideal for use in optical communication systems and distributed sensors.

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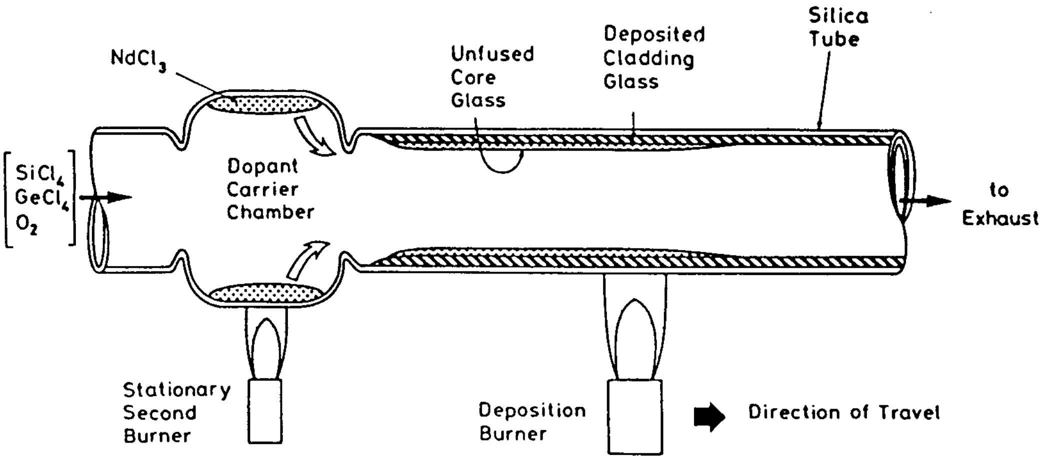

Fig.1. MCVD process for low vapour-pressure dopants.

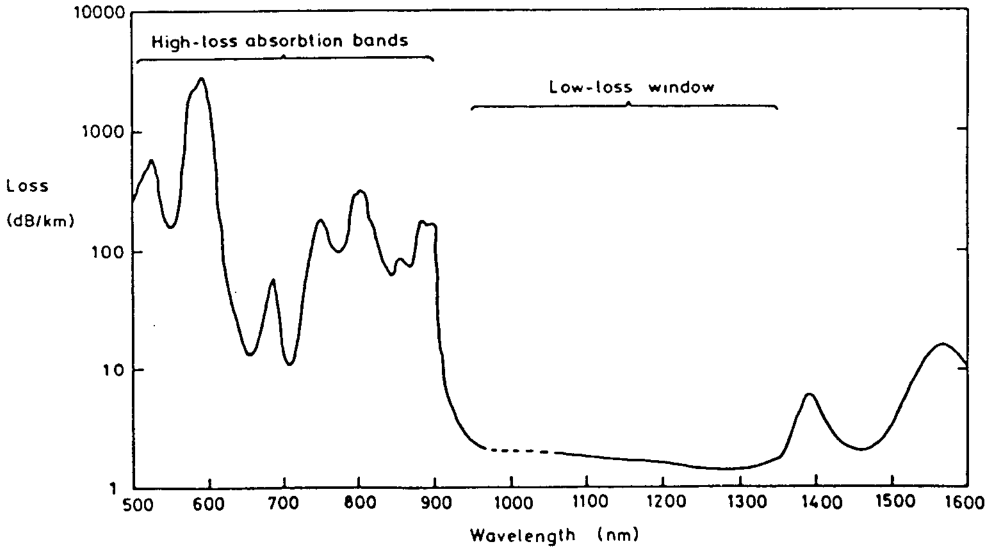

Fig.2. Spectral attenuation of fibre containing 30 ppm Nd^{3+}

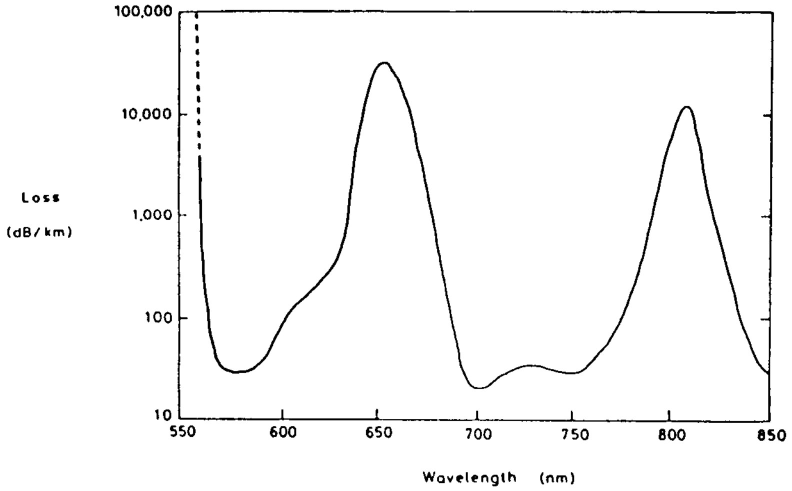

Fig.3. Spectral attenuation of fibre containing 0.25 wt % Er^{3+}