LOSS IN MICROSTRUCTURED FIBRE WITH A SHORT TAPER

J.T. Lizier and G.E. Town

School of Electrical & Information Engineering, University of Sydney, NSW 2006,
Australia. towng@ee.usyd.edu.au

Abstract

Losses in tapered microstructured fibres have been calculated as a function of shape and length using finite-difference time-domain calculations. Minimal losses are incurred even in non-optimally shaped tapers shorter than 100 micron. The results have important implications for splice losses and device applications.

1. INTRODUCTION

Tapered microstructured optical fibres are of interest for applications in spot size conversion [1]. It has previously been shown using finite-difference time-domain modeling that significant changes in the guided mode diameter and numerical aperture may be obtained with minimal loss in optimally-shaped tapers as short as 50µm [2]. Here we present details of loss calculations in microstructured fibres with tapered transitions of varying length and non-optimal shape. We show that even relatively short non-optimally shaped tapers may still be highly adiabatic, and hence provide low loss transitions.

2. ADIABATICITY IN TAPERED WAVEGUIDES

The adiabaticity, α, of the mode transition through the taper may be defined in terms of the local taper angle (with respect to the fibre axis), θ_t , and local diffraction angle, θ_0, [3].

$$\alpha = {}^{\theta_0}\!/\!{}_{\theta_t} \qquad (1).$$

Using the effective index approximation [4] and the Gaussian beam approximation for SIFs, the diffraction angle in regularly microstructured optical fibre may be expressed in terms of the fibre parameters as

$$\theta_0 = \frac{\lambda\sqrt{\ln V_{eff}}}{\pi\rho'} \qquad (2),$$

in which the effective core radius is $\rho'=0.64\Lambda$ [5], Λ is the spacing of a hexagonal lattice of holes in the HF cladding, and V_{eff} is the effective normalized frequency parameter, given by

$$V_{eff} = (2\pi\rho'/\lambda)\sqrt{n_{co}^2 - n_{cl}^2} \qquad (3),$$

where n_{cl} is the effective index in the HF cladding, and n_{co} the refractive index of the background material. Eq. (2) is consistent with experimental measurements of the diffraction angle from HFs for the range of parameters tested [6].

Large adiabaticity is desirable throughout the taper to minimise radiation and reflection losses from the transition. In a tapered fibre both the taper angle and diffraction angle, and hence the adiabaticity, vary with position through the transition. A figure of merit to compare the overall adiabaticity of differently shaped tapers may be defined as the integral of $1/\alpha$, or non-adiabatic integral (NAI).

We have previously derived an optimal taper shape in which the adiabaticity is constant, hence maximising the minimum adiabaticity for a given taper length [2]. By contrast, in this work we consider the performance of a non-optimally shaped taper, with radius

$$\frac{R_1 + R_2}{2} - \frac{R_1 - R_2}{2}\tanh\left(\frac{3\pi.[z - (z_1 + z_2)/2]}{2.(z_2 - z_1)}\right) \qquad (4),$$

i.e. a hyperbolic tangent taper, in which R_1 and R_2, and z_1 and z_2, refer to the radii and positions at the start and end of the taper. Whist the taper described by Eq. 4 is unlikely to be realised exactly in an experiment, it is a convenient shape to use for purposes of this study, and is likely to be closer to the taper shapes achievable in practice than the optimally shaped taper presented in [2].

Figure 1 shows the inverse adiabaticity ($1/\alpha$) for a wavelength of 1μm in a tanh-shaped down-taper 30μm long, with with $d/\Lambda = 0.79$, and Λ decreasing from 6.4μm to 0.8μm. The adiabaticity is relatively high at the start and end of the taper, but low in the mid-region, and significant transmission losses through the taper might be expected due to the low local adiabaticity.

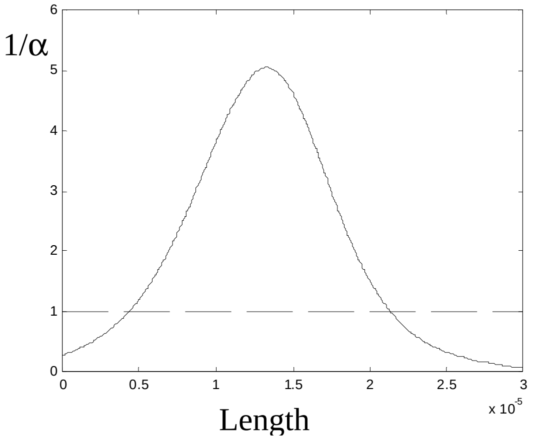

Figure 1. Inverse adiabaticity of the tanh-shaped microstructured fibre downtaper.

The transmission loss through the tanh-taper as a function of both wavelength and taper length was calculated using finite-difference time-domain calculations of the fields propagating in the microstructured fibre, using a customised and highly optimised version of published code [7]. The results include splice loss to SMF-28 type step index fibre for the fundamental mode (approximately 0.5dB). The total loss is plotted in Fig. 2, and shows that at $\lambda = 1.5$μm the minimum loss is achievable even in relatively short tapers, despite the non-optimal shape.

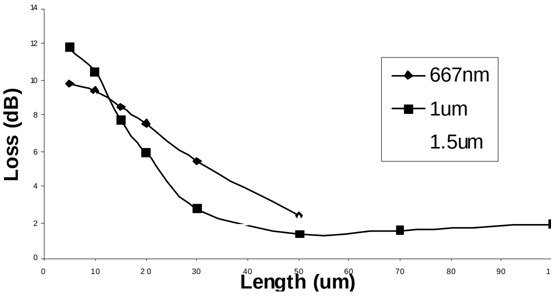

Figure 2. Loss vs length (including slice loss) in the tanh-shaped microstructured fibre downtaper.

The figure of merit for the 30μm tanh-taper shown in Fig. 1 is $NAI = 3.6 \times 10^{-5}$. From loss calculations in both optimal and tanh-shaped tapers of different lengths it was found that for minimal loss the $NAI < 1.5 \times 10^{-5}$. The NAI may be reduced by simply increasing the length of the taper, or by improving the taper shape. Whilst optimally shaped tapers only 50μm long can provide minimal transition loss at $\lambda = 1.5$μm [2], it is apparent from our results that tanh-shaped tapers perform almost as well, requiring only a 50% longer taper length to achieve a similar figure of merit. Consequently there is not a great deal to be gained by improving the taper shape, and in practice increasing the length is likely to be easier.

3 CONCLUSION

Finite difference time domain calculations of transmission losses in adiabatically tapered microstructured fibres shows that minimal loss may be achieved even in very short tapers of non-optimal shape. The latter is not surprising considering the strong guidance achievable in high-effective index contrast waveguides.

Two important implications of this result for practical applications are; i) tapering of microstructured fibres over distances comparable to their diameter may allow new applications in which the centimetre tapers commonly used are impractical, and ii) fusion splicing of microstructured fibre is likely to result in low splice losses, even when the diameters of the two fibres are significantly different, due to the natural taper and reduction in hole-size resulting from surface tension during fusion splicing.

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