ACCURACY AND RESOLUTION OF PREFORM INDEX-PROFILING BY THE SPATIAL-FILTERING METHOD

I. SASAKI, P.L. FRANCOIS, D. N. PAYNE

DEPARTMENT OF ELECTRONICS, UNIVERSITY OF SOUTHAMPTON, SOUTHAMPTON, ENGLAND

Non-destructive determination of the refractive-index profile provides a valuable tool for assessment and quality control of optical-fibre preforms. The spatial-filtering technique[1,2] allows data to be rapidly and conveniently acquired, and we have reported high-resolution profiling of both multimode and single-mode preforms by this method, together with comparative results obtained by other means. We report here an assessment of the factors influencing the accuracy and resolution of the technique and outline some of the improvements which have been made.

The spatial filtering method involves illuminating the preform transversely with a collimated beam and collecting the transmitted, refracted light with a lens placed so as to form an image of the preform (Fig. 1). The transmitted light is processed with a spatial filter, for example a knife edge[1] or a chopper[2], to enable the deflection of a ray to be determined as a function of the radial position at which it traverses the preform (the 'deflection function'[3]). The refractive-index profile may then be computed from the deflection data by means of an integral transform[4]. A typical result which demonstrates the resolution obtainable is given in Fig. 2 for a CVD graded-index preform. Even the layer structure at the core-cladding boundary is visible, i.e. a resolution of about 10μm.

Factors influencing the resolution may be summarised as follows:

1. *Lens resolution.* The resolution of the high-quality camera lens used is ~ 12μm (80lp/mm) and this ultimately limits the detail visibility. Experiments are underway with a higher-resolution lens to extend the system resolution.
2. *Beam collimation.* It was initially thought that the accuracy with which the deflection angles could be measured, and hence the resolution, would be limited by the angular divergence of the illuminating beam (Fig. 1). It has now been shown theoretically and experimentally that owing to the nature of the electronic detection process this is not the case. A relatively divergent beam (several degrees) can be used to give a larger signal, the optimum condition being when the beam divergence is chosen to image the light source at the preform image plane.
3. *Effective detector size.* The effective detector size referred to the preform limits the smallest feature which can be observed.

Since preforms with known spatial frequency content are not available, it is difficult to obtain the absolute system modulation transfer-function; however, an experiment has been conducted (Fig. 3) using a silica rod immersed in liquid to simulate a step-index preform test-target. By varying the magnification of the preform image, deflection functions were obtained for the 4 equivalent detector sizes d shown and the results Fourier analysed to determine their spatial-frequency content. The theoretical curve was calculated from the known deflection-function expression. Fig. 3 shows that for d less than ~ 16μm the resolution is limited, probably by the lens performance, but that small detector is still advantageous.

4. *Diffraction.* Diffraction of light within the preform and at the spatial filter limits the resolution to a level which initial considerations show to be well below that presently obtainable.

Two main factors limit the accuracy of the measurement; both depend upon the preform geometry.

1. *Preform optical thickness.* In common with other methods of preform profiling, it is assumed that the preform is a thin phase object. In practice, the finite preform thickness produces an image distortion and thus an error Δy in the radial coordinate y, as shown in Fig. 4 as a function of the ray deflection angle. In addition, geometrical abberations in the lens contribute to the effect to an extent shown in Fig. 4 for a typical lens. It can be seen that provided the ray deflection angle is smaller than 5^o, the error is negligible. The majority of graded-index preforms fall into this category.

2. *Preform ellipticity.* Undoubtedly the major source of error in preform profiling arises from the assumption in the mathematical reconstruction that the preform is circularly symmetric. In practice, however, some preforms exhibit significant asymmetry, leading to errors in both geometry and relative index-difference Δ. Calculations for an elliptical parabolic-index preform show that the maximum error $\delta\Delta$ in Δ occurs when a projection is taken along either the major or minor axis:

$$\frac{\delta\Delta}{\Delta} = \pm\left(\frac{a - b}{a}\right) = \pm\,\varepsilon$$

where a and b are the major and minor axes dimensions. Intermediate projection orientations lead to smaller errors.

For small ellipticity, an average of the profiles taken on major and minor axes yields the correct result (to order ε^2). For larger ellipticity or highly asymmetric preforms (as for example used to fabricate polarisation-maintaining fibres), a three-dimensional reconstruction of the profile can be used, as shown for the core of a single-mode preform in Fig. 5. In this case, 23 projections of the deflection function were taken at various orientations and a tomographic reconstruction procedure used[5]. Here a new interpolation algorithm has been employed to permit a high resolution reconstruction to be obtained with only a few preform projections.

Further work to be reported allows an accurate single index-profile section to be obtained from a number of projections with a minimum of computation, thus providing an intermediate solution to profiling of preforms with moderate departures from circularity.

Thanks are due to R. J. Mansfield, E. J. Tarbox and M. R. Hadley for supplying the preforms. P. L. Francois is on leave from CNET, Lannion, France.

REFERENCES

1. I. Sasaki, D. N. Payne and M. J. Adams, Electronics Letters, 16, (1980), pp. 219-221.
2. I. Sasaki, D. N. Payne, R. J. Mansfield and M. J. Adams, Proc. ECOC 6 (York, UK, 1980), pp. 140-143.
3. P. L. Chu, Electronics Letters, 15, (1977) pp. 736-738.
4. D. Marcuse, Applied Optics, 18, (1979) pp. 9-13.
5. P. L. Chu and C. Saekeang, Electronics Letters, 15, (1979) pp. 635-637.

DYNAMIC SPATIAL FILTERING

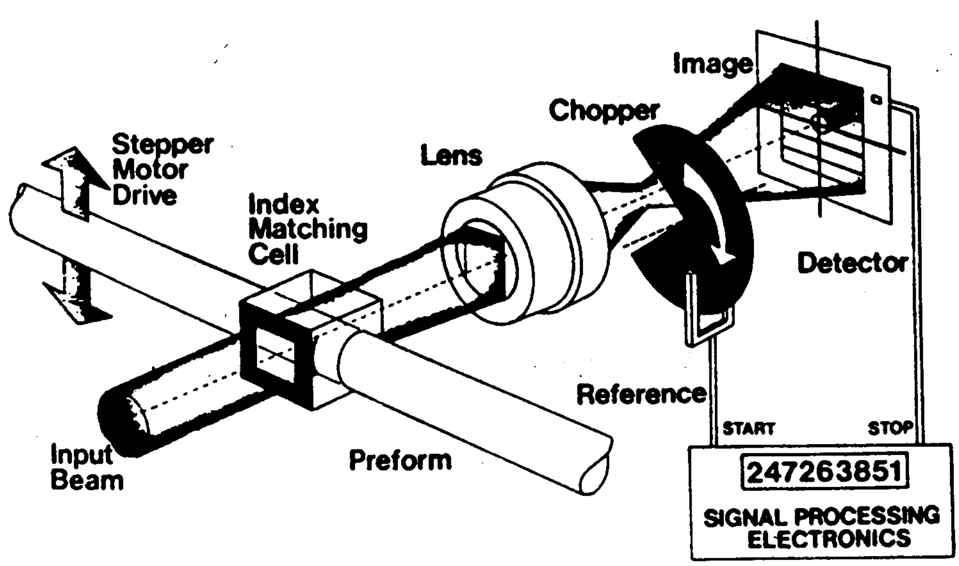

Fig. 1 Experimental Apparatus

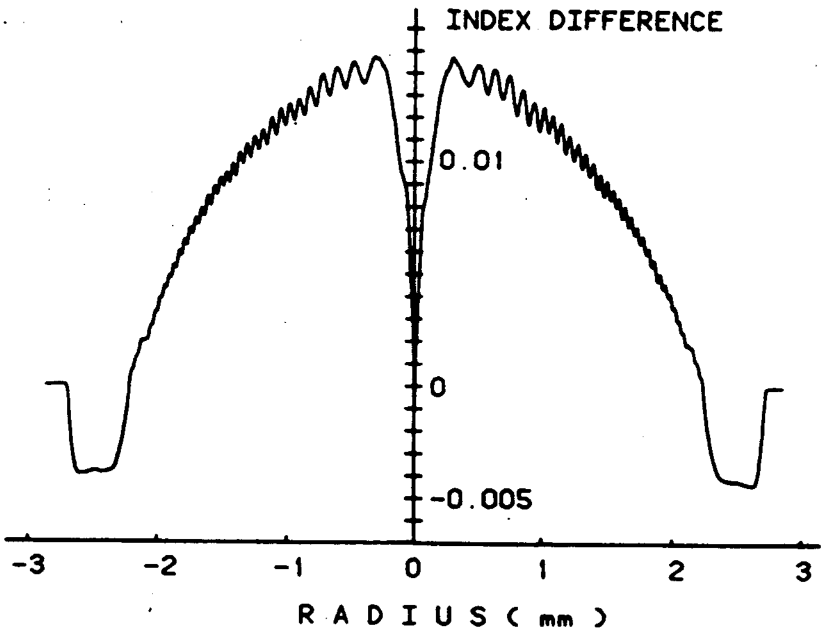

Fig. 2 High-resolution plot of multimode preform

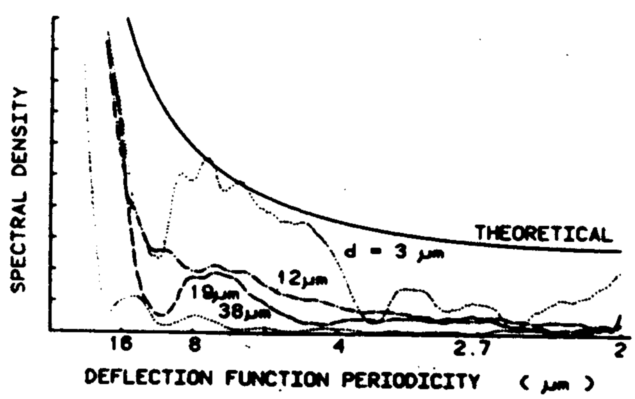

Fig. 3. Deflection function resolution for detector sizes shown.

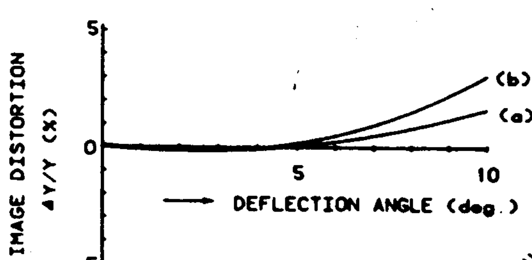

Fig. 4. Image distortion v. ray deflection angle
(a) effect of preform thickness
(b) including lens abberation

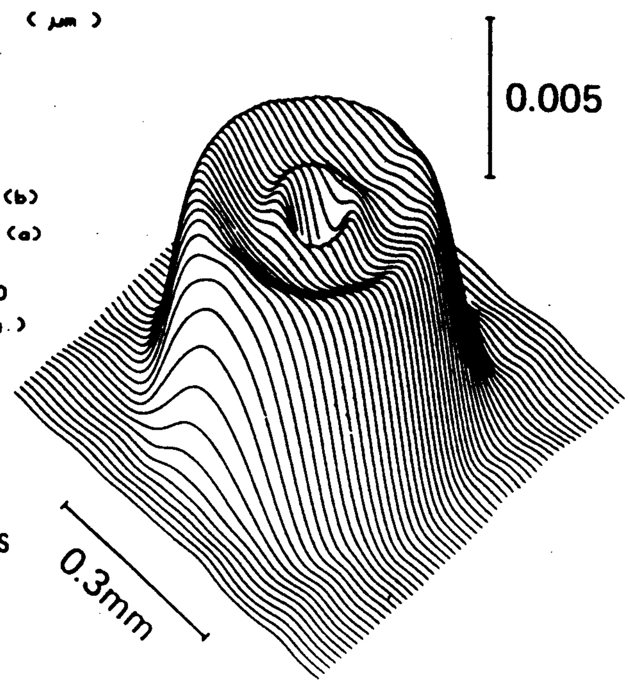

Fig. 5. 3-D reconstruction of core of monomode preform