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Tapered-Rib Adiabatic-Following Fiber Coupler

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Abstract - We present the design and experimental verification of a Tapered-Rib Adiabatic-Following Fiber Coupler (TRAFFiC). This device is a monolithically integratable structure fabricated in AlGaAs designed to increase the coupling efficiency of conventional optical fibers to tightly confined semiconductor waveguide devices. This approach offers the possibility of significantly reducing fiber butt coupling losses from the typical values of 7 to 10 dB to values of 0.5 to 3 dB. This long-standing packaging problem is one of the major impediments to the widespread acceptance of semiconductor-based optoelectronics. Moreover, the design can be implemented with minimal increase in fabrication complexity since it uses only epitaxial growth, lithography and etching.

The absence of an efficient and low cost means of connecting optical fibers to semiconductor waveguide devices, e.g. diode lasers and Photonic Integrated Circuits (PICs), currently poses one of the largest barriers to wide scale commercialization of semiconductor optoelectronic devices. This problem arises because of the small size of semiconductor waveguides compared to optical fibers. The 1-2 μm elliptical modal spot of typical semiconductor waveguides is neither well-sized nor shaped to match to the standard 8 μm circular modal spot of conventional single mode optical fibers. Directly coupling light from a fiber to the small waveguide typically results in 7 to 10 dB insertion loss. Non-integrated solutions that improve this coupling, often increase coupling at the cost of tight alignment requirements ($< 1 \mu\text{m}$) and are thus prohibitively expensive.

Recently several groups have presented devices that address this problem with a variety of monolithic approaches. An excellent survey of these is provided by Ref. 1. Our designs, shown in Fig. 1, are essentially Shani-Henry couplers,² similar to that discussed in Ref. 3, but with several modifications to increase performance and process tolerance.

Many tapered mode converters of this type require very sharp taper points, and the rounding of these points increases the losses substantially. We have avoided this potential process intolerant problem in our device designs. Figs. 2 shows the effect of a finite taper width on the overlap of the conventional fiber mode with the mesa mode. Notice that coupling losses are low and constant for taper end widths less than 1.8 μm .

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The major theoretical source of loss in our designs are caused by stair-stepping brought about by pixelization in the lithographic processes. This effect is shown in Fig. 3. It is worth pointing out that the excess loss due to pixelization can be minimized in the design process and that it scales linearly with pixel size.

We have fabricated and tested devices exhibiting losses of approximately 2-3 dB (0.5 dB to mesa overlap loss + 0.8 dB excess taper loss + ~ 1.2 dB estimated material/waveguide loss). The devices currently being fabricated incorporate lower-loss waveguide designs, have improved coupling to fiber and excess pixelization taper loss. These devices have predicted fiber-to-waveguide coupling losses to 0.9 dB (0.2 dB fiber to mesa overlap loss + 0.5 excess taper loss + 0.2 dB estimated material/waveguide loss). Furthermore, for these new designs a $\pm 10\%$ variation in our most critical processing dimension brings about a variation of only ± 0.15 dB respectively.

Fig. 1 A schematic representation of the (TRAFFiC) device. (a) Top View. (b) A cross section showing the mesa mode, which is the fundamental mode of the device for rib widths $< 1.8 \mu\text{m}$ for the device discussed in Fig. 2-3. (c) A cross section showing the fundamental mode in transition from the mesa to the rib. This transition occurs at rib widths of $1.8\text{-}2.1 \mu\text{m}$. (d) A cross section showing the fundamental mode confined to the rib, widths of greater than $2.1 \mu\text{m}$.

Fig. 2 The effect of finite taper point width on fiber-to-mesa waveguide coupling. For all rib waveguide widths less than 1.8 μm the fundamental mode is confined to the mesa where it has good overlap with conventional fiber.

Fig. 3 Excess taper loss at each pixel step. The lateral tapering of the upper rib waveguide is comprised of a series of discrete steps. The size of the steps is defined by the pixel size of the lithographic mask. This figure shows the loss associated with each of the (0.025 μm) steps. The sum of these individual losses sets a lower bound on the excess taper loss.

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- [3] R.N. Thurston, Eli Kapon and Arie Shahar, *Opt. Lett.*, vol. 16, pp.306-308, 1991.

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