

Fabrication and characterization of planar waveguide couplers for multimode fiber-based local area networks

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Abstract — We report on fabrication and characterization of low-cost, compact, multimode fiber-matched 1x2 and 2x2 couplers for short-distance communications. The couplers were fabricated using polymer waveguide technology and show very promising characteristics.

I. INTRODUCTION

As broadband communication services are entering down from long-haul optical fiber links to the local area network (LAN) to meet emerging bandwidth-hungry desktop applications, the key issue network designers are facing is that of cost. While the use of multimode fiber and short-wavelength sources in such networks provides a robust, cost-effective alternative to single-mode fiber networks, there remains a conspicuous absence of affordable multimode optical components capable of advanced network functions.

In this paper, we report on design, fabrication, and characterization of novel multimode 1 x 2 and 2 x 2 integrated couplers, for the multimode fiber-based LAN. The design utilizes an extension of the self-imaging principle and waveguide tapering [1]. Self-imaging effect is used to obtain low excess losses and good output power uniformity, while the waveguide taper is employed to reduce the device length. The design has a promising potential for multimode couplers with high port count, i.e., 1 x N and N x N couplers with N > 2 [1]. Earlier simulation results, using three-dimensional beam propagation method (3D-BPM) [2], have shown that such devices exhibit low excess losses, low power imbalance, and relaxed fabrication and excitation tolerances [1]. Relaxed excitation tolerance indicates that the design is less sensitive to modal noise, which is a critical problem in the widely used multimode Y-junction-based power splitters, especially when light is coupled from a source directly into the device. The couplers have been fabricated in polymer waveguide technology using conventional photolithographic and etching processes and inexpensive commercially available polymers. The devices have been characterized and the results are presented and briefly discussed.

2. DESIGN AND SIMULATIONS

In earlier works we have analyzed the performance of tapered multimode interference (MMI) couplers that are multimodal both in the vertical as well as the horizontal directions [1]. We have used a modified modal propagation analysis, which has shown that the design rules for these highly multimodal couplers are similar to the ones that are single mode in the transverse direction [1,3]. The length of a 1 x N coupler is given by

$$L_{\text{MMI}} = 4Mn_c w_0^2 / 4N\lambda\chi, \quad (1)$$

where M and N are integers having no common divisor with N being the number of the access ports, n_c is the refractive index of the core layer, w_0 is the width of the coupler section, and χ is a geometric factor depending on the initial width w_0 of the coupler section and the minimum width w_1 in the middle of the MMI section [3]. Using relation (1) we have designed a number of 1 x 2 and 2 x 2 power splitters. The dimensions of the couplers' access waveguides were designed to be 40 x 40 μm^2 and the refractive index contrast was 0.02. The refractive index contrast and channel waveguide dimensions are chosen in practice to satisfy the simultaneous requirements of minimizing coupling losses with standard multimode fiber while utilizing the refractive index values of cheap, widely available polymeric materials. The coupler part of each device has been tapered down from start width of $w_1 = 100 \mu\text{m}$ to different minimum widths of the taper, in order to obtain various device lengths as shown in Table I. Results from 3-D BPM simulations, presented

MMI coupler type	Start/ min. taper width [μm]	MMI length [μm]	Excess loss [dB]	Imbalance [dB]
1 x 2	100/100	8883	0.03	0.015
	100/71	5684	0.04	0.02
	100/43	2842	0.15	0.05
2 x 2	100/43	9810	< 0.01	0.35

Table 1. Performance characteristics of various parabolically-tapered multimode MMI couplers, simulated using 3D BPM software [1].

in Table I, show that very low excess losses and power imbalance have been obtained for very short devices.

3. FABRICATION

The couplers were fabricated in polymer waveguide technology. The waveguide structure comprises a UV curable resin called UV15 [4] as a core layer and PMMA as an upper and a lower cladding. At the design wavelength, being $\lambda = 850$ nm, UV15 and PMMA have refractive indices of 1.51 and 1.488, respectively. The layers were deposited using spin coating and the channel structures were defined using reactive ion etching (RIE) [5].

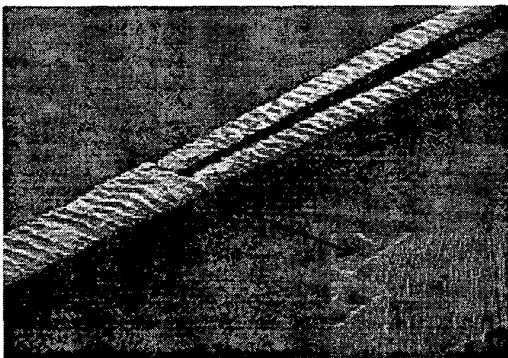


Figure 1: SEM electron micrograph of a 1 x 2 tapered coupler. A close up showing the side-wall roughness is shown in the inset.

Fig. 1 shows an electron scanning microscope micrograph of the output part of a 1 x 2 tapered coupler. The etching process has resulted in channel waveguides with well-defined widths and steep side-walls. However, a close up picture of the side-wall, presented in the inset of the figure, shows that the side-walls are rough. This side-walls roughness leads to optical losses of ~ 3 dB/cm at $\lambda = 850$ nm. By applying side-wall smoothing process which includes heating and dipping the fabricated structure in a diluted PMMA solution, the optical losses were reduced to < 1 dB/cm.

4. OPTICAL CHARACTERIZATION

In the loss measurement setup a 50/125 μm graded multimode fiber was used to couple light into and out of the devices. An index matching gel was placed between the waveguide and the multimode fiber to reduce the coupling losses. In Fig. 2 a histogram that shows the power imbalances of the various 1 x 2 and 2 x 2 multimode couplers is presented. The devices have shown low power imbalance, only slightly higher than

the simulations results. Note that the imbalance depends on the excitation conditions; the values presented here are taken for optimum fiber-to-chip coupling. Excess losses of ~ 1.5 dB were measured for couplers. No notable variations in the excess losses between different couplers were observed, indicating that taper induced radiation losses are insignificant.

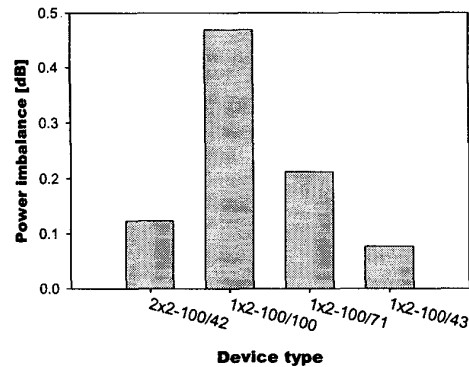


Figure 2: Histogram of the imbalance of different couplers. As a parameter the device type and the start and minimum widths of the tapers are shown.

5. CONCLUSIONS

Compact, multimode fiber-matched, 1 x 2 and 2 x 2 integrated couplers have been fabricated using low-cost polymer waveguide technology. Characterization results have shown that the devices have very interesting properties for LAN applications.

ACKNOWLEDGEMENT

We would like to thank Sulus for his input in the waveguide fabrication.

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