393.

RECTANGULAR MODE TRANSFORMERS IN TAPERED SINGLE-MODE FIBRES

Indexing terms: Optical fibres, Optoelectronics, Integrated optics, Optical waveguides

A single-mode fibre, polished on both sides and subsequently tapered, yields a low-loss circular-to-rectangular mode transformer. This device should permit more efficient interconnection of circular fibres to rectangular integrated-optic and semiconductor waveguides.

Introduction: The value of the single-mode fibre taper in the construction of fibre devices is widely recognised. The changes in fundamental mode size brought about by a taper allow closer matching to the modes of other waveguides, and tapered fibre ends have found widespread use for interconnecting fibres with optical elements such as diode lasers[1] and isolators.[2]

Previous work on the single-mode fibre taper has been restricted to variations in the taper width only, with a uniformly circular cross-sectional shape throughout the transition. However, low-loss transitions are possible in which the cross-sectional shape also changes.[3] The realisation of such a transition is reported in this letter. In particular, a circular-to-rectangular transition was constructed in a tapered single-mode fibre, in which the fundamental mode was transformed in shape from circular to rectangular.

Principle of operation: It is well established that light entering a single-mode fibre taper spreads out from the core and becomes guided in the fundamental mode of the waveguide formed by the cladding/air interface.[4] This waveguide dominates the guidance of the fundamental mode at taper ratios greater than about 3 : 1. If the taper is sufficiently gradual, little loss accompanies this transition.

The cladding waveguide is highly multimode, so the fundamental mode is strongly confined by the cladding and closely follows the shape of the boundary.[5] If the taper cross-section is rectangular, then the fundamental mode shape will also be rectangular. Therefore, such a taper functions as a mode shape transformer, the circular core mode is transformed into a rectangular cladding mode, and vice versa.

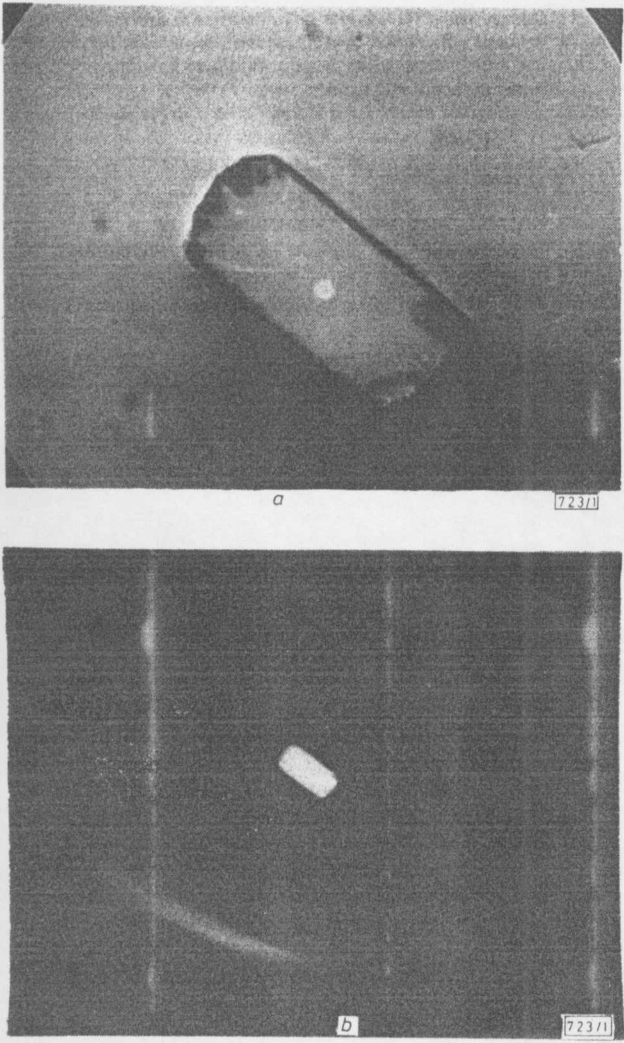
Fundamentally, a rectangular taper should be no more prone to waveguide transition loss than a conventional circular taper, for a given taper angle. Similar adiabaticity considerations prevail in both cases.

Construction: A motor-driven polishing wheel[6] is used to introduce a rectangular shape into a standard single-mode fibre (diameter 125 μm, cutoff wavelength 1150 nm). Two parallel sides are polished flat, and these constitute the long sides of the rectangle. The two short sides retain the circular curve of the original fibre cross-section, but the closer the polished sides approach the fibre core, the more 'rectangular' the cross-section becomes. By polishing each side to the same depth, the rectangle is produced. The polished region is then tapered in the conventional manner in a flame, and the throughput loss of the whole transition is monitored.

Results: Rectangularly polished fibres with symmetric and parallel-sided cross-sections were routinely produced. As would be expected, the polishing process did not introduce any loss prior to tapering. Many rectangular mode transformers were then made by tapering these polished fibres.

The cross-section of an untapered polished fibre is given in Fig. 1*a*, showing the rectangular shape. The cross-section of a similarly polished fibre, after being subsequently tapered, is given in Fig. 1*b*. In this case, the aspect ratio of the rectangle was 2·2 : 1, and the throughput loss of the taper was 0·4 dB. The taper ratio was about 4·5 : 1, which was sufficient to bring about cladding guidance in unpolished fibre. The cladding mode behaviour of the rectangular tapers was confirmed by the application of index matching fluid, leading to a total loss of power.

To investigate whether the circular-to-rectangular transition


a
723/1
b
723/1

is in itself a source of loss, a uniformly rectangular fibre (with a circular core) was also tapered to a similar taper ratio. This nonstandard fibre had been fabricated from a rectangular preform, and had an aspect ratio of 2·5 : 1 without needing to be polished. A taper throughput loss of less than 0·1 dB was readily obtained.

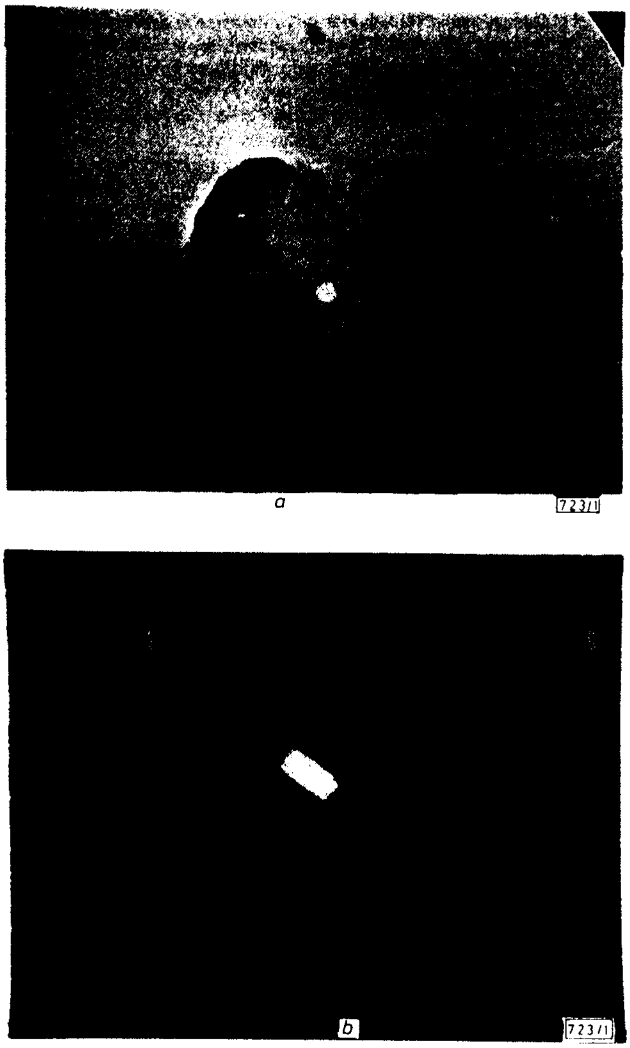


Fig. 1 *Photographs, to same scale, of cleaved cross-sections of two similar rectangularly polished fibres*

Fibre (*a*) was not tapered, fibre (*b*) was tapered with taper ratio of 4·5 : 1

Discussion: The new mode transformer described above radically alters the shape of the fundamental mode from its initial circular shape.

In a previous design of mode transformer,[7] a single-mode fibre with a rectangular core was fabricated from special soft glasses. The initial rectangular core diffused into a circular shape in part of the fibre after heat treatment, resulting in a core cross-section which gradually varied from a rectangle to a circle along the fibre. However, because the initial rectangular core waveguide was single-mode, the fundamental mode was weakly confined by the core and was near-circular to begin with. The change in the shape of the core therefore had little effect on the mode shape.

In contrast, the tapered mode transformer reported here is made from standard off-the-shelf silica fibre, and because of the highly multimode and strongly confining nature of the taper waveguide, there is a true circular-to-rectangular mode transformation. Such transitions should permit more efficient interconnection of fibres and other optical waveguides.

The typical throughput loss for the tapered rectangularly polished fibres was 0·4 dB. This is probably due to scattering from the rough polished surfaces; finer polishing should therefore reduce this loss. The circular to rectangular transition in itself does not introduce any further loss, as was demonstrated by tapering the rectangular fibre. The loss of one mode transformer is in any event half the measured throughput loss of the tapered fibre, since each tapered fibre is cleaved at its waist to yield two mode transformers.

The circular-to-rectangular transition discussed here is of particular interest for waveguide interconnection. However, other shape transitions are also possible with this polishing and tapering approach. For instance, a circular-to-semicircular mode shape transformer has been fabricated with the above technique, and may give low-loss joints between fibres and ion-diffused waveguides, in which the modal fields can be semicircular in shape.

Conclusion: A simple taper-based circular-to-rectangular mode transformer in single-mode fibre has been demonstrated.

Acknowledgments: The support of Sumicem Optoelectronics (Ireland) Ltd. is gratefully acknowledged. A research studentship (LD) was provided by the British Council and by the Government of the People's Republic of China.

C. D. HUSSEY
T. A. BIRKS
A. M. WINGFIELD
A. NIU
R. KENNY

Lightwave Technology Research Centre
University of Limerick
Plassey Technological Park
Limerick, Republic of Ireland

L. DONG

Optical Fibre Group
Department of Electronics and Computer Science
University of Southampton
Southampton, SO9 5NH, United Kingdom

15th August 1989

References

1 SCHWANDER, T., SCHWADERER, B., and STORM, H.: 'Coupling of lasers to single-mode fibres with high efficiency and low optical feedback', *Electron. Lett.*, 1985, **21**, pp. 287–289
2 WARBRICK, K. J.: 'Design of a compact optical isolator'. IEE Colloquium on All-Fibre Devices, London, 1988, pp. 5/1–5/4
3 HUSSEY, C. D., and BIRKS, T. A.: 'Fabrication of wavelength-flattened tapered couplers using polishing for cladding removal', *Electron. Lett.*, 1988, **24**, pp. 1072–1073
4 JEDRZEJEWSKI, K. P., MARTINEZ, F., MINELLY, J. D., HUSSEY, C. D., and PAYNE, F. P.: 'Tapered-beam expander for single-mode optical-fibre gap devices', *Electron. Lett.*, 1986, **22**, pp. 105–106
5 SNYDER, A. W., and ZHENG, X. H.: 'Optical fibres of arbitrary cross sections', *J. Opt. Soc. Am. (A)*, 1986, **3**, pp. 600–609
6 HUSSEY, C. D., and MINELLY, J. D.: 'Optical fibre polishing with a motor-driven polishing wheel', *Electron. Lett.*, 1988, **24**, pp. 805–807
7 SHIGIHARA, K., SHIRAISHI, K., and KAWAKAMI, S.: 'Modal field transformer between dissimilar waveguides'. European Conference on Optical Communication, Barcelona, 1986, pp. 185–188