Micron-size bending radii in silica-based waveguides

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"Silica bench" technology is well-developed and widely used in waveguide interferometric filters for channel multiplexing and de-multiplexing [1-4], and other WDM applications [4,5]. Waveguide cross-sections are relatively large so as to permit coupling to and from optical fibers with low insertion loss. There is also a relatively small loss penalty attributable to surface roughness. However, the density of integration of optical components, for example arrayed waveguide gratings (AWGs), is limited in this technology by the relatively large bending radii required to keep the radiation losses within acceptable bounds [3,4]. In addition, large components invite yield problems, so miniaturization is important.

A technology that allows small bending radii and large-angle waveguide T's would enable denser integration and smaller structures. We present here theoretical results and are currently preparing experimental evidence on a method that can increase the density of integration by orders of magnitude. A reduction in bending radius by a factor of 30-500, and of the complete bend structure dimension by 10-100 times, is predicted.

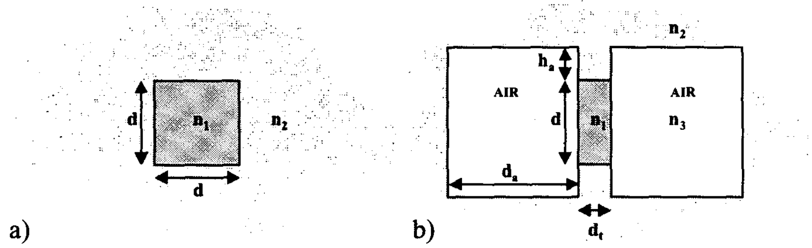

Fig. 1. Normal (a) and trench-flanked (b) waveguide cross-sections. Dimensions are d (width of low-index waveguide, and height of both), d_t (trench waveguide width), d_a (air trench region width), and h_a (extent of air trench above and below the waveguide).

The method judiciously incorporates air trenches into the structure in locations where there would otherwise be unacceptably high radiation loss (such as at sharp bends). Because of this high (local) index difference, evanescent tails extending into the cladding at the bend are greatly suppressed, and the coupling of light into radiation modes is greatly reduced. On the other hand, the use of air trenches is kept to a minimum in order to preserve the advantages of low index contrast wherever possible.

The proposed air trench solution is demonstrated in designs of a waveguide bend and T-splitter. Simulations were done using the Finite Difference Time Domain (FDTD) method, primarily in two dimensions. They show that

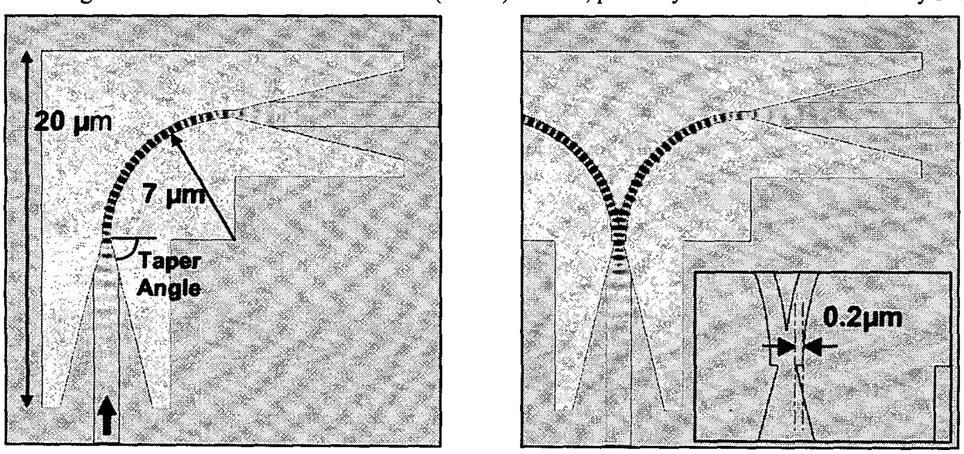

Fig. 2. Waveguide bend (left) and derived waveguide T-splitter (right). The electric field of a 50fs Gaussian pulse travelling through the bend clearly shows little radiation present in the turn. The inset on the right shows a waveguide step displacement (0.2 μm) at the input of the T-splitter.

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a waveguide bend designed to have a throughput efficiency of 98% can be reduced in size by a factor of 10-100 with the use of air trenches, with the bending radius itself reduced 30-500 times.

One set of designs is shown for illustration, where we have worked with an index contrast of 2.0:1.9 (core index:cladding index). Figure 1 shows cross-sections of a normal waveguide in the low index contrast circuit (a), and a waveguide with incorporated lateral air trenches – as found in the bend region (b). The bend "component", as shown in Figure 2, includes two air trench-flanked tapers (for mode transformation) and a high index bend region. With a bend radius of 7μm and the complete structure having an edge length of 20μm, we obtain 99% throughput efficiency with <-33dB reflection. For comparison, a regular waveguide bend with similar (98%) throughput efficiency would require a bend radius of 230μm. A T-splitter is also shown (Figure 2, right) and achieves a slightly worse throughput of 98% with <-30dB reflection. Note that a step displacement of the output waveguides is required at the input (Fig. 2, right inset) to most efficiently accommodate the incoming mode.

The input and output tapers have the function to compress and uncompress the waveguide mode between the low-index contrast waveguide and the high-index contrast bend (both of which are single mode) with minimal loss. In the above simulations, a taper angle of 76° was chosen in order to minimize device size (steep taper angle) while retaining enough length in the taper to preserve quasi-single mode behaviour (shallow taper angle). For illustration, a smaller bend radius (2μm) with a steeper taper (55°) is shown in Figure 3, along with a comparison to the transmission spectrum of the bend in Figure 2. Multimode behaviour can be seen in the field plot of this bend in Fig. 3, leading to degraded performance.

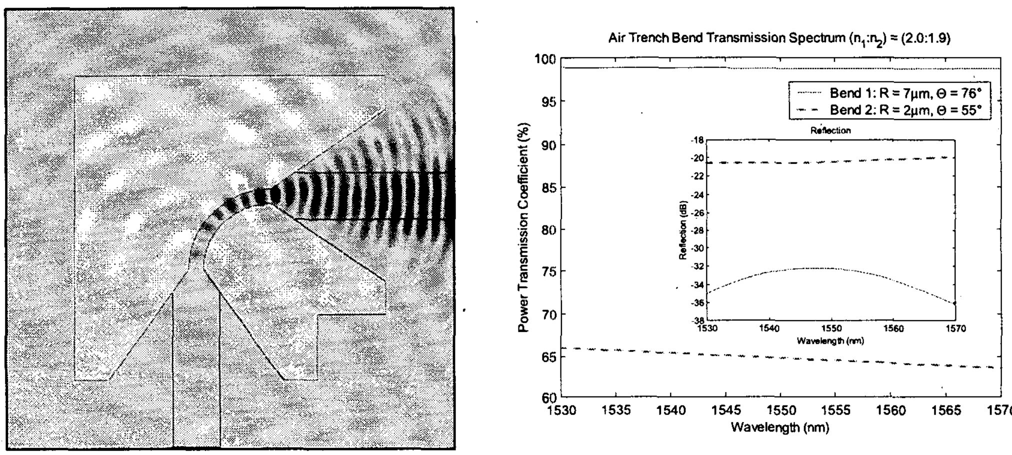

Fig. 3. Waveguide bend (left) with steep taper angle (55°) and small bend radius (2μm). Poor taper performance between the high and low index sections shows multimode behaviour at the output and hence degraded throughput efficiency. Similarly to Fig. 2, a 50fs Gaussian pulse is seen in the field plot. Transmission and reflection spectra (right) are shown for this bend and the bend in Fig. 2.

Simulations of structures similar to those in Fig. 2 in lower index contrasts (1.49:1.48) have resulted in even larger reductions of bending radius – from 6300μm for a regular bend down to 8μm with the use of an air trench. In this case the complete bend structure including tapers would have an edge length of ~130μm, a reduction by a factor of 50. The response for both structures above is virtually flat over the Erbium bandwidth of 1530-1570nm. By the time of the topical meeting we expect to have fabricated and tested some generic structures.

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