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Pulse Delay Measurement of the Zero Wavelength of Material Dispersion in Optical Fibres

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Abstract — Pulse delay measurements on fibres are reported over a wide wavelength range straddling the zero of material dispersion. Results for phosphosilicate and a range of germania-doped fibres indicate that the wavelength of negligible material dispersion lies in the range 1270—1350 nm. The optimum wavelength depends on the concentration for fibres containing germania.

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Pulsmessungen bei der Null-Wellenlänge der Materialdispersion in optischen Fasern

Zusammenfassung — Es wird über Pulsverzögerungsmessungen an Glasfasern berichtet, wobei die Wellenlänge der Materialdispersion bis zum Wert Null reicht. Die Ergebnisse für Phosphorsilikate sowie Germanium-dotierte Fasern zeigen, daß die Wellenlänge der vernachlässigbaren Materialdispersion im Bereich von 1270 nm bis 1350 nm liegt. Die optimale Wellenlänge hängt von der Konzentration der Fasern ab, die Germanium enthalten.

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1. Introduction

The bandwidth of an optical transmission line is limited by
1) transit time differences which exist between modes,
2) waveguide dispersion caused by the frequency dependence of the group velocity of the individual modes and
3) the wavelength dispersive properties of the glass refractive index, known as the material dispersion.

The intermodal time-delay differences can be effectively equalised by propitious choice of the core refractive-index profile, leaving the limitation of waveguide and material dispersion. The latter dominates when using GaAs devices with their characteristically broad spectral spread and in many applications results in a curtailment of the potential bandwidth of both single and multimode fibres.
Extrapolations from previous fibre measurements [1, 2] using a pulse delay technique in the 600—900 nm spectral region indicate that the material dispersion becomes negligibly small at wavelengths near 1270 nm for fibres based on phosphosilicate glass. We present here further pulse measurements at wavelengths on both sides of the zero of material dispersion and which cover the entire wavelength region of interest to optical communications. The results enable the wavelength λ_0 of the dispersion zero to be determined in both phosphosilicate and germania-doped fibres. Sources designed to emit at λ_0 will maximise the transmission capacity of the fibre.

2. Experiment

The pulse-delay technique used is similar to that reported previously [1], whereby the transit time of a pulse through a length of fibre is measured as a function of wavelength. The experimental arrangement is shown in **Fig. 1**. A dye laser followed by a temperature-tuned $LiNbO_3$ parametric-oscillator provides 1 µs pulses in the wavelength range 780—2600 nm, while the dye laser alone covers wavelengths from 580—620 nm. Pulses of 0.5 ns duration suitable for injection into the fibre are extracted from the output by means of a Pockels-cell pulse-slicer.
The transmission time of the pulse through the fibre is measured by a digital time-delay generator in conjunction with an oscilloscope. The delay is chosen such that the oscilloscope time-base is triggered just as the pulse emerges from the length of fibre. The time-delay generator thus provides the major portion of the required delay, while small variations with wavelength are read directly from the oscilloscope display at 0.5 ns/div. The time delay is checked periodically with a counter/timer to allow for instrument drift.

3. Theory

Neglecting a small waveguiding effect, the transient time τ of a pulse in a dispersive medium is given as a function of wavelength λ by

$$\tau = \frac{L}{C}\left(n - \lambda \frac{dn}{d\lambda}\right) \tag{1}$$

where L is the fibre length and n the refractive index. In order to least-squares fit the experimentally-determined variation of τ with λ, we make use of a technique developed earlier [3] whereby the physical nature of the glass refractive-index is exploited to process the data. Since it is well known that the index n is accurately described by a three-term Sellmeier equa-

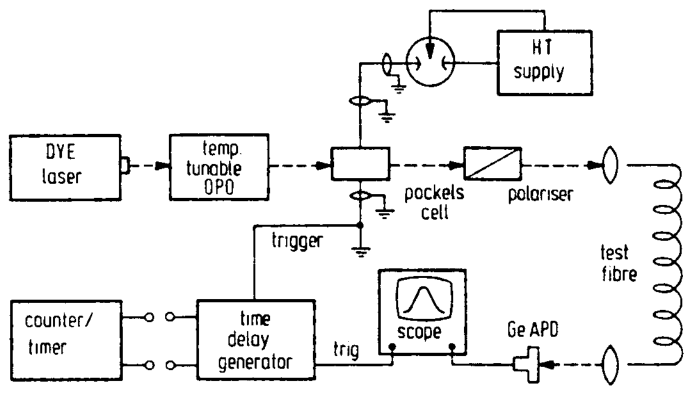

Fig. 1.
Experimental arrangement.

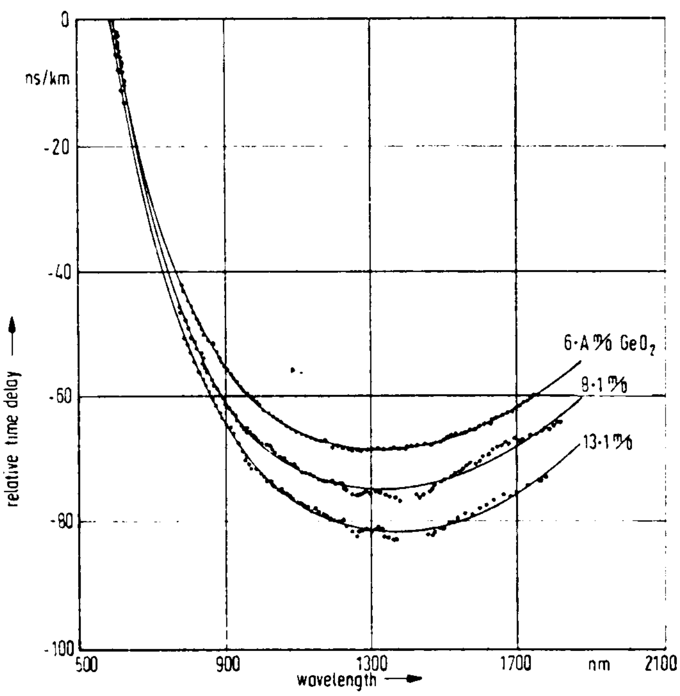

Fig. 2.
Pulse transit time per kilometre relative to that at 580 nm for fibres having the germania concentrations shown.

Fig. 3.
Comparison of material dispersion of fibres containing 15 m/o P_2O_5 and 13.1 m/o GeO_2 with that of pure silica.

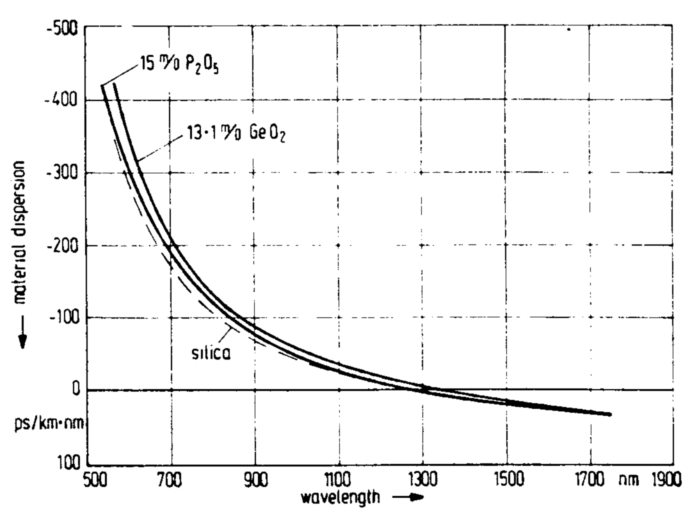

Table 1

Fibre	Type	Length (km)	Composition m/o P_2O_5	GeO_2	SiO_2
VD150L	Graded	0.568	15	0	85
VD202L	Graded	1.239	5.4	6.4	88.2
VD208L	Step	0.818	0	8.1	91.9
VD209L	Step	0.660	0	11.0	89.0
VD210L	Step	1.217	0	13.1	86.9

tion [4], it follows that eqn. (1) may be rewritten in the form of a Sellmeier and its derivative. A series expansion leads to

$$\tau = a + b\lambda^{-2} + c\lambda^{-4} + d\lambda^{2} + e\lambda^{4} \quad (2)$$

Equation (2) may then be readily fitted to the data and the coefficients a to e determined. The material dispersion parameter M is given by

$$M = \frac{d\tau}{d\lambda} \quad (3)$$

Note that in order for the curve-fitting procedure outlined above to yield an accurate estimate of the zero wavelength, it is necessary to make pulse delay measurements over a wide wavelength range straddling λ_0.

4. Results

Four germania-doped and one phosphosilicate fibre have been tested. The germania fibres were fabricated to form a series having an increasing dopant content, ranging from 6.4 to 13.1 m/o GeO_2. The fibre parameters are given in **Table 1.**

The measured transmission delay relative to that at 590 nm is shown in **Fig. 2,** omitting VD150L whose result lies close to that of VD202L, and VD209L for clarity. The gaps in the measurements correspond either to regions of high fibre attenuation or to wavelengths unobtainable from the laser. The fitted curves using eqn. (1) are also shown in the figure and it is clear that an increasing GeO_2 content is accompanied by a larger variation in transit time and a minimum delay point which shifts to longer wavelength.

The material dispersion parameter computed from eqn. (3) is given in **Fig. 3** for fibre VD210L (13.1 m/o GeO_2) and VD150L (15 m/o P_2O_5), together with the result calculated from refractive index data for undoped silica. The curves confirm the earlier extrapolated result [1] that the material dispersion of phosphosilicate glass differs little from that of silica. However, the addition of 13.1 m/o germania to silica produces an increase in the material dispersion of ≈ 25 ps/km · nm at 0.9 µm. The computed results for the series of four germania-doped fibres permit a determination of the effect of GeO_2 concentration on the wavelength λ_0 of zero material dispersion. This is illustrated in **Fig. 4** and it is seen that λ_0 shifts progressively to longer wavelength with increasing GeO_2 content. In contrast, λ_0 for a 15 m/o P_2O_5 glass is found at 1272 nm, a result similar to that of silica.

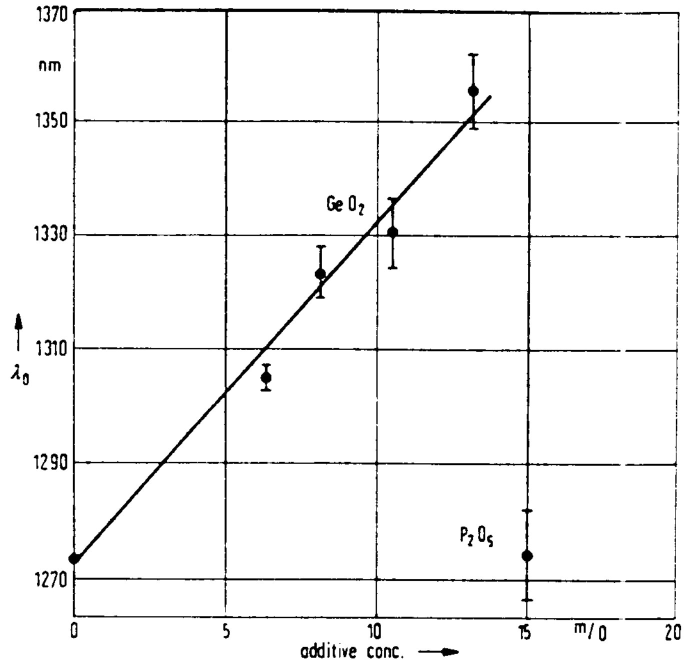

Fig. 4.
Effect of concentration of additive on wavelength λ_0 of zero material dispersion.

5. Conclusion

Pulse delay measurements on fibres made over a wide wavelength range reveal that the optimum source wavelength for minimisation of material dispersion effects in multimode fibres lies in the region 1270—1400 nm depending on the dopant and its concentration. The importance of this spectral region is further emphasised by its proximity to the fibre minimum loss wavelength. This should provide added impetus for the development of suitable sources and detectors to exploit these advantages.

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