DEFINITIVE PROFILE-DISPERSION DATA FOR GERMANIA-DOPED SILICA FIBRES OVER AN EXTENDED WAVELENGTH RANGE

Indexing terms: Dispersion, Optical fibres

New results are presented for the wavelength dependence of the profile-dispersion parameter P in optical waveguides fabricated from germanosilicate glasses. These results show that P is independent of both GeO_2 concentration and thermal history of the glasses.

Introduction: The value of the index exponent (α_{opt}) required to minimise the intermodal pulse broadening in a multimode optical fibre depends on the wavelength-dispersive properties of the core and cladding glasses.[1] In a recent publication,[2] we demonstrated that large discrepancies exist between the measured values of α_{opt} for fibres fabricated from germania-doped silica, leading to confusion as to the most appropriate index profile to fabricate. The inadvertent choice of a profile which deviates only slightly from the optimum could result in a considerable decrease in bandwidth. To date, it has been common practice to attribute these discrepancies to either the differing thermal histories of the glass samples, or to the suggestion that the profile-dispersion parameter P may be a function of GeO_2 concentration.[3] The purpose of this letter is to present new results for the wavelength dependence of α_{opt} which clearly demonstrate that P is independent of the dopant concentration over the range tested, and therefore that the profile dispersion is indeed homogeneous throughout the core of a graded-index fibre, as assumed in Reference 1. Furthermore, thermal history is shown to have little effect.

Experiment: Details of our experimental technique for the measurement of P directly on the fibre have already been reported.[4] More recently, an expansion of the range of the measurement further into the infrared to 1900 nm has been achieved by using a germanium as well as a silicon photodetector, in conjunction with a prism monochromator for wavelength selection. In addition, attention to experimental detail has considerably improved the accuracy and reproducibility of the method.

The raw data, in the form of the variation of the fibre numerical aperture (n.a.) with wavelength λ over the range 350 nm–1900 nm, are processed by the method developed in Reference 4. Using a least-squares technique, the experimental data are fitted to an equation of the form

$$(na)^2 = A + B\lambda^2 + C/\lambda^2 \qquad (1)$$

This form of equation arises from expanding the 6-term Sellmeier law which results from the combined effect of core and cladding glasses; two terms have resonance wavelengths in the infrared and four terms are centred in the ultraviolet. The coefficients A, B, C thus have a degree of physical significance in that they may be expressed in terms of resonance wavelengths and oscillator strengths. By differentiation of eqn. 1, the approach furnishes a convenient method for the determination of P, and hence α_{opt}.

To obtain a realistic estimate of the certainty with which α_{opt} is given by the experiment, an error analysis has been implemented. Since the experimental data for $(na)^2$ are available only over a finite range of λ (albeit considerably larger than the range of immediate interest) it is anticipated that the accuracy of fit achieved with eqn. 1 is best near the centre of the range and decreases towards the extremities located at 350 nm and 1900 nm. The error analysis confirms that this is indeed the case, with the region of maximum accuracy lying between 700 and 1500 nm. A typical error of $\pm 0{\cdot}02$ is found in α_{opt}.

Results: Measurements have been performed on three germania-doped step-index fibres with pure silica claddings; their characteristics are given in Table 1. The maximum GeO_2 content tested (17·5 moles %) is typical of the level used at the core centre of production graded-index fibres. Fig. 1 shows the measured variation of $(na)^2$ with wavelength for the 17·5 moles % GeO_2 fibre, sample c, together with the least-squares fit using eqn. 1. The figure contains 468 data points and is composed of three separate measurements performed on the same fibre using angular reference apertures[4] of three different sizes.

Table 1 DETAILS OF FIBRES USED IN THE EXPERIMENTS

Fibre sample	GeO_2 concentration*	n.a. at 530 nm
	moles %	
a	11·7	0·205
b	16·3	0·236
c	17·5	0·247
d	11·7 annealed	

* Determined on our samples by Corning Glass Works Microprobe Laboratory, to whom acknowledgments are made for a series of meticulously detailed measurements

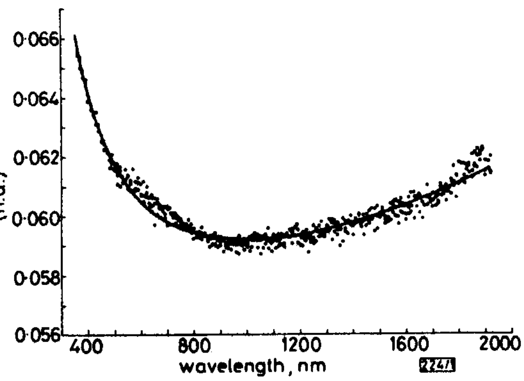

Fig. 1 *Variation of $(na)^2$ with wavelength for fibre having 17·5 moles % GeO_2/silica core and silica cladding (sample c)*

The purpose of the latter is to demonstrate the reproducibility of the experiment and to eliminate the possibility of systematic error (such as that caused by differential attenuation of high-order modes) affecting the measurement. It may be seen from the Figure that the results are remarkably consistent, leading to a high degree of confidence in the accuracy of the method.

The variation of α_{opt} with wavelength, deduced from the experimental data, is shown in Fig. 2 for the range of binary silicate glasses tested (samples a, b, c). The results for the three samples are very nearly identical, being within the thickness of the line. The curves clearly indicate that for the range of compositions tested, α_{opt} is independent of germania concentration. The 99% confidence limits obtained from the error analysis are shown by the dotted lines.

To test the effect of thermal history on the fibre samples, the 11·7 moles % fibre (sample a) was subjected to an annealing schedule of 30 min at 1230°C, followed by cooling to room temperature at the rate of 100°C/h. It is thought that this

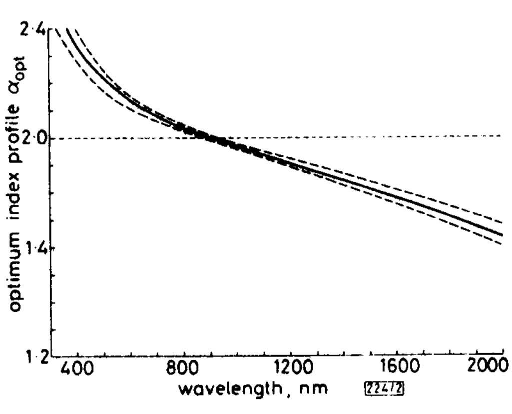

Fig. 2 *Optimum index profile as a function of wavelength for binary GeO_2 SiO_2 graded-index fibres, samples a, b, c*

Fine dashed lines show 99% confidence limits schedule represents an adequate simulation of the thermal history of the bulk glass samples used by other workers.[3,5-7] The variation of α_{opt} with wavelength for the annealed fibre (sample *d*) is compared with that for the as-drawn fibre in Fig. 3, and although there is a slight departure from the results

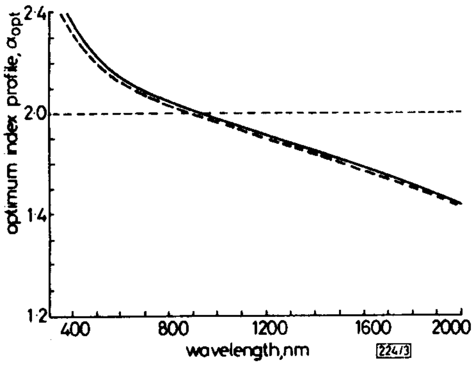

Fig. 3 *Effect of thermal history on predicted index profile obtained using sample a*

Dashed line shows result after annealing

obtained prior to annealing, the difference is not thought to be of any experimental significance. Thus *P* would appear to be independent of the thermal history of the glass.

Conclusions: We have presented results obtained in our laboratories for the profile dispersion of fibres fabricated with various GeO_2 concentrations in the core glass and having a pure fused-silica cladding. The results cover a wide wavelength range, and show that the profile dispersion is independent of the dopant concentration for the range of compositions tested. Furthermore the results show that the profile dispersion is relatively unaffected by the thermal history of the glass. Thus these factors cannot be used to explain the large discrepancies[2] that exist between the measurements published by various workers in the field. The results have shown the desirability of collecting comprehensive data over a wide spectral range and the necessity of interpreting this data with a physically meaningful analysis.

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