RESOLUTION LIMIT OF THE NEAR-FIELD SCANNING TECHNIQUE

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Abstract

The near-field intensity distribution in a fully-excited fibre is calculated by superposition of propagating modes. It is shown that the resolution of the near-field scanning technique is limited by the number of modes supported by the fibre. Experimental confirmation is given.

1. Introduction

In common with other methods of profile appraisal, the widely-used near-field scanning (NFS) technique [1] has certain characteristic limitations which should be considered when interpreting the scans. In particular, the modal nature of propagation within the fibre imposes a limitation on the finest resolvable detail in a manner not unrelated to the way in which diffraction limits the spatial resolution of a lens. We present here a theoretical and experimental study of this effect, applicable not only to the NFS technique but also to similar methods which exploit the total field distribution within the fibre [2,3]. Our results show that in general the attainable accuracy is good when scanning typical multimode fibres, but that serious errors may be incurred if the method is applied to fibres which support an insufficient number of modes. In addition we suggest a method whereby the resolution may be improved.

2. Theory

The near-field intensity distribution has been calculated theoretically for both step- and parabolic-index guides by superposition of the field amplitudes of all modes propagating within the fibres. A typical result is shown in fig.1. The field exhibits two readily identifiable features: (a) A 'tail' associated with energy propagating outside the core extends into the cladding region. Theoretically the tail may be shown to penetrate a distance 2R/V (where R is the core radius, V the normalised frequency) into the cladding of a step-index fibre before its amplitude has fallen to 5% of that at the core centre. (b) A series of oscillations is superimposed on the expected near-field pattern, their amplitude being largest near a sudden discontinuity in refractive index. A ripple amplitude as large as 10% of the index difference can occur near the abrupt core/cladding discontinuity in a step-index fibre. The oscillations result from the summation of a finite number of modes and must therefore decrease in both amplitude and period with

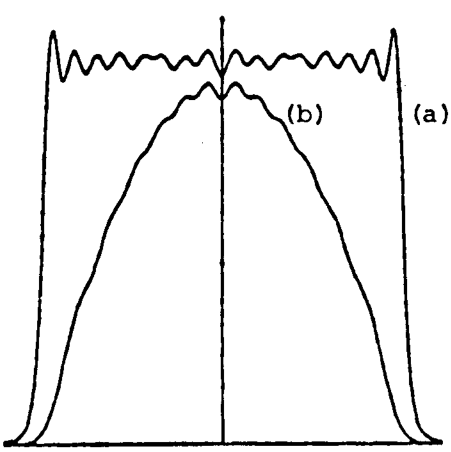

Fig.1 Calculated near-field intensity distribution for (a) step-index (b) parabolic-index fibre having V = 25.

increasing V-value of the fibre. A simple WKB argument demonstrates that the ripple half-period and hence the spatial resolution of the method is given (as a fraction of the core radius) by $\pi/2V$ for a step-index fibre; $2/V$ for a parabolic-index fibre; and $\pi\Gamma(3/2 + 1/\alpha)/2V\Gamma(1 + 1/\alpha)\Gamma(3/2)$ for a graded α-profile, where Γ denotes a gamma function. Thus a resolution of better than 10% of the core radius is obtainable when V exceeds 20.

Further theoretical analysis shows that the modal ripple may be nearly eliminated by using a source having a spectral width of approximately 100nm. In this case the range of ripple periods present in the near field causes additive cancellation for all oscillations except those occurring adjacent to sharp index discontinuities.

Computations of the effect on the near field of a dip similar to that commonly found at the core centre in fibres made by the CVD process, indicate that localised ripples are expected with an amplitude dependent on the dip dimensions and a period largely determined by the fibre V-value.

3. Experimental Confirmation

Since the spatial resolution is a function only of the number of modes supported by the fibre, it is possible to vary the V-value and verify the above results by scanning a given fibre at a number of different wavelengths.

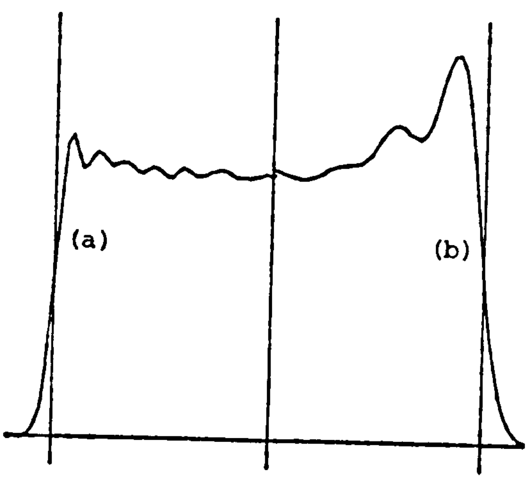

Fig. 2 Experimental near fields for a step-index fibre having (a) V = 24 and (b) v = 10.

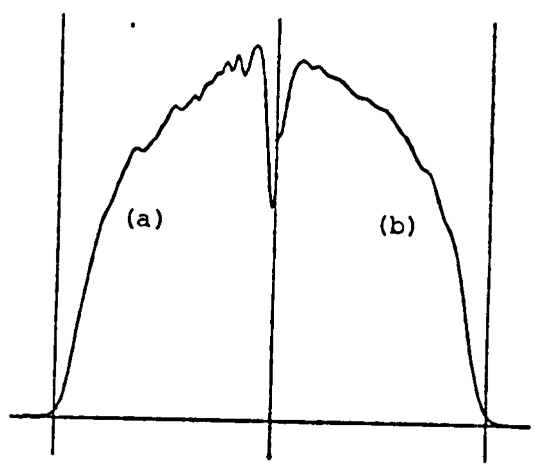

Fig.3 Experimental NFS of graded-index fibre having (a) V = 71 (b) V = 43.

Fig. 2 illustrates the effect on a step-index fibre (after correction for leaky modes [4]). It is seen that the V = 24 scan is remarkably similar to that shown in fig. 1. Additionally, the wavelength dependence of the ripple period is in excellent agreement with the theoretical predictions and confirms the improvement in resolution which occurs with increasing V-value.

Further confirmation is provided in fig.3, showing a graded-index fibre produced by CVD. The V = 71 scan (LHS) clearly shows smaller cladding 'tails' than does the V = 43 (RHS) plot and, furthermore, the extent of the central dip is less well resolved in the latter case. This is illustrated in greater detail when only the central portion is scanned (Fig. 4). Note that the ripple structure near the fibre centre shown in figs. 3 and 4 may result either from the individual CVD layers or from modal effects associated with the dip. Since from fig. 4 the ripple period does not vary with the wavelength, in this case it may be concluded that the layer structure dominates. The V = 93 plot provides excellent resolution of this detail.

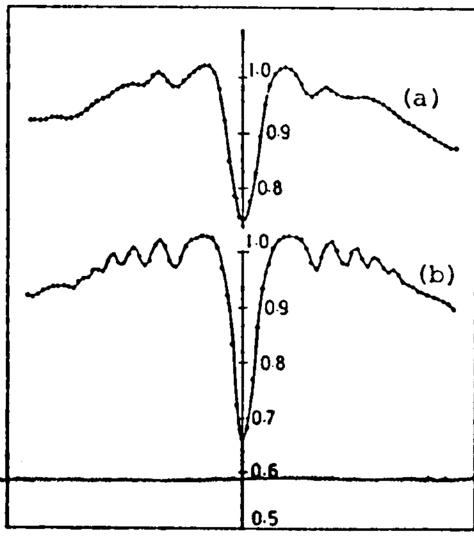

Fig. 4 Central dip detail from fig.3. (a) V = 44 (b) V = 93.

4. Discussion

We distinguish two near-field characteristics of practical importance to profile determination: i) the distortion of the near field arising from the presence of modal ripples and ii) the ability of the method to distinguish fine detail in the index profile. As outlined earlier, the former may be substantially reduced by using a source having a spectral spread of ~100nm, while the latter is optimised by operating within the blue region of the spectrum. Thus it is possible to improve the performance of the NFS and related techniques by the use of a light source with a powerful blue spectral content, such as a filtered Xenon-arc lamp.

5. References

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