

# Micro-Device for Coupling, Multiplexing and Demultiplexing Using Elliptical-Core Two-Mode Fiber

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**ABSTRACT:** In this paper we propose and demonstrate experimentally a fiber optic micro-device that is capable of tunably splitting, multiplexing and demultiplexing optical signals using elliptical-core two-mode optical fiber. A crosstalk of 15 dB with an insertion loss of 1.2 dB has been obtained.

## 1. INTRODUCTION

Passive fiber components such as couplers, multiplexers and demultiplexers are essential elements in fiber optic telecommunication and sensing technology. Various kinds of devices have been developed for these applications over the past twenty years. The fused biconical tapered fiber coupler (Hill et al 1985) and the polished fiber coupler (Lefevre et al 1988) are the couplers most frequently used today. The former has excess loss as little as 0.1 dB and the latter has been shown particularly suitable for polarization preserved applications. There are also two major classes of wavelength division multiplexer (WDM) and demultiplexers. The first is constructed based on the operation of the fused biconical taper fiber coupler. Since the coupling ratio of this kind of coupler is strongly dependent on the operating wavelength (Marcuse 1972), it can be used as WDM for the wavelength difference between two operating wavelengths is large (Winzer et al 1981). Another class of WDM is designed based on a fiber optic micro-device which uses dispersive components such as gratings or interference filters to separate the operating wavelengths (Allard 1990). Recently, based on elliptical-core (e-core) two-mode fibers, an intermodal coupler, modal filter, acoustic-optic frequency shifter, and fiber sensor have been demonstrated by Kim et al (1987), Kim et al (1986) and Huang et al (1990). In this paper we propose and demonstrate experimentally a fiber optic micro-device using the e-core two-mode fiber to multiplex and demultiplex two optical signals. The objective of this paper is first to show the principle of operation of this new fiber optic micro-device and then to describe the experiments that verify the concept.

## 2. PRINCIPLE OF OPERATION

Figure 1 illustrates the schematic of the two-mode fiber micro-device. Since the e-core fiber is operated in its two-mode regime, only the  $LP_{01}$  and  $LP_{11}^{\text{even}}$  modes are excited. For an e-core fiber the electric field of the  $LP_{lm}$  mode can be written as

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$$E(LP_{lm})=E_{lm}(x, y) \exp(j\beta_{lm} z), \quad (1)$$

where  $\beta_{lm}$  is the propagation constant of the mode and  $E_{lm}(x, y)$  gives a description of the transverse electric field amplitude. The differential phase delay  $\Delta\Phi$  between the  $LP_{01}$  and  $LP_{11}^{even}$  modes is given by

$$\Delta\phi = \Delta\beta L, \quad (2)$$

where  $\Delta\beta$  is the difference in the propagation constants of the two modes and  $L$  is the length of the fiber.

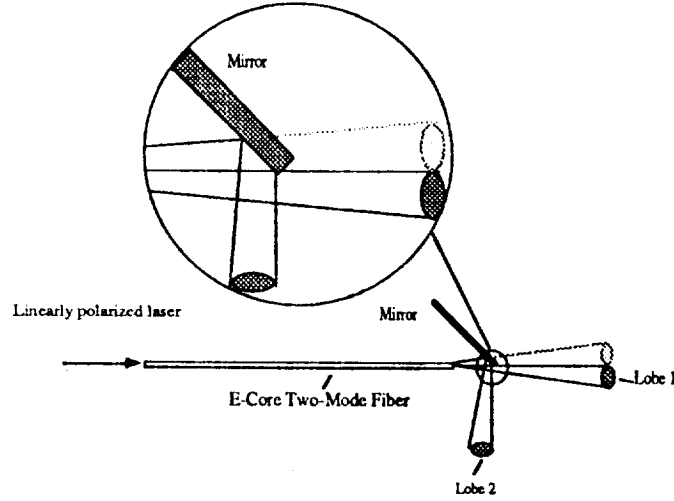


Figure 1. Schematic of an elliptical-core two-mode fiber micro-device.

The interference between the  $LP_{01}$  and  $LP_{11}^{even}$  mode field gives a two-lobe spatial intensity pattern at the fiber endface, and hence at the far-field from the end of the fiber, as shown in Figure 2. It is noted that a  $\pi/2$  phase shift, known as the Gouy phase shift, between the patterns at the fiber endface and in far field (Huang et al 1989), has been taken into account. The shape of the spatial intensity pattern is determined solely by the differential phase delay  $\Delta\phi$ . In Figure 2, it is recognized that the left lobe is at its brightest and the right lobe is at its dimmest provided that  $\Delta\phi$  is  $\pi/2$ . When  $\Delta\phi$  is  $\pi$ , the brightest lobe on the left becomes the dimmest and the dimmest on the right changes to the brightest. Therefore, by controlling the differential phase delay  $\Delta\phi$  between the  $LP_{01}$  and  $LP_{11}^{even}$  modes, the optical power in the e-core two-mode fiber can be divided into two channels.

One way to change  $\Delta\phi$ , as suggested by Equation (2), is to alter the length of the fiber  $L$ . A variation in the fiber length causes an oscillation of the intensity between the two lobes at the output. If a detector with a spatial filter, such as a pin-hole detector, is used to pick up a fraction of the power in only one lobe, the output of this detector is a sine function of the change in the fiber length. This modulation effect has been used in the past for strain measurement (Huang et al 1990 and Murphy et al 1990). In the process of fabricating the Y coupler as shown in Figure 1, we also

and Murphy et al 1990). In the process of fabricating the Y coupler as shown in Figure 1, we also applied axial strain on the fiber to observe the toggling of the two-lobe spatial intensity.

It is further recognized that the two-lobe spatial intensity distribution can be changed by controlling

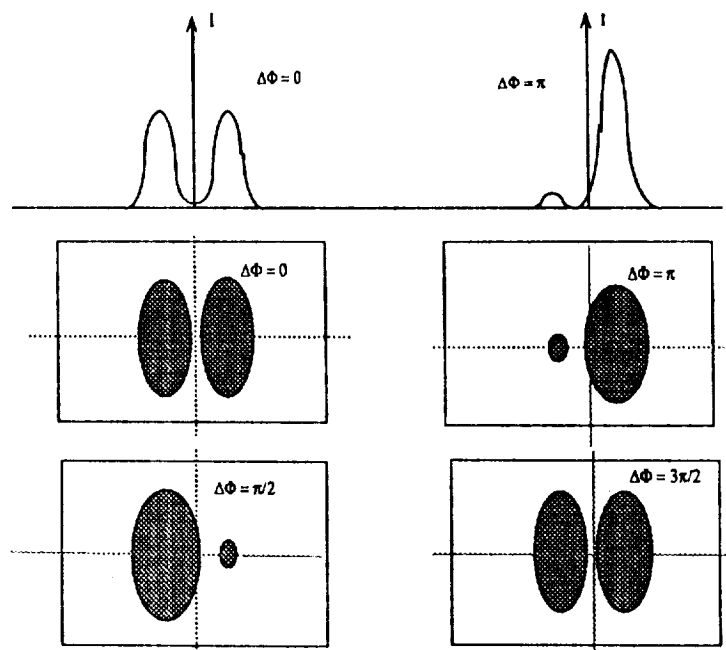


Figure 2. View of the two-lobe intensity distribution.

the wavelength. Because  $\Delta\beta$  in Equation (2) is a function of the operating wavelength [8], a continuous change of the wavelength of light launched into the fiber would also toggle the optical power between the two lobes. This phenomenon was used in the past for demodulation in e-core two-mode fiber sensing applications by Wang et al 1991. We simultaneously launch two laser beams of different wavelengths  $\lambda_1$  and  $\lambda_2$  into the e-core two-mode fiber. These two wavelengths are properly chosen in such a way that  $\lambda_1$  corresponds to a maximum intensity in lobe 1 and  $\lambda_2$  corresponds to a maximum intensity in lobe 2, as indicated in Figure 1. Therefore, two optical signals, carried by  $\lambda_1$  and  $\lambda_2$ , respectively, are separated into two channels. It is realized that the selection of  $\lambda_1$  and  $\lambda_2$  is not unique since the intensity of either of these two lobes is a periodic function of the operation wavelength.

### 3. EXPERIMENTS

To observe the two-lobe behavior, we launched a linearly polarized light of wavelength 633 nm into the e-core fiber ( $1.25 \times 2.5 \mu\text{m}$  core), manufactured by Andrew Corporation, which operated in its two mode regime. It is customary to align the polarization orientation of the light with the major axis of the elliptical core to obtain a clear spatial intensity pattern. A thin aluminum front surface mirror was used to separate the two lobes as illustrated in Figure 1. For the convenience of investigation, the optical power of each individual lobe was collected by two photodetectors. Figure 3 shows the output of the two photodetectors, represented by channel 1 and channel 2 on

the oscilloscope, when we gradually applied an axial strain on the e-core fiber. From Figure 3, it is

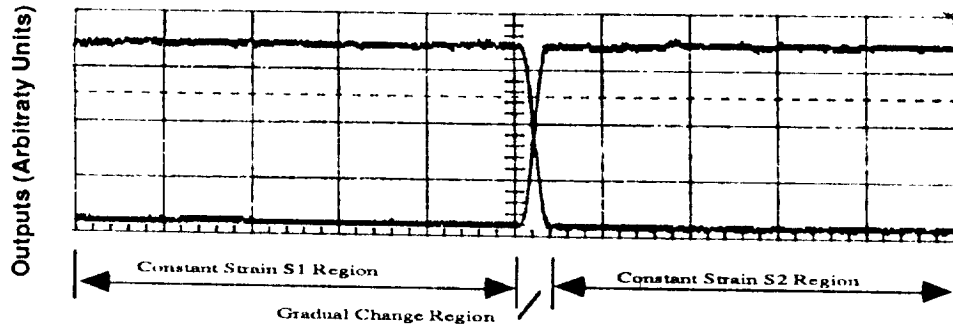


Figure 3. Oscilloscope trace of the two channel outputs.

Figure 3 shows the output of the two photodetectors, represented by channel 1 and channel 2 on the oscilloscope, when we gradually applied an axial strain on the e-core fiber. From Figure 3, it is noted that the device shown in Figure 1 can be used as a splitter with a tunable splitting ratio.

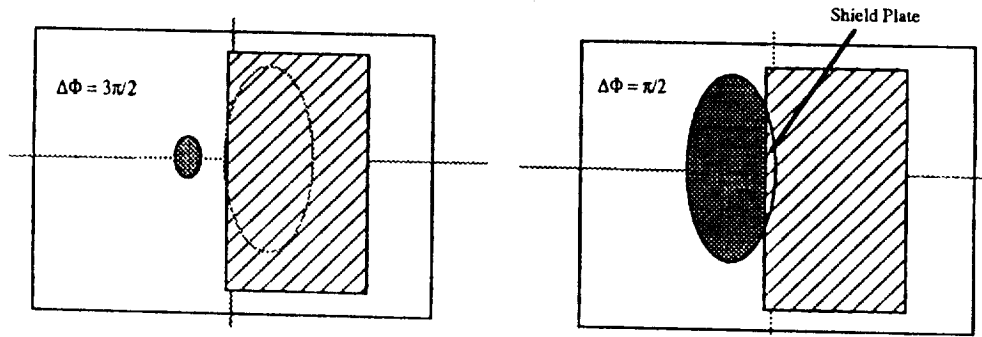


Figure 4. View of the aperture positions.

To obtain experimentally the relation between the cross talk and insertion loss of this WDM device, we used an opaque plate with a sharp edge to block a part of optical power from reaching the photodetector as shown in Figure 4, and we subsequently changed the position of the plate. For each position of the plate, maximum ( $I_{max}$ ) and minimum ( $I_{min}$ ) intensity values could be found by axially stretching the fiber. The total input power was measured by cutting this e-core two-mode fiber. The insertion loss, given by  $-10 \log (I_{max}/I_{total})$ , was derived from this experimental data. Having these experimental results, we plotted the relation between the cross talk and insertion loss as presented in Figure 5.

The dependence of the two-lobe spatial intensity pattern on operating wavelength was investigated by first launching an Argon laser beam into the e-core two-mode fiber. The wavelength was tuned within a certain range (590 nm to 650 nm) and the results are shown in Figure 6. This experimental data plot demonstrates the wavelength dependence of the two-lobe spatial intensity distribution. Since the Argon laser could produce only discrete wavelengths, we could not determine the exact maximum or minimum power of a lobe. To explore this effect further, a semiconductor laser with a central wavelength of 816 nm, manufactured by GALA, was employed. Since the wavelength of a semiconductor laser is dependent on its current in general, it could be controlled within a certain range by adjusting the current knob. Unlike the Argon laser, this semiconductor laser could generate a continuous change of wavelength. The experimental result is presented in Figure 7. The

significant changes of the laser wavelength.

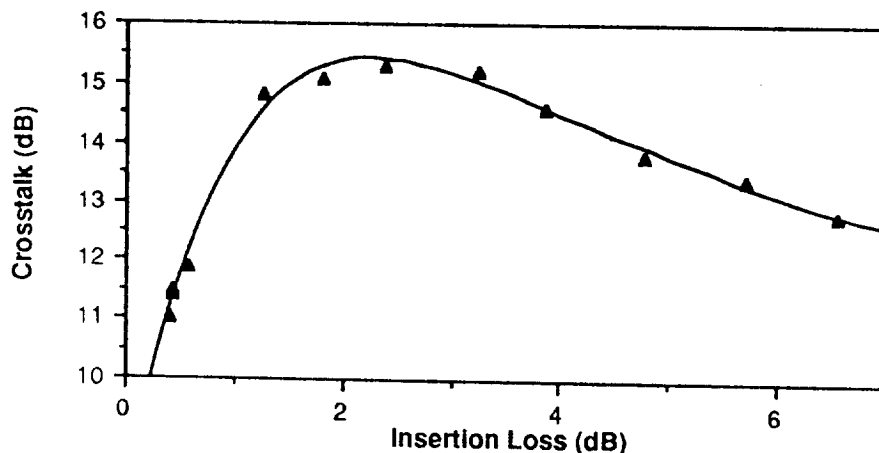


Figure 5. Crosstalk as a function of the insertion loss. The triangle dots are the experimental data. The solid line is the calculation results based on the theoretical model given in another our paper, entitled "Analyses of Near- and Far-Field Two-Lobe Patterns Outside the Output Endface of a Two-Mode Fiber", published in this proceeding.

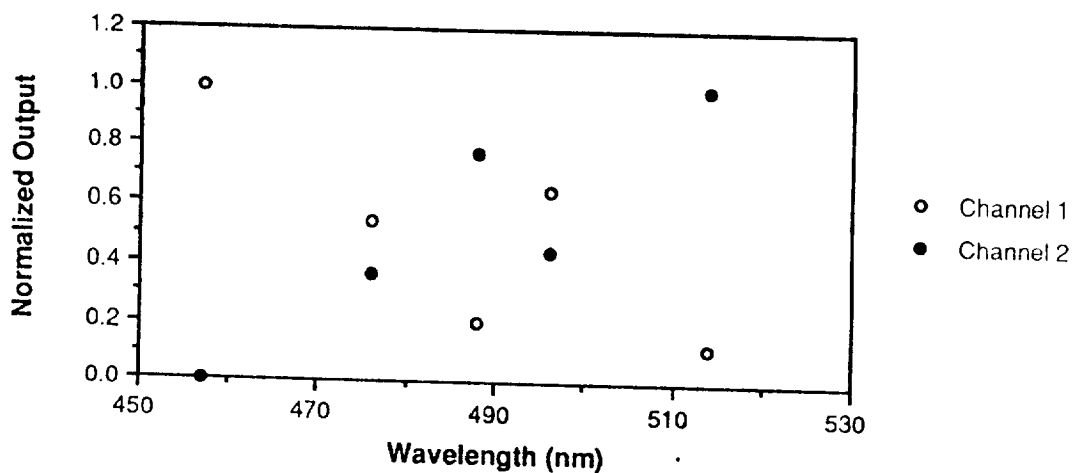


Figure 6. Outputs of the two channels as functions of the operating wavelength.

To demonstrate the feasibility of the device in practical fiber systems, the output from the e-core two-mode fiber was collimated by a quarter pitch GRIN lens and the former two photodetectors were replaced by two single mode fibers with quarter pitch GRIN lenses attached. An insertion loss of 1.2 dB with a crosstalk of 15 dB has been obtained using a HeNe laser source. The insertion loss of this configuration could be reduced further by applying anti-reflection coatings on those GRIN lenses.

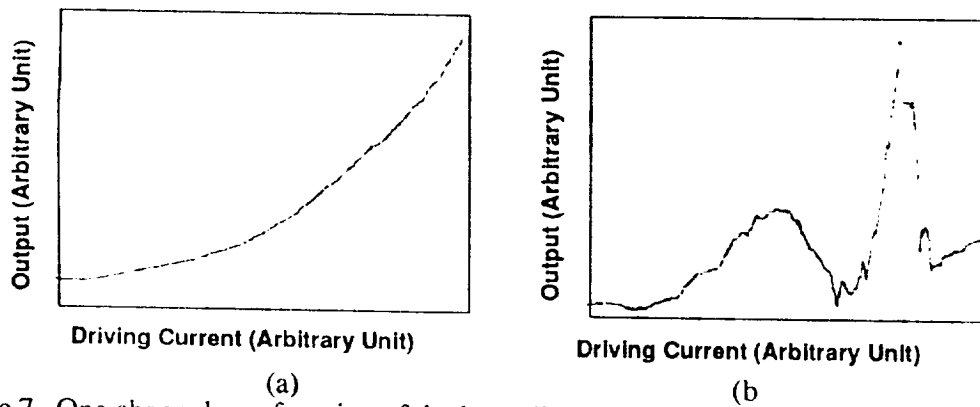


Figure 7. One channel as a function of the laser diode current. a) The output of the laser as a function of the laser current. b) The output of the lobe intensity on the laser current.

## CONCLUSIONS

A micro-device based on the two-lobe pattern obtained at the output of elliptical-core two-mode fiber has been described. It has been demonstrated that this fiber device can be used as a fiber splitter, a wavelength multiplexer and a demultiplexer. Crosstalk of 15 dB has been achieved with an insertion loss of 1.2 dB. It is our hope that further research on this fiber device would lead us to develop low loss and highly accurate practical fiber optic components.

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