NEW SILICA-BASED LOW-LOSS OPTICAL FIBRE

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A new type of silica-based optical fibre has been made from relatively cheap and abundant materials. The attenuation is very low over the entire range from the near ultraviolet to the gallium-arsenide-laser wavelength. The minimum loss of 2·7 dB/km occurs at 0·83 μm.

Introduction: In many ways, a suitable configuration for an optical-fibre waveguide is a compound glass core surrounded by a compound glass cladding of lower refractive index. Many fibres of this type have been reported, but the best transmissions obtained so far are in the region of 30 to 40 dB/km. The loss is largely due to transition-metal ion impurities, which are difficult to remove completely. A variant of the cladded glass fibre is Selfoc[1] fibre, in which the core has a parabolic variation of refractive index and a minimum loss of less than 20 dB/km has been obtained.

Silica, on the other hand, is produced commercially in a very pure form having a bulk-transmission loss of the order 2 dB/km at a wavelength of 1·06 μm. However, for it to be incorporated as one component of a cladded fibre, a second, compatible material must be found, having a similar softening temperature, expansion coefficient etc., to use as core or cladding, depending on the refractive index. One possibility is to modify the optical properties of silica by the addition of another oxide to form a simple compound glass containing a high proportion of silica. Thus, in 1972, a vapour-deposition technique[2] was used to deposit a titania–silica core glass on the inside of a silica tube, which was subsequently drawn into a fibre. Fibres[3] have also been drawn from rods of silica cladded with a boric-oxide–silica-glass layer, and we have successfully repeated this technique. More recently,[4] low losses have been announced with a modified silica core material, apparently comprising a mixture of silica and germania. Subsequently, there have been further reports of the successful use of the silica–germania mixture[5, 6] and also of the borosilicate-cladded silica fibre.[6]

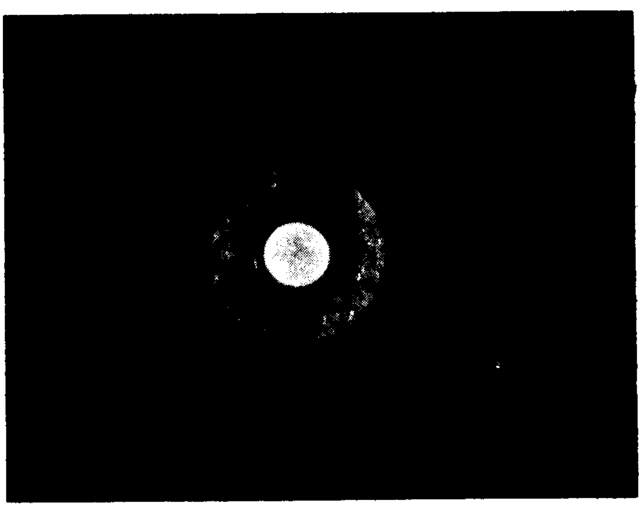


Fig. 1 *Cross-section of phosphosilicate-core fibre illuminated from far end*

Although commonly used in the semiconductor industry, and readily available in pure form, germania is expensive and likely to become more so, since germanium is not an abundant element. An alternative, cheaper and more common material would therefore be preferable, providing that it can be combined with silica to form a suitable low-loss glass. We have tried a number of combinations and find that a phosphosilicate glass core in a pure silica cladding provides a very low-loss fibre. Phosphorus is one of the most common elements and is relatively cheap, and the resulting fibre has a number of interesting properties. The most important wavelength range for optical-fibre communication systems is that of the various semiconductor light sources based on gallium arsenide, namely 0·8 to 0·9 μm, and, although not yet fully developed, the fibre has its minimum loss of 2·7 dB/km in this region. Further, the addition of phosphorus pentoxide to silica to form a binary glass does not appear to increase significantly either the intrinsic material absorption or the scattering.

Manufacture: The phosphosilicate glass is made by a controlled chemical-vapour-deposition technique. The starting materials are purified silicon tetrachloride and phosphorus oxychloride, which are vapourised, mixed with oxygen and passed through a tube of silica cladding glass. This tube containing the flowing gas mixture is traversed through a fibre-pulling furnace, which is operated at an appropriate temperature. Simultaneous oxidation and fusion occurs so that a clear phosphosilicate glass is deposited on the inner surface. A suitable thickness is obtained in about 1 h. The composite tube is then simultaneously collapsed and drawn into a fibre, or the operation can be carried out in two separate stages. We use a graphite resistance-heated furnace, which has been developed in these laboratories. The operating temperature, which can be in excess of 2200 °C, is monitored by a thermocouple to allow accurate control and repeatibility.

Fig. 1 shows a typical fibre cross-section, illuminated from the far end. There is a dark spot in the centre, presumably due to some volatilisation of phosphorus pentoxide from the

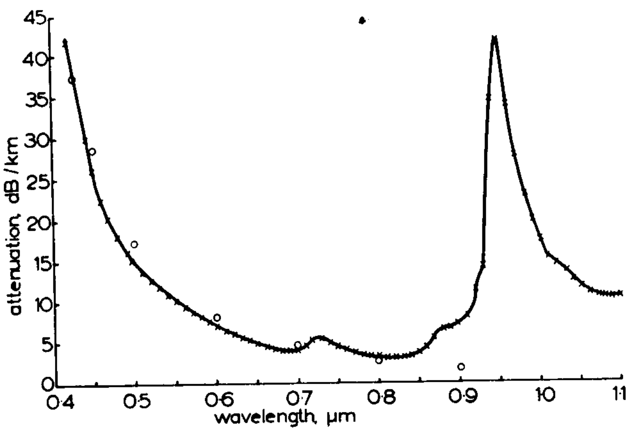


Fig. 2A *Spectral-loss curve for 244 m length of fibre comprising a phosphosilicate core in Suprasil cladding*

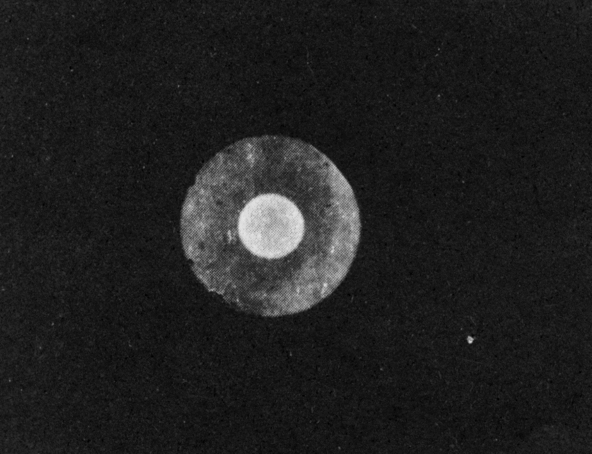
The numerical aperture is 0·14. The predicted ultimate loss in pure silica (Reference 7) is shown by the points marked ○

inner surface of the deposited layer at the temperature (>2000 °C) required for fibre drawings. The fibres typically have a core diameter of 50 μm, an overall diameter of 150 μm and are drawn in lengths of about 1·2 km. The numerical aperture can be varied up to 0·18 or more as desired by control of the relative concentration of phosphorus pentoxide in the core.

Fibre attenuation: The loss in pure bulk silica is mainly by Rayleigh scattering, but with a small absorption component from the intrinsic ultraviolet absorption edge. There may also be impurity bands such as those due to hydroxyl ions. The addition of a second oxide in making a high-silica-content glass for use as core material is expected to introduce an additional component of scattering due to compositional fluctuation. The intrinsic absorption may also be increased, depending on the proximity of the ultraviolet-absorption edge of the additive.

Fig. 2A shows the spectral absorption curve of the SiO_2/P_2O_5 core in Suprasil cladding. The main features are as follows:

(*a*) Most striking, perhaps, is the smoothness of the curve over the short-wavelength portion, where, as indicated by Fig. 2A, the loss is below that of pure silica,[7] showing that the addition of phosphorus pentoxide to silica does not increase either the scattering or the absorption. In addition, there is no evidence of the drawing-induced colour centres at 0·6 μm, which have been observed elsewhere.[8] The minimum attenuation measured at 0·83 μm is 2·7 dB/km. The total loss at 0·633 μm is 5·8 dB/km, compared with the Pinnow *et al.* prediction[7] of 7 dB/km, of which 4·8 dB/km is due to scattering. This implies that our intrinsic absorption is only



1 dB/km and is therefore less than the expected value of $\simeq$ 2 dB/km. Also, at 0·45 μm, again assuming the scatter loss to be that of silica, i.e. 19 dB/km, our intrinsic absorption is 7 dB/km, compared with a predicted value for silica of 10 dB/km. Further, the total scattering in the fibre at 0·633 μm has also been measured directly by an integrating sphere, and the loss of 5·8 dB/km obtained is greater than that of silica, thus implying an even smaller intrinsic absorption. It would appear that the intrinsic absorption is less than that predicted.[7] If this is correct, the ultimate loss at 0·85 μm could be less than 2 dB/km. To determine the true limit of intrinsic absorption, the loss measurements must be extended to wavelengths below 0·4 μm.

(*b*) The effect of the OH impurity can be clearly seen, particularly the peak at 0·95 μm rising to 40 dB/km. We believe that the OH bands are not characteristic of the phosphosilicate core material, but are due entirely to the high hydroxyl content of the Suprasil cladding, which has a bulk loss of 1000 dB/km at this wavelength. The normalised frequency of the fibre represented in Fig. 2A is $V = 20$, and hence of the order of 10% of the power is carried by the cladding, so that the loss contribution of the latter at 0·95 μm will be significant. This has been confirmed by making further fibres with

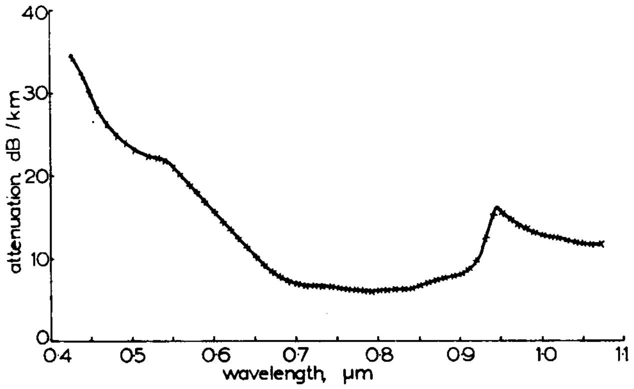


Fig. 2B *Spectral-loss curve for 133 m length of fibre comprising phosphosilicate core in lossy cladding*
Heralux

Heralux instead of Suprasil, with the result shown in Fig. 2B. Heralux is a natural fused-quartz product in which the water content is only about 10% of that in Suprasil, and, as expected, the main OH peak has been reduced from 35 to 6 dB/km. Thus it should be possible to eliminate the OH bands* with a further improvement in the manufacturing technique. The minimum loss with Heralux is higher than with Suprasil cladding, because of the higher overall impurity level, but, nevertheless, Heralux is much cheaper, and the loss, even so, is not high.

(*c*) Partially obscured by the hydroxyl absorption peaks at 0·88 and 0·95 μm in Fig. 2 is the third main feature of the spectral-loss curve, namely the broad ferrous-iron absorption band centred at about 1 μm, giving rise to an attenuation of 10 dB/km at 1·06 μm. Iron can produce appreciable absorption even when present in very small concentrations, and we believe the effect to be accentuated in phosphosilicate glasses, which tend to reduce this particular impurity mainly to the ferrous, rather than the ferric, state. Supporting evidence is produced by the very low loss at the blue end of the spectrum, indicating the absence of ferric ions. Nevertheless, although the effect of iron can be serious it should be possible to eliminate it from the core and to obtain a lower loss* at 1·06 μm with the Suprasil cladding by further material purification.

Conclusion: A new type of silica-based fibre has been made from relatively cheap and abundant materials and having an attenuation which is

(*a*) exceptionally low over the full range from the gallium-arsenide-laser wavelength to the near ultraviolet

(*b*) somewhat lower than has been predicted for pure silica.

The minimum attenuation is 2·7 dB/km and occurs at 0·83 μm. By controlling the phosphorus-pentoxide concentration in the core, the numerical aperture can be varied up to 0·18 or more as desired. The intrinsic loss of phosphosilicate glass appears to be no greater than that of pure silica.

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* After this letter was accepted for publication, the attenuation, as measured in a length of 1·2 km, has been reduced appreciably at all wavelengths above 0·85 μm, and is now 2·4 dB/km at 1·1 μm. The OH bands have also been virtually eliminated, and peaks of less than 1 dB/km at 0·95 μm have been obtained