WAVELENGTH-DISPERSIVE PROPERTIES OF GLASSES FOR OPTICAL FIBRES:
THE GERMANIA ENIGMA

Indexing terms: Optical dispersion, Optical fibres

A comparative study is made of the wavelength-dispersive properties of germania-doped glass for optical-fibre waveguides and some important discrepancies are revealed. New results are presented for profile dispersion of this material over an extended wavelength range.

A considerable amount of data is now available concerning the wavelength dependence of the refractive index of silica doped with germania and, in principle, this should aid the design of multimode fibres with minimal pulse spreading. However, there would seem to be considerable discrepancies between reported data from different sources, leading to confusion as regards both the optimum index profile and the operating wavelength that minimises material dispersion. In this study, new results are presented and compared with those available from other sources, the latter being processed where necessary to reveal the relevant parameters.

Theoretical background: Olshansky and Keck have considered pulse broadening in fibres fabricated from dispersive materials and which have $\alpha$-law profiles. They predict an optimum $\alpha$-profile described by $\alpha = 2 - 2\beta - 12\lambda/5$, where $\Delta$ is the relative-index difference between core and cladding and $P$ is the profile dispersion parameter, defined as

$$P = \frac{n_2 \lambda d\Delta}{N_2 \Delta d\lambda}$$

Here $\lambda$ is the wavelength, $n_2$ is the index at the core centre and $N_2 = n_2 - \Delta n_2 / d\lambda$ is the corresponding group index. Implicit in the theory is the assumption that $P$ is purely a property of the additive used to modify the refractive index of the base glass and is not a function of its concentration; thus $P$ is assumed constant throughout the core of a graded-index fibre. If this is not the case, other more complex forms of theoretical analysis are required, leading to an optimal index profile which is not of the power-law type.

Refractive-index measurements on bulk GeO$_2$/SiO$_2$ glasses have been reported by Fleming and Kobayashi et al., details are given in Table 1. From the data given in References 8-10 it is a simple matter to calculate $P$ for a set of GeO$_2$-doped fibres with a composition at core centre equal to that of the measured bulk sample, and whose cladding consists of pure SiO$_2$, the index data for which is well known. The computed results are given in Fig. 1. There is a significant difference in the curves, even for quite similar concentrations, between the bulk-glass results of Kobayashi et al. and Fleming; furthermore, there is little agreement between bulk-glass results and those obtained on fibres. Fleming's results would clearly indicate an inhomogeneous profile dispersion and hence the departure of optimum fibre index profiles from the $\alpha$-law type. On the other hand, the results of Kobayashi et al. would imply a profile dispersion somewhat closer to linear, particularly for their samples B, D and E.

**Discussion:** On the basis of the fibre and bulk measurements given above, various theoretical predictions have appeared in the literature. Using their values of $P$ determined on a 22 m/o GeO$_2$-doped fibre and assuming $P$ independent of concentration, Kaminow and Presby have predicted a fibre based on a ternary P$_2$O$_5$/GeO$_2$/SiO$_2$ glass that exhibits a profile close to optimum over an extended wavelength range. Adopting the
diagonally opposed assumption of nonlinear profile
dispersion, however, and using the measurements of Fleming, Arnaud has calculated optimum profiles (not of the α-type)
for fibres with germania-doped cores and boron-doped claddings. More recently a hybrid theory—the ‘multiple-α
profile’—has become available. Using a modified form of this
theory, in which the profile dispersion is required to be linear,
and the measured data from References 8 and 9, an optimum
configuration has been proposed based on GeO₂ and B₂O₃
dopants (although we note that both References 8 and 9 predict nonlinear profile dispersion for GeO₂ over a wide
range of compositions).

From the foregoing, it may be seen that little agreement on
the wavelength-dispersive properties of GeO₂-doped glasses
exists at present and therefore that predictions for optimised
fibre structures should be treated with some caution, at least
until measurements of the properties of this material can be
substantiated.

Fig. 2 Wavelength of zero material dispersion λ₀ as a function of
Germania concentration

The data is taken from the References given in the key. The solid
line is the best fit to our own data (solid points)

Wavelength of zero material dispersion: The material-dispersion
parameter $M$ has been measured in multimode germania-doped fibres and in bulk samples. The
wavelength $λ₀$ corresponding to zero material dispersion for various concentrations of germania has been reported for
g graded-index and step-index multimode fibres and also for
bulk samples measured in two different laboratories by an
identical technique. These results are summarised in Fig. 2,
which also shows the data from our own laboratories,
based on the incorporation of two further points.

For the measurements on germania-doped fibres, the step-
index results of Payne and Hartog lie in general above the
graded-index results obtained by Chilton Lin et al. However,
as pointed out in Reference 14, it is difficult to interpret data
obtained on graded-index fibres since the results represent a
weighted mean of the properties of the core and cladding
compositions. Consequently it is not possible to determine
material properties directly from the results of Reference 13
since they represent a mixture of core and cladding values,
the proportion of each depending on the excitation conditions.

The fact that the result for a graded-index fibre having a
certain composition at core centre is lower than that of an
equivalent step-index fibre is consistent with this observation.

It is again clear that little agreement for the wavelength of
zero material dispersion exists between results from various
sources, a fact which is perhaps not surprising, at least for the
bulk glass measurements, since the values for $M$ (derived from
the second derivative of index) are likely to be even more at
variance than the values for $P$ (obtained from the first
derivative).

Conclusions: We have presented further results obtained in our
laboratories for both profile and material dispersion and
compared these with the results obtained elsewhere. It is clear that
several fundamental questions remain to be resolved. The
results published to date reveal little as to the linearity or
otherwise of the profile dispersion, since major discrepancies
exist in results even for similar compositions. Furthermore,
large differences exist in the predictions for the wavelength of
zero material dispersion.

It is hoped that the presentation of data given here will
serve to caution designers in their selection of available results,
since the use of inappropriate values could result in an order-
of-magnitude error in predicted bandwidth.

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References

1. OLSHANSKY, R., and KECK, D. B.: 'Pulse broadening in graded-
2. ARNAUD, J. A.: 'Optimum profiles for dispersive multimode fibres',
3. MARCATILI, E. A. J.: 'Modal dispersion in optical fibres with
arbitrary numerical aperture and profile dispersion', Bell Syst.
4. OLSHANSKY, R.: 'Optical waveguides with low pulse dispersion over
5. PRESBY, H. M., and KAMINOW, I. P.: 'Binary silica optical fibres:
 refractive index and profile dispersion measurements', Appl. Opt.,
1976, 12, pp. 3029-3036
of profile dispersion in optical fibres: a direct technique',
7. SLADEN, F. M. E., PAYNE, D. N., and ADAMS, M. J. (to be
published)
8. FLEMING, J. W.: 'Material and mode dispersion in GeO₂, B₂O₃, SiO₂
9. KOBAYASHI, S., SHIBATA, S., SHIBATA, N., and IZAWA, T.,
'Refractive-index dispersion of doped fused silica', International conference on integrated optics and optical fibre communication,
1977, pp. 309-312
Lett., 1978, 14, pp. 326-328
11. KAMINOW, I. P., and PRESBY, H. M.: 'Profile synthesis in multi-
12. PAYNE, D. N., and HARTOG, A. H.: 'Determination of the wave-
length of zero material dispersion in optical fibres by pulse-delay
13. CHINLON LIN, COHEN, L. G., FRENCH, W. G., and FOERT-
MEYER, V. A.: 'Pulse delay measurements in the zero-material-dispersion region for germanium- and phosphorus-doped silica
fibres', ibid., 1978, 14, pp. 170-172
14. ADAMS, M. J., PAYNE, D. N., SLADEN, F. M. E., and
HARTOG, A. H.: 'Optimum operating wavelength for chromatic
equalisation in multimode optical fibres', ibid., 1978, 14, pp. 64-66

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