Fused collinear 3x3 fiber coupler

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Abstract: We present a theoretical analysis of a fused collinear 3x3 fiber coupler. It has been fabricated with low excess loss, large bandwidth, a high degree of stability and polarization insensitivity.

Key words: couple mode, fiber couplers

Introduction

There are two kinds of 3x3 fiber coupler: nonplanar 3x3 fiber coupler that is mostly fabricated in an equilateral triangular form and collinear (planar) 3x3 fiber coupler where the cores of the three fibers inside it lie in the same plane. It is easy to fabricate a nonplanar 3x3 fiber coupler [4]. However, collinear 3x3 fiber coupler is difficult to realize because all the three fibers in it must be kept completely parallel and weakly coupled during the fabrication. We haven't found any products of this kind coupler.

In recent years, collinear (planar) 3x3 fiber coupler has attracted increasing attention [5-6]. This is mainly due to its potential device applications as interferometer, switch, resonator and buffer.

In this paper, we present a theoretical analysis of a fused collinear 3x3 fiber coupler. We prove that we can use a collinear 3x3 fiber coupler as a good interferometer when coupling strength θz equals to $\pi/2$ or $3\pi/2$.

We fabricated this kind of collinear 3x3 fiber coupler that agreed well with theoretical analysis and performance of this kind of coupler showed that it has the characteristic of low excess loss, large bandwidth, a high degree of stability and polarization insensitivity.

Theoretical analysis

Assume that the collinear 3x3 fiber coupler has a symmetrical structure and

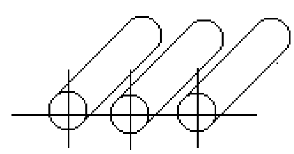


Fig.1. Collinear 3x3 fiber coupler

all three fibers in it are identical (see Fig. 1). Using the coupled-mode theory for weakly guiding fibers [1-3], its coupling equation can be expressed as

$$\frac{\mathrm{d}}{\mathrm{dz}}\begin{bmatrix}\mathbf{E}_1\\\mathbf{E}_2\\\mathbf{E}_3\end{bmatrix}(z)=\begin{bmatrix}\mathrm{j}\beta & \mathrm{j}k_1 & \mathrm{jk}_2\\ \mathrm{j}k_1 & \mathrm{j}\beta & \mathrm{j}k_1\\ \mathrm{jk}_2 & \mathrm{j}k_1 & \mathrm{j}\beta\end{bmatrix}\begin{bmatrix}\mathbf{E}_1\\\mathbf{E}_2\\\mathbf{E}_3\end{bmatrix} \quad (1)$$

where k_1 is the coupling coefficient between two adjacent fibers F1, F2 (or F2, F3), k_2 is the coupling coefficient between F1 and F3, $\mathbf{E}_i$ is the optical

*A.M.Liu is being attached to Institute for InfoComm Research as a exchange student field of a fiber Fi (i=1,2,3) and β is the transmission coefficient of a fiber.

In a collinear 3x3 fiber coupler, coupling between F1 and F3 is so weak that we can neglect it, that is to say, $k_2 \approx 0$. Equation (2) can be solved and we can get the relationship between the optical field in the three-input and three-output ports of a 3x3 fiber coupler through a transfer matrix T.

$$\begin{bmatrix} \mathbf{E}_1 \\ \mathbf{E}_2 \\ \mathbf{E}_3 \end{bmatrix}(z) = \mathbf{T}\begin{bmatrix} \mathbf{E}_1 \\ \mathbf{E}_2 \\ \mathbf{E}_3 \end{bmatrix}(0) \qquad (3)$$

Where

$$\mathbf{T} = e^{i\beta z}\begin{bmatrix} \frac{1}{2}(1+\cos\theta z) & i\frac{\sqrt{2}}{2}\sin\theta z & \frac{1}{2}(\cos\theta z - 1) \\ i\frac{\sqrt{2}}{2}\sin\theta z & \cos\theta z & i\frac{\sqrt{2}}{2}\sin\theta z \\ \frac{1}{2}(\cos\theta z - 1) & i\frac{\sqrt{2}}{2}\sin\theta z & \frac{1}{2}(1+\cos\theta z) \end{bmatrix} \qquad (4)$$

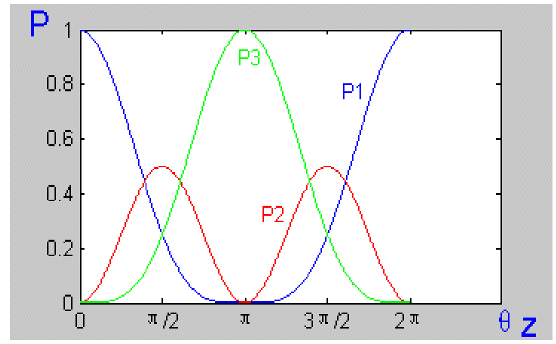
$$\theta = \sqrt{2}k_1 \qquad (5)$$

In this paper, we are dealing only with the case of a single input. For a collinear 3x3 fiber coupler shown in Fig. 1, if complex amplitude of an optical field, launched at the input port i, is

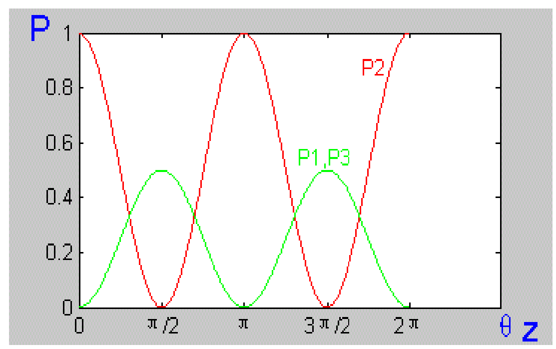
$$\mathbf{E}_i(0) = 1 \,(\text{Normalized}) \qquad (6)$$

We can compute output intensities as functions of coupling strength θz ($0 \leqslant \theta z \leqslant 2\pi$) and present them in Fig.2 for different input ports.

In Fig.2 we notice that the power launched into fiber F2 are divided by fibers F1 and F3 at the output end equally without output in fiber F2. If the power is launched into F1 (or F3), half of total power is coupled to F2 and the rest is shared by fibers F1 and F3 equally when coupling strength θz equals to $\pi/2$ or $3\pi/2$. This is a distinguishing characteristic of this kind of coupler and



(a)



(b)

Fig. 2. Curves of output intensities versus the coupling strength θz (Fig.2 (a) F1 or F3 as input and Fig.2 (b) F2 as input. Pi (i=1,2,3) denote output intensities of fiber Fi)

hence it has potential as a good interferometer because of its symmetrical structure. We are trying to use this feature in the following fabrication.

Fabrication

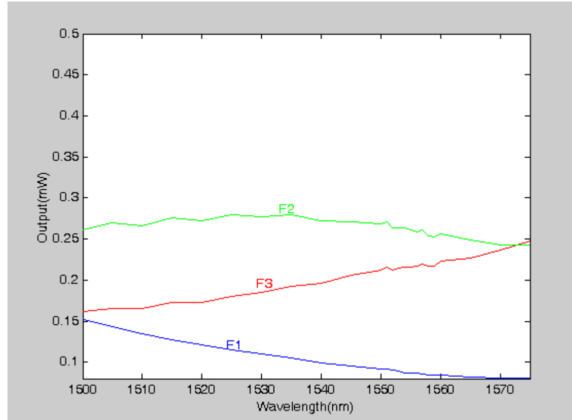
The fibers we used for fabrication are Corning G.652 single-mode fiber. The machine, which we used to fabricate the coupler, is designed for fusing 2x2 fiber coupler. To produce an ideal collinear 3x3 fiber coupler, three more conditions must be satisfied during the whole fusing and drawing process.

- To keep the three fibers strictly in the same plane
- To have no coupling between fibers F1 and F3.
- To have weak coupling between adjacent fibers

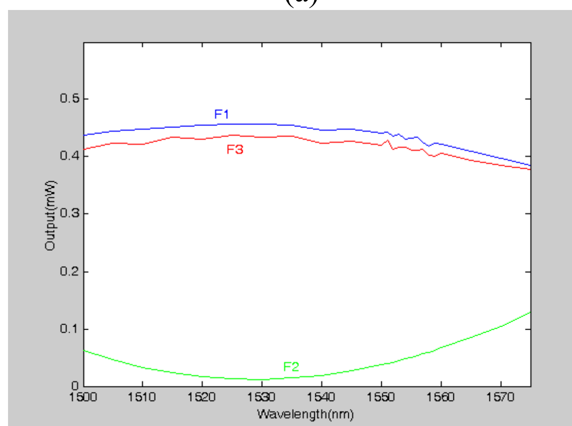
It is critical in fabricating a 3x3 collinear fiber coupler to keep three fibers in the same plane during the fusing and drawing process. In order to avoid any asymmetry or coupling between F1 and F3, we tried to keep the three fibers parallel and fixed them with a special glue. A predetermined length of jacket was striped from the three fibers first. The jacket-removed, cleaned fibers were then placed into a special clamp that could hold three fibers to ensure that they are kept in the same plane. A moving microflame, controlled by a motor, walked through the heating area back and forth to avoid temperature gradients in the fiber fusion region. Proper control of the temperature and moving speed of flame, and drawing speed, was necessary to keep weak coupling between adjacent fibers and low extra loss of the coupler. We launched a light into F2 to monitor the whole fabrication process. The fusion and drawing process was stopped when we watch that the output of F2 reached an ultra low value while output from F1 was about 3db lower than input power. The result agreed with theoretical analysis very well.

Result

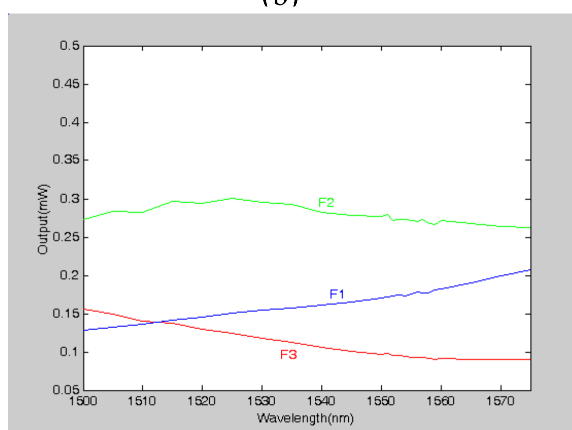
We measured output characteristics of a fused 3x3 collinear fiber coupler at different wavelengths using a tunable laser source and a detector. The input levels at different wavelengths were all 1mw. Fig. 3 shows the output of the three fibers in 3x3 collinear fiber coupler



(a)



(b)



(c)

Fig. 3 The output of three fibers in 3x3 collinear fiber coupler (Fig. 3 (a), (b) and(c) is for F1, F2 and F3 as inputs respectively)

(Fig. 3(a), (b) and (c) is for F1, F2 and F3 as inputs respectively). We can see from Fig.4 that:

The extra loss of the coupler is fairly low due to weak coupling. (Typically 0.2~0.4dB);

When the power is launched into F2, the output of F2 was ultra low (there is small leakage mainly due to weak coupling between F1 and F3); the majority of output power was shared equally by F1 and F3. There is a little difference between them mainly due to fact that the three fibers in the coupler are not identical.

When the power is launched into F1 (or F3), almost half of the power comes out from F2 and the rest from F1 and F3.

When the power is launched into F2, the output will be almost the same over a wide wavelength range (<0.5dB for 50nm).

We also tested the dependence of output on temperature variation and different

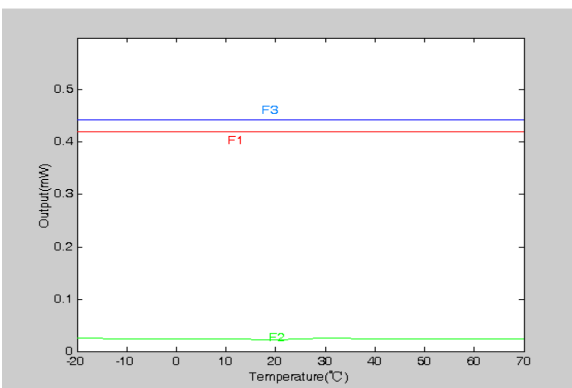


Fig. 4 dependence of output on temperature

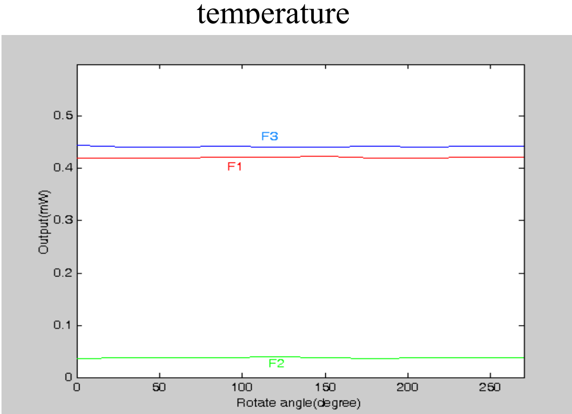


Fig. 5 dependence of output on different input polarization angles

input polarization on fiber F2 input at 1550nm wavelength. The results in Fig.4 and Fig.5 show that the fused 3x3 collinear fiber coupler has a high degree stability of temperature and polarization insensitivity.

We can see that collinear coupler not only has the strongpoints of a common 2x2 or 3x3 fiber coupler but also has distinguishing characteristics that can lead to potential device applications.

Conclusion

A theoretical analysis of a fused collinear 3x3 fiber coupler has been presented. Collinear 3x3 fiber coupler was fabricated by us which agreed quite well with the theoretical analysis. The performance of this kind of coupler showed that it has low excess loss, large bandwidth, a high degree stability of temperature and polarization insensitivity.

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