VARIATION OF REFRACTIVE-INDEX PROFILES IN SINGLE-MODE FIBRE PREFORMS MEASURED USING AN IMPROVED HIGH-RESOLUTION SPATIAL-FILTERING TECHNIQUE

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1. INTRODUCTION

The non-destructive measurement of refractive-index profiles (RIP) in optical fibre preforms is of considerable importance to both preform fabrication and to fibre propagation assessment[1,2]. Recently we have reported[3] a technique based on spatial filtering which allows direct visualisation of the preform deflection function[4] and reveals the RIP in considerable detail. The method has the advantage that it requires a minimum of equipment and is simple to apply. We report here a further development involving dynamic filtering which allows both enhanced performance and easier computer automation. The capability of the new equipment is demonstrated by using it to reveal the evolution of the RIP along the length of a single-mode fibre preform and to predict at each point the wavelength region of monomode operation. It is shown that considerable variation can occur towards the ends of the preform and that this causes a shift of the cut-off wavelength. The method thus provides a powerful tool for preform diagnosis.

2. DYNAMIC SPATIAL FILTERING

A parallel beam of light incident tranversely on a preform suffers refraction (fig. 1). The relationship between the deflection Φ experienced by a ray and its radial point of incidence y (the deflection function)[4] is determined by the preform index profile; it is the object of the experiment to ascertain this relationship, from which the profile can be deduced. A spherical lens with focal length f placed to receive the emergent light transforms the ray angle Φ to a position ω in the focal plane (fig. 1) according to

$$\omega = f \tan \Phi \qquad (1)$$

A chopper blade positioned in the focal plane thus progressively sweeps a linear spatial distribution of angles Φ dispersed along the ω axis. A photodiode placed at a given radial position in the preform image therefore sees a chopped light signal, the phase of which depends on the distance ω from the optic axis (and hence angle Φ from equation 1) that the associated ray transverses the focal plane.

The time t(y) which elapses between the chopper blade passing a reference point and the instant a ray at position ω is extinguished is given by:

$$t(y) = \frac{1}{\sigma}\left[\Theta_0 - \tan^{-1}\left(\frac{\omega}{R}\right)\right] = \frac{1}{\sigma}\left[\Theta_0 - \tan^{-1}\left(\frac{f\ \tan\Phi}{R}\right)\right] \quad (2)$$

where σ is the blade angular-velocity, R is defined in fig. 1 and Θ_0 is the angular position of the reference relative to the vertical. Consequently, the relationship between Φ and y can be obtained by measuring for each position in the preform image the time interval t(y) between the signals given by the reference and image detectors, from which the associated angle Φ is found using equation 2. The data is automatically transferred to a computer which performs a simple transform[3] to reveal the index profile. It can be seen that only a minimum of inexpensive equipment is required and the method involves no particularly critical alignment procedures.

3. RESULTS

Figure 2 shows a typical example of the RIP for a multimode fibre with $GeO_2/P_2O_5/SiO_2$ core and B_2O_3/SiO_2 buffer layer. The resolution of detail is excellent and the individual deposited layers can be clearly seen, despite being relatively small in this preform. A point of interest is that the preform does not possess the central GeO_2 - depleted depression which we normally find drops to the level of pure silica. In this case GeO_2 flow during collapse has virtually eliminated the effect, although there is some evidence of overcompensation.

Figure 3 shows results obtained for the RIP of a single-mode fibre preform having a silica substrate, a B_2O_3/SiO_2 buffer layer and a GeO_2/SiO_2 core. The preform was scanned at 31 intervals along its entire length in order to observe the variation in profile. For clarity, only the results obtained from the end corresponding to the start of deposition where most variations occur are shown, together with a single RIP taken from the other end (55cm); the profile was not found to vary substantially from the 20cm to the 55cm position. For comparison the RIP obtained by thin-slice interferometry at a position close to 55cm is shown superimposed and, despite a small difference in diameter, the agreement is excellent. The profile is characteristic of the single-mode preforms we have measured and departs radically from a step, having a large axial depression which varies in extent along the length, particularly near the ends where the burner reverses its transverse.

When pulled into a fibre of constant diameter the variation in RIP causes the cut-off wavelength λ_c of the LP_{11} mode to vary along the fibre length. λ_c for a fibre pulled to a certain diameter can be predicted[5] by integration of the RIP's of fig. 3.

The results calculated for a fibre of 70μm diameter pulled from various sections along the preform are shown in fig. 4. The cut-off wavelength is found to be substantially constant (~ 870nm) for the central 70% of the preform length, but rolls off to shorter wavelength at the start-of-deposition end (0cm) and increases slightly to longer wavelength at the other. A large departure is seen at 6cm and corresponds to an increase in core diameter at this point (see fig. 3).

Also shown in fig. 4 is the value of λ_c measured by the bend-loss method[6] on a 70 $\pm$ 0.2μm diameter fibre pulled from the 7cm position in the preform. The measured fibre cut-off is lower than that predicted from the preform by about 90nm. The reason for this is believed to be the consistent underestimation of λ_c by the bend-loss measurement[7].

4. CONCLUSIONS

The dynamic spatial-filtering scheme provides an attractive and reliable method for preform diagnostics, being simple to implement and giving profiles of high accuracy. It has proved invaluable for several preform studies, as evidenced by the example given here in which the variation in cut-off wavelength with preform length has been quantified. It was found that the predicted fibre cut-off varied considerably near the start-of-deposition end, but remained substantially constant for the remainder of the length.

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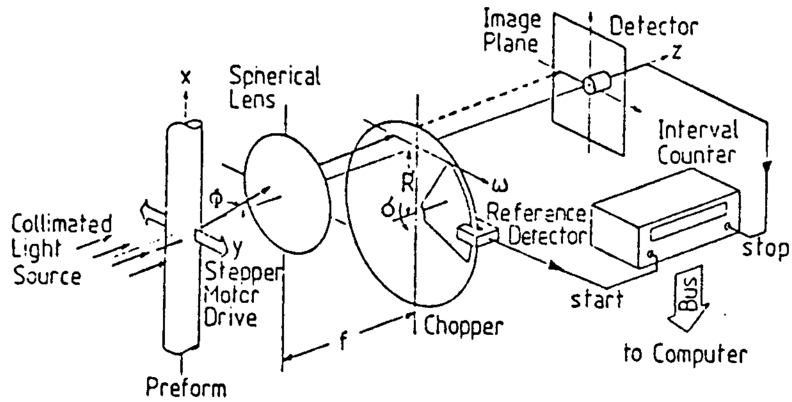

Fig. 1 Experimental Arrangement

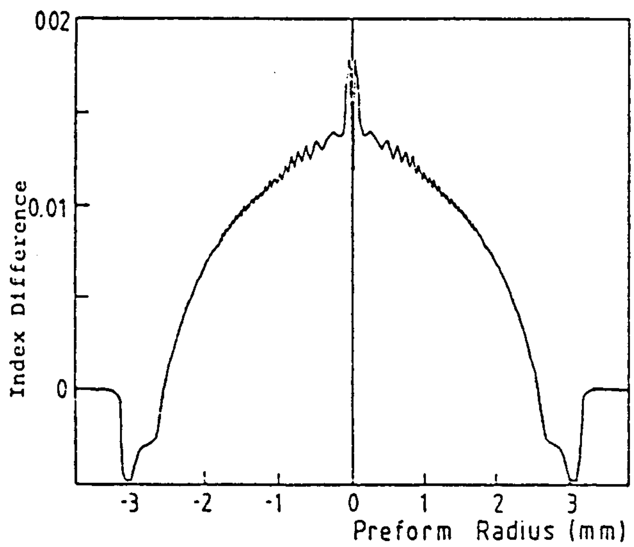

Fig.2 Multimode preform RIP

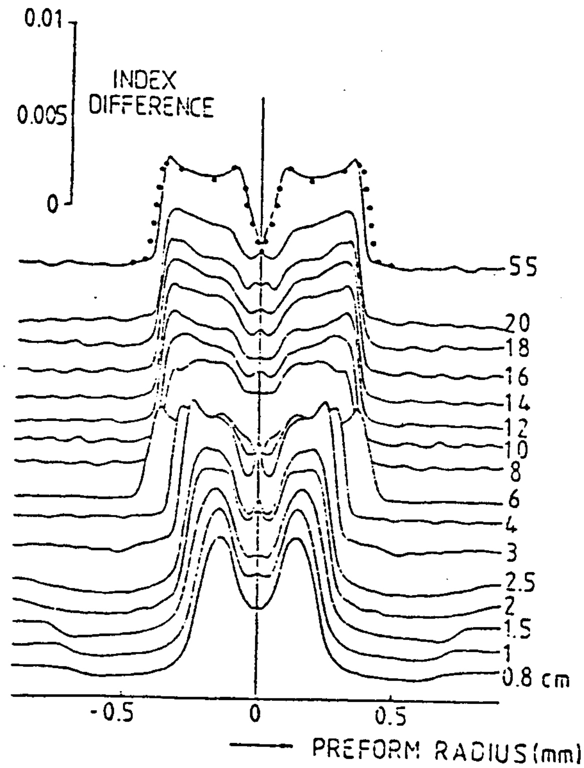

Fig.3 Single-mode preform RIP at various positions

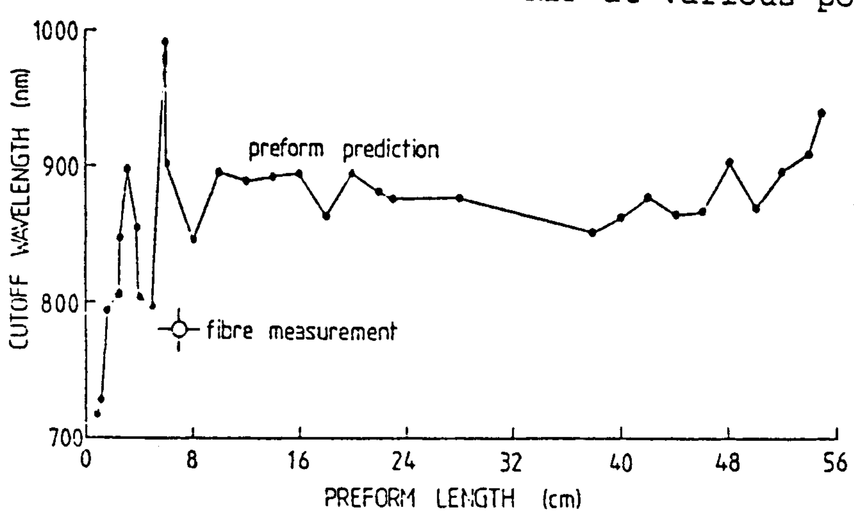

Fig. 4 Cut-off wavelength for 70μm OD fibre