PREPARATION OF WATER-FREE SILICA-BASED OPTICAL-FIBRE WAVEGUIDE

Indexing terms: Fibre optics, Light absorption, Losses, Optical waveguides

A technique is described whereby the hydroxyl absorption bands of the new phosphosilicate-core optical-fibre waveguide, which arise from impurities in the cladding, can be largely eliminated. The resulting fibre has ultralow loss over the entire wavelength range 0·4–1·1 μm.

Introduction: A problem commonly encountered in the preparation silica-based optical fibres is the presence of OH absorption bands at a number of wavelengths,[1–5] particularly at 0·95 μm. We have observed the same effect in a new type of fibre[6, 7] comprising a phosphosilicate glass core in a silica cladding. These fibres are made by an accurately controlled chemical-vapour-deposition technique in which silicon tetrachloride and phosphorus oxychloride are simultaneously oxidised and fused into a clear layer of phosphosilicate glass on the inside of a silica tube that is subsequently drawn into a fibre.

It is found that, when the silica tubing used is of a synthetic grade of high hydroxyl content (1200 parts in 10^6), such as Suprasil, the minimum attenuation is between 2 and 3 dB/km, and the OH band at 0·95 μm rises to a peak of about 40 dB/km. On the other hand, with Heralux tubing, in which the water concentration is only one-tenth that in Suprasil, but the level of other impurities is higher, the minimum loss rises to 6 dB/km, but the peak at 0·95 μm falls to 15 dB/km. This is a strong indication that the cladding has an appreciable effect on the transmission loss, which is to be expected, since, at the normalised frequency of the fibre of $V = 20$, it carries approximately 10% of the propagating power. We conclude, therefore, that the OH impurity giving rise to the absorption bands is present mainly in the cladding and not in the vapour-deposited core. It follows that, if the relative amount of optical power propagating in the impure cladding can be decreased, the hydroxyl bands can be correspondingly reduced.

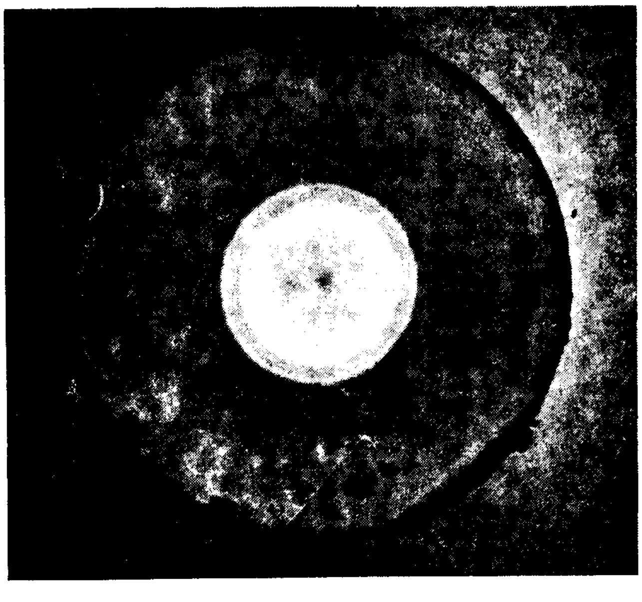


Fig. 1 *Cross-section of stepped-refractive-index fibre*
Showing the Suprasil cladding and three successive core layers of increasing refractive index. The overall diameter is 145 μm

Method: One method of doing this during the preparation of the phosphosilicate-core fibre would be to deposit initially a silica layer of low hydroxyl content on the inside of the commercial silica supporting tube. This can be done, but, to produce simultaneous oxidation and fusion to a clear glassy layer, the deposition rate must be kept low. Thus the time taken to build up the required thickness of this layer is unnecessarily long. However, if, instead, a layer of phosphosilicate glass having a suitably small proportion of P_2O_5 is deposited, the deposition rate can be increased appreciably, and the refractive index is not changed greatly from that of silica.

An alternative approach is to use the fact that a graded-refractive-index core effectively restricts the optical power to a region closer to the fibre axis than in a normal cladded fibre. Reflections at the core–cladding interface do not occur, except for those rays propagating near the critical angle, and hence the amount of power contained in the cladding is reduced. With our method of vapour deposition, the fabrication technique for a graded-refractive-index fibre is a simple one and involves only successive changes in the relative concentration of the reacting gases. The first layer may now, as before, contain a suitably small proportion of P_2O_5 and may be deposited at a much higher rate than the silica. The second, and subsequent, layers contain increasing concentrations. The total deposition time for the entire core is about 1 h. However, we have found that a stepped approximation to a graded-refractive-index core, in which the refractive index increases in three successive steps, is equally effective in confining the optical power to the core region. We have fabricated fibres of all three types, but present here the results obtained only for the latter version.

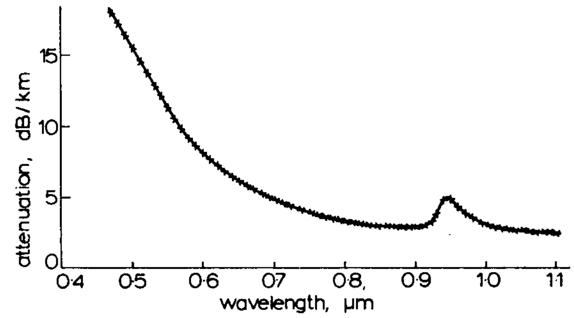
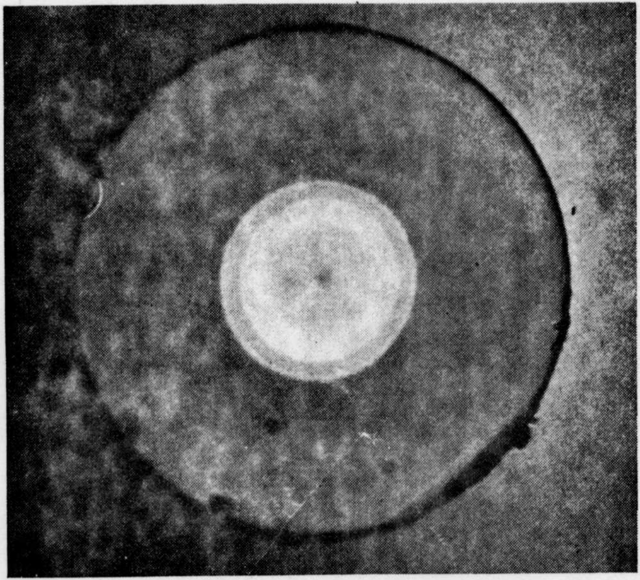


Fig. 2 *Spectral attenuation curve of 1·2 km length of phosphosilicate-core silica-cladded fibre shown in Fig. 1*

Results and discussion: A typical fibre cross-section (Fig. 1) clearly shows the Suprasil cladding and the three layers of increasing refractive index. The overall diameter is 145 μm and the numerical aperture of this particular fibre is 0·16. The spectral attenuation has been measured over the entire drawn length of 1·2 km and the resulting curve (Fig. 2) is remarkably smooth. As predicted,[7] the broad iron absorption band in the vicinity of 1 μm has been largely removed by some fairly straightforward improvements in fabrication techniques. Further, the intermediate layers have almost eliminated all the OH bands. The only one remaining is that at 0·95 μm, but its height has been reduced to 2 dB/km. In fact, in some other samples, the magnitude is only 0·8 dB/km and the effect of the wings of the band at the semiconductor-laser wavelength is negligible. As a result of these modifications, the attenuation is very low over the entire wavelength range and is below 5 dB/km between 0·7 μm and the highest wavelength measured (1·1 μm) with a minimum of 2·4 dB/km. Even at 0·45 μm, the loss is less than 20 dB/km and transmission in the near ultraviolet, in particular, is considerably better than has previously been reported[8] for conventional u.v.-transmitting fibres. It should be noted that extrapolated absorption and scatter measurements suggest that, at least from 0·4 to 1·1 μm, the intrinsic loss of phosphosilicate glass is similar to that of pure silica. This indicates that, with further improvements, it should be possible to obtain an attenuation of less than 2 dB/km in the régime (from 0·85 to 0·9 μm) of gallium-arsenide devices, and still lower values at longer wavelengths. Measurements on some preliminary 1 km lengths of graded-refractive-index fibres show that they have a slightly higher overall attenuation, but similarly small hydroxyl peaks. Again, it is expected that further improvements are possible.

Conclusion: The phosphosilicate glass produced by vapour deposition has ultralow loss over the entire wavelength range so far investigated (0·4 to 1·1 μm). When used as the core material in an optical fibre, the effect of impurities in a silica cladding of commercial quality can be greatly reduced by adopting the technique of (*a*) a buffer layer surrounding the core, (*b*) a graded-refractive-index distribution or (*c*) a stepped approximation to a graded refractive index. The resulting fibre has an attenuation comparable with that of the core.



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