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An Efficient MMI SOI Splitter with Multimode Input/Output Waveguides

Fang Qing, He Yuejiao, Xin Hongli, Li Fang, and Liu Yuliang

(Institute of Semiconductors, Chinese Academy of Sciences, Beijing 100083, China)

Abstract: A 1 ×8 multimode interference power splitter with multimode input/output waveguides in SOI material is designed by the beam propagation method and fabricated by the inductive coupled plasma etching technology for use in fiber optics communication systems. The fabricated device exhibits low loss and good coupling uniformity. The excess loss is lower than 0.8dB, and the uniformity is 0.45dB at the wavelength of 1550nm. Moreover, the polarization dependent loss is lower than 0.7dB at 1550nm. The device size is only 2mm ×10mm.

Key words: multimode interference; power splitter; SOI; multimode input/output waveguides
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1 Introduction

In the optical communication systems, problem-solving greatly depends on processes having high flexibility and compatibility with current demands in the subscriber loop. In terms of a component viewpoint, the subscriber loop requires massive power splitting for distribution purposes. Multimode interference (MMI) couplers, based on the self-imaging effect[1], are rapidly gaining popularity. Such couplers termed MMI have already been applied as power splitters[2~5], optical switches[6], attenuators[7], and optical receivers[8] in the optical communication systems, due to their excellent properties and ease of fabrication. MMI power splitters have been widely researched using those materials such as SiO_2[9], SiO_2/Al_2O_3[5], InP/InGaAsP[10], and GaAs/AlGaAs[11]. SOI material has excellent electrical and optical properties, and SOI technology shows great potential for monolithic complementary metal-oxide semiconductor (CMOS) devices, so the SOI device is also very important. The reports of power splitters based on SOI are few. Reference[3] is about SOI material, it is only a 3dB splitter and some performances are not reported such as the polarization dependent loss. Compared to concatenations of single-mode couples or Y-junction splitters, MMI power splitters are attractive alternatives because of their compactness, low excess loss, wide band-width, and acceptable manufacturing tolerances. In the previous researches, a single-mode waveguide is always used as the input waveguide of MMI, but in our design the multimode input/output waveguides are used. Moreover, it is easy to measure and fabricate the device by employing the multimode wide waveguides. In this paper, we report the structural design of a 1 ×8 power splitter based on the self-imaging principle in the material of SOI at 1.55μm wavelength, and optimize the input/output waveguides for the best performances. At last, we fabricate and test our designing device.

2 Design and analysis

In this section, we will describe the design of a 1

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×8 multimode interference power splitter. In Fig. 1 the geometry of the splitter is shown. Figure 1 also defines the characteristic parameters for the power splitter. W_i and W_o are the widths of input and out-

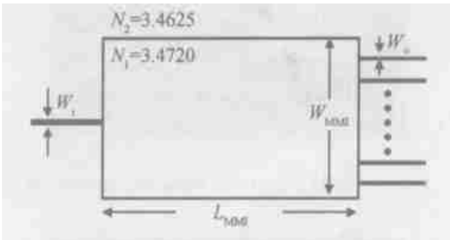

Fig. 1　Characteristics of designed 1 ×8 MMI power

put ridge waveguides, respectively. W_{MMI} and L_{MMI} are the width and length of the multimode waveguide section, respectively. The center-to-center distance between the waveguides at the output port is 250μm for fiber connections taking into account the typical cladding thickness of optical fibers of 125μm. In this design the total ridge height is 4.6μm, and the slab height is 2.4μm. So the ridge (effective) refractive index N_1 is 3.4720, the cladding (effective) refractive index N_2 is 3.4625. The length of MMI, L_{MMI}, is calculated by the symmetric interference self-imaging mechanisms as follows[12].

$$L_{MMI} = \frac{N_1}{N\lambda_0}\left(W_{MMI} + \left(\frac{N_2}{N_1}\right)^{2\sigma} \times \frac{\lambda_0}{\pi(N_1^2 - N_2^2)^{1/2}}\right)^2 \quad (1)$$

where λ_0 is the free-space wavelength, 1.55μm, $\sigma = 0$ for TE and $\sigma = 1$ for TM, the output number of the splitter, N, equals to 8. For the single-mode input and output waveguides, $W_i = W_o \leq 3$μm. The output tapers are used for diminishing the loss; start and end widths equal to 8μm and W_o, respectively. The length of output taper is 800μm. The S-bends radius must enough big for small bend loss in the output port. The BPM simulation indicates that when the bend radius is bigger than 10mm the bend loss will be less than 0.1dB. In the experiment the minimal radius must be 15mm, considering the experimental technology accuracy. We used the finite difference beam propagation method (BPM) to calculate the field evolution through the structure. Through the simulation it was found the center-to-center distance ($W_{MMI}/8$) of ≥ 15μm between neighboring taper is needed to avoid significant coupling. In our case, W_{MMI} is 120μm, and L_{MMI} = 4172μm. The device size is 2mm ×10mm.

In the previous researches, a single-mode waveguide is always used as the input waveguide of MMI based on the self-imaging effect. A single-mode input waveguide certainly ensures a good property for MMI section. But appropriate increase of the input/ output waveguides' widths can enhance the performance of the whole device, because a narrow diffraction pattern is formed for a wide input waveguide at the end of self-imaging[13]. The optical power entering the taper waveguides is more when a narrow diffraction pattern exists. The loss is smaller. The results by BPM simulation are shown in Fig. 2. These results demonstrate that the appropriate increasing width of input/ output waveguides can obviously reduce the loss and uniformity. When the input/ output waveguides all equal to 7μm the loss and the uniformity are minimal, 9.24dB and 0.15dB, respectively; the polarization dependent loss is lower than 0.2dB at 1.55μm. Figure 3 is the results of the loss and uniformity versus wavelength. The loss, the uniformity, and the polarization dependent loss are all small at the wavelength of 1.54μm and 1.56μm.

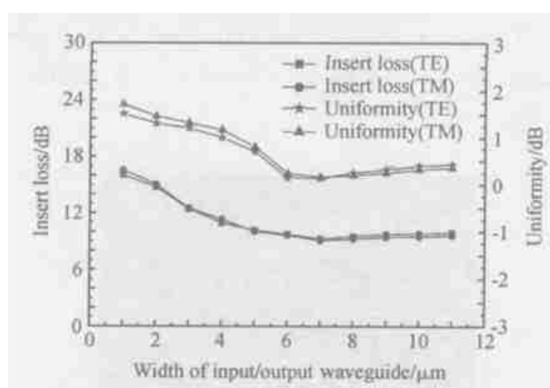

Fig. 2　Loss and uniformity versus width of input/ output waveguides

3　Fabrication

A 1μm-thick buried SiO_2 layer is thick enough to

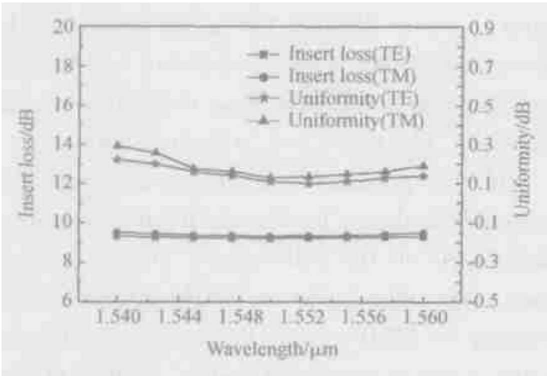

Fig. 3 Loss and uniformity versus wavelength

prevent the optical field from leaking into the substrate. During the experiment, we applied a 0.4μm-thick SiO_2 cover layer thermally grown on the top of silicon in order to avoid etching the top of rib waveguides. A 4.8μm-thick silicon on insulator (SOI) wafer is etched 2.2μm to form a rib waveguide by the inductive coupled plasma (ICP) etching technology. In order to reduce the roughness of lateral faces of all the waveguides, a 0.4μm-thick SiO_2 cover layer is grown thermally after ICP etching process, again. The SiO_2 cover layer can not only prevent the optical signal from being affected by other signals but also protect the rib waveguides from being destroyed. In Fig. 4, the scanning electron micrograph demonstrates an excellent uniform inscription of output waveguides with smooth fraction. The same features are observed in the cross-section view of an input rib waveguide shown in Fig. 5.

Fig. 4 SEM picture of 1 ×8 MMI splitter

4 Results and discussion

Figure 6 is the field image of the device output

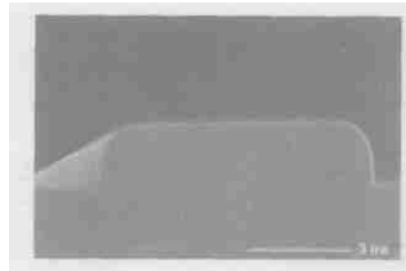

Fig. 5 SEM picture of input rib waveguide

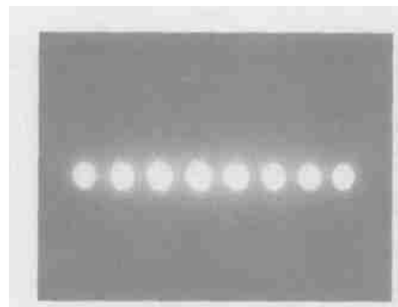

Fig. 6 Field image of the output facets

facets. It shows that 8 channels' powers are very equilibrium. In order to measure the performances of the splitter quantificationally, we must take out the measure about the interfered factors, such as the coupling loss between the optical fiber and the device. During our measurement, we use the cone-type lens optical fiber for reducing the loss. The coupling loss is obtained from the 7μm-width straight waveguides. We measure the total loss of two different length straight waveguides (2cm length and 1cm length), shown in Fig. 7. It indicates that except for the coupling loss the others loss is about 0.5dB for a 1cm-length and 7μm-width straight waveguide. That is, there is about 5.5dB coupling loss for 7μm-width straight waveguide. Expect for the coupling loss each channel loss of the SOI splitter is shown in Fig. 8. And Figure 9 is the results of the uniformity of device. Figure 10 is the each channel polarization dependent loss (PDL). Figure 8 shows all channel loss of the device is less than 10.5dB at the wavelength from 1540nm to 1560nm, and the maximal insert loss of the channels is 9.95dB at 1550nm. The excess loss of the device is 0.8dB. From Fig. 9, the uniformity at 1550nm is 0.45dB, smaller than 1.0dB between 1540nm and 1560nm. A 0.7dB PDL is shown at

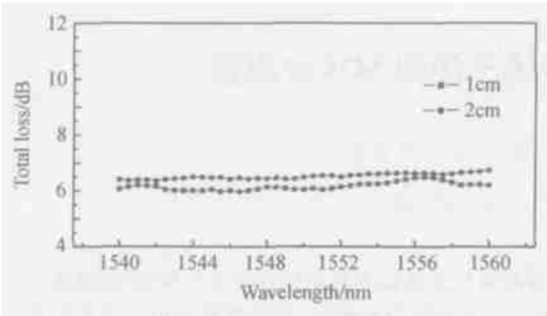

Fig. 7　Total loss of 7μm-width straight waveguide

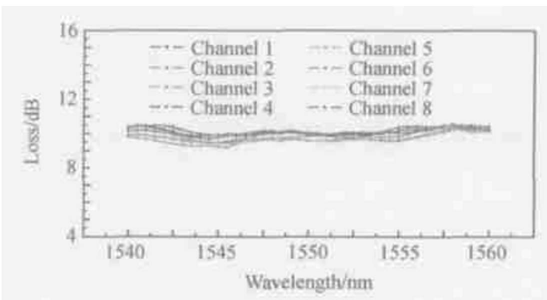

Fig. 8　Each channel loss of the splitter

1550nm in Fig. 10 ,and the PDL is under 1.5dB between 1540nm and 1560nm. Compared to the results of design at 1550nm ,the loss is 0.6dB poorer ,the uniformity is 0.3dB poorer and the PDL has 0.5dB more. From Fig. 5 ,it is clear that the top shape of rib waveguide becomes arc , not rectangle , which results from the bad etching control condition. The etching condition will make the waveguide small , deviating from the design. Figure 3 shows that the insertion loss and the uniformity will sharply rise if the width of waveguide is less than 7μm. So those measuring results are mainly resulted from the defects of the machining process ,which deviates the results of the simulation.

5　Summary

We have designed and fabricated 1 ×8 SOI MMI splitter by applying the multimode waveguides as the input/ output waveguides. Compared to the results of previous 1 ×8 device , the measurement results affirm that the device exhibits good performances. At the wavelength of 1550nm ,the excess insert loss ,uniformity ,and PDL of the device are 0.8dB , 0.45dB , 0.7dB , respectively. Those performances are still good at these wavelengths between 1540nm and 1560nm.

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采用多模输入/输出波导的多模干涉型 SOI 分束器

方 青 贺月娇 辛红丽 李 芳 刘育梁

(中国科学研究院半导体研究所, 北京 100083)

摘要: 一个适用于光纤通信系统中的 1 ×8 多模干涉功率分束器被设计并通过 ICP 刻蚀方法成功研制. 这种基于 SOI 材料的功率分束器是采用多模波导作为输入/输出波导;经过光束传播方法模拟,该器件显示出了优良的性能. 测试结果表明,在 1550nm 波长处器件的传波损耗低于 0.80dB,损耗均匀性为 0.45dB,而且偏振相关损耗低于 0.70dB. 器件的尺寸只有 2mm ×10mm.

关键词: 多模干涉; 功率分束器; SOI; 多模输入/输出波导

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