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DESIGN AND IMPLEMENTATION CONSIDERATIONS FOR A PRACTICAL SELF-ALIGNED SINGLE-MODE FIBRE-HORN BEAM EXPANDER

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ABSTRACT

A new design and implementation technique for the single-mode fibre-horn beam expander is outlined. This new design is more practical both in its fabrication technique and in its application, than the previous approach. The field evolution along the beam expander has been measured and the fundamental limits to the rate of tapering examined.

Introduction

The optical fibre-horn has been proposed as a self-aligned beam expander for single-mode fibre optics [1,2]. The introduction of beam expansion optics into single-mode fibre technology is a requirement of the very small core sizes involved. Beam expansion can relax the mechanical tolerances for axial and lateral alignment by an order or two of magnitude. The cost however is an increased sensitivity to angular misalignment. The addition of self-aligned beam expansion in the fibre structure eliminates the need for lenses, which requires stable and critical alignment, and can be achieved by (i) "tapering down" a fibre as in the overjacketed beam expander [3] where a factor of three beam expansion is possible, or (ii) by "tapering up" a fibre by enlarging the cross sectional dimension [1], which can yield an order of magnitude beam expansion of the modal field. Such beam expanders must keep the fundamental mode intact with very little mode coupling or loss. In this paper we report on the fabrication and design limitations of a practical fibre-horn beam expander containing: a fibre pigtail, which is permanently spliced to an input fibre, an expanding tapered section which yields the beam expansion, and a uniform section which facilitates axial and lateral alignment while alleviating any angular misalignment problems.

Fabrication

(a) Structure: Fibre-horn beam expanders have been fabricated by taking the taper present in the transition from fibre to preform when the normal operation of fibre drawing is stopped. The taper transition region is then approximately 6 cm long . The termination with a conic shape does not facilitate easy handling although excellent laboratory studies have been reported [1]. By stretching the preform prior to fibre drawing to the required diameter and subsequently tapering to produce the fibre pigtail the better structure of figure 1 can be obtained. An important incidental advantage of this process is a much higher yield from the preform.

(b) Refractive index profile: A single-mode fibre is relatively immune from on-axis dips or perturbations to the refractive index profile in normal operation. On expanding the core, the influence of the refractive index profile on the fundamental mode field distribution can be very significant when a Gaussian shaped mode is desired. The core refractive index should therefore be uniform (ideal step index) or graded with a maximum on the fibre axis (e.g. α-profiles). In the present study, an MCVD preform with a pure silica core and a depressed cladding as shown in fig. 2 was fabricated thereby avoiding the possibility of a dip on axis due to the burn-off of dopants in the preform collapse stage.

(c) Taper rate: Mode conversion and loss from the fundamental mode in the fibre-horn can be minimised by obeying a certain slowness or adiabatic condition [4]. If z is the distance along the taper and ρ the local outside dimension of the taper then the adiabatic condition can be written as

$$\left|\frac{d\rho}{dz}\right| \leqslant \frac{\rho}{z_b} \quad ; \qquad z_b = \frac{2\pi}{(\beta_1-\beta_2)}$$

where z_b is a 'beat length', β_1 is the propagation constant of the fundamental LP_{01} mode and β_2 is the propagation constant of the LP_{02} mode which is the closest most likely mode to which coupling will occur. The adiabatic condition is shown in fig. 3 for the preform with the refractive index profile in fig.2 given that the fibre is single moded at λ = 633 nm (Core radius = 2 µm , NA = 0.11 and fibre radius = 40 µm). Also shown in fig. 3 are the actual taper angles for the fibre-horn in Reference 1 and the fibre-horns of fig. 1(b). Clearly for case A the adiabatic condition is exceeded. Examining this horn in more detail by cleaving at different points along the structure, and measuring the near field distribution as shown in fig. 4, it is found that the optical field which initially expands as a Gaussian beam in the adiabatic region P-Q, undergoes severe mode conversion on exceeding the adiabatic limit in the region R-S.

Discussion

The adiabatic condition shows that it can be possible to achieve any level of beam expansion provided that the length of the fibre-horn is sufficiently long. In practice, it would be desirable to minimise the length of the horn while achieving a suitable level of beam expansion. By stretching the present preform to a 1 mm diameter say, a factor of up to ten beam expansion is possible. In this case the fibre pigtail can be cleaved using standard tools while the 1 mm section could be cleaved using a "hand" cleave. Larger structures for larger levels of beam expansion require larger length horn sections combined with difficult handling procedures.

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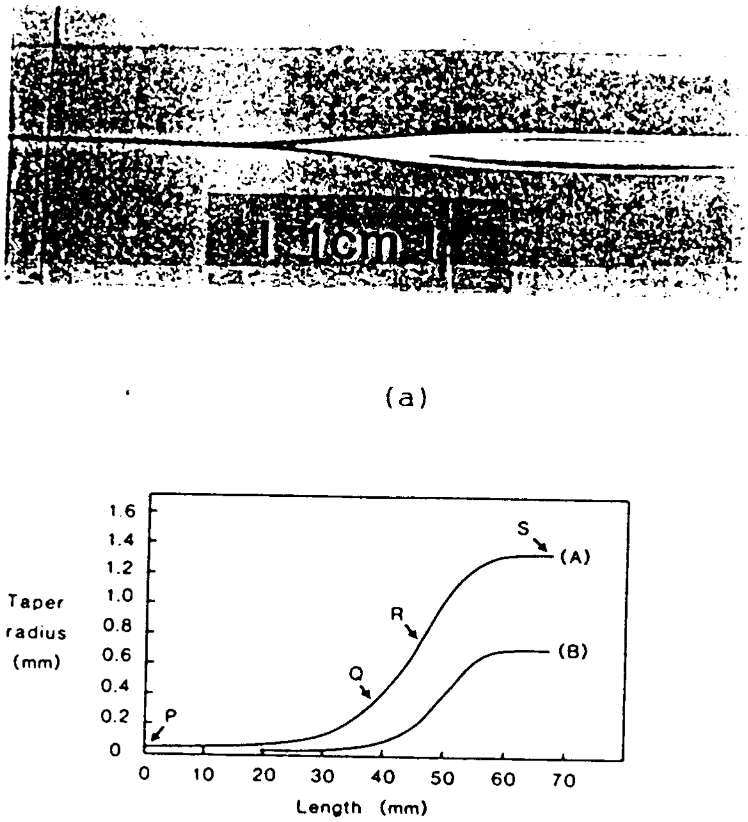

(a)

(b)

Fig.1: (a) A practical fibre-horn self-aligned beam expander (b) taper radius as a function of length for a non-adiabatic taper (A) and an adiabatic taper (B).

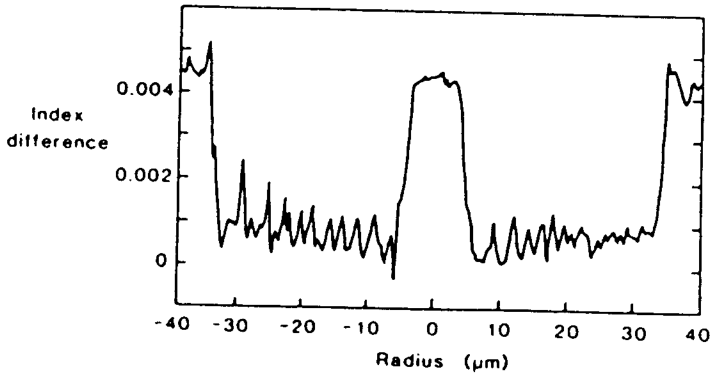

Fig.2: Refractive index profile of the pure silica core fibre from which the fibre-horns were fabricated.

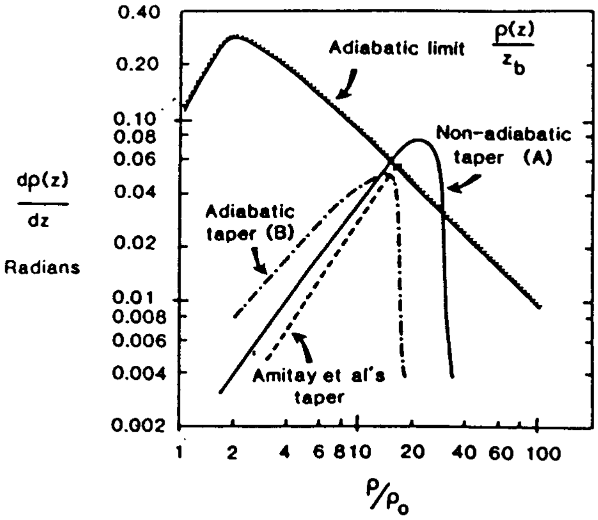

Fig.3: Actual taper angles for the non-adiabatic taper (A), the adiabatic taper (B) and the taper in Ref. 1, compared with the adiabatic limit.

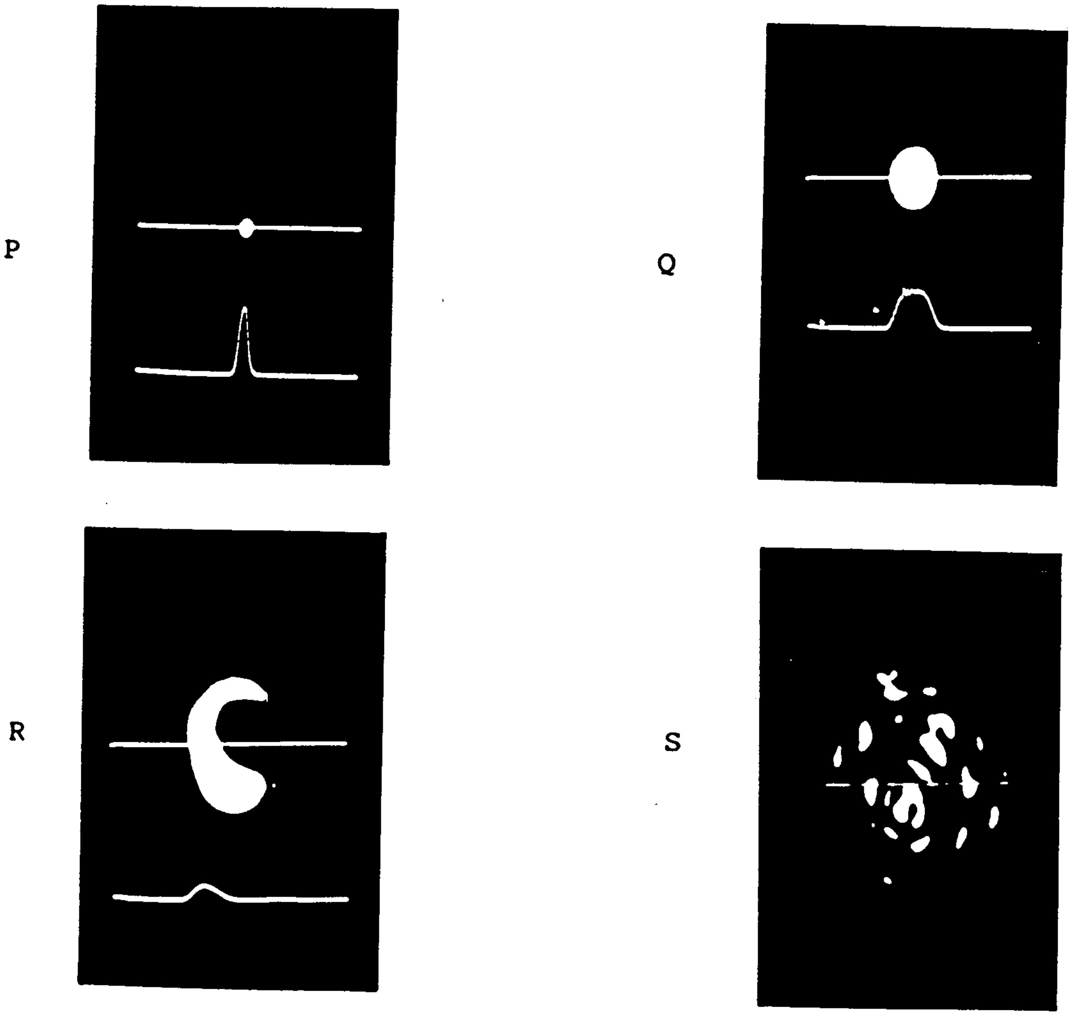

Fig.4: Measured near field distribution at the points indicated in fig. 1(b) on the non-adiabatic taper (A).