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NEW SMALL-SIZE SINGLE-MODE OPTICAL POWER SPLITTER BASED ON MULTI-MODE INTERFERENCE

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Abstract *A new type of planar integrated optical power splitter is presented here. The Multi-Mode Power Splitter (MMPS) works on the principle of modal interference in a multi-moded section. The device achieves equi-phase, balanced power partition from one single-moded waveguide into two single-moded waveguides. Simulations and experimental results show that low excess loss (around 1 dB) and very low unbalance (lower than 0.15 dB) can be attained with extremely short devices (20-30 μm for Si-based devices and 50-70 μm for InP-based devices).*

Introduction Photonic Integrated Circuits (PIC's) include a number of planar optical components used for signal routing and signal processing. Equal optical power partition is of great importance to successfully achieve on-chip functions such as signal distribution, monitoring, mixing, etc. Power splitting can in principle be achieved by means of (very long) adiabatic Y-junction structures, or (extremely lossy) dispersion-based structures. For practical optical integrated circuits Two-Mode Interference (TMI) couplers [1] and, more recently, Multi-Mode Interference (MMI) couplers [2-3] working on the self-imaging principle [4] have been reported. Although the optical couplers can provide power splitting at reasonable excess loss and unbalance figures, they are primarily intended for optical signal mixing. Their design and realization is still rather critical with respect to some process parameters. We present here a novel principle to achieve simple and reliable equi-phase balanced optical power splitting.

Operation Principle Figure 1 shows a structural view of the MMPS. It consists of a single-moded input waveguide, a short multi-moded (MM) section and two single-moded output waveguides. Figure 2 shows the evolution of the mode profiles within the MM section. The input signal (In) excites the fundamental (HE00) and second order mode (HE02) (Fig 2.a). These modes propagate along the z-axis and, due to the difference in their propagation constants, a phase difference accumulates. When this phase difference is equal to π, the total field profile (Out) is composed of the fundamental mode plus the second order mode shifted by π (Fig 2.b). The resultant field profile presents two lobes and will couple with very high efficiency to the output pair of single-moded waveguides.

Design and Modeling of the Devices The basic idea is to obtain mode interference between the fundamental and the second order mode propagated in the MM section. Hence, the width W_{MM} must be chosen such that the MM section supports more than two modes but less than four. The single-moded input waveguide is centered with respect to the MM section and will therefore excite only the even symmetric modes. In order to achieve the desired interference, the length of the MM section must be equal to:

$$L_{MM} = \frac{\pi}{\beta_{00}-\beta_{02}} = \frac{\lambda}{2\,(N_{00}-N_{02})}$$

where λ is the free-space wavelength, β_{00} and β_{02} are the propagation constants, and N_{00} and N_{02} are the effective indices of the fundamental and second order mode in the MM section.

The propagation constants in all waveguides were calculated with the Effective Index Method (EIM). A one-dimensional overlap integral was applied for the computation of the excitation coefficients of the fundamental and second order mode, at the input of the MM section (Fig 1.a and Fig 2.a). The modal fields at the end of the MM section (Fig 1.b and Fig 2.b) were calculated with the propagation constants of each mode, and the total field was obtained by adding these modal fields. The excitation coefficient of the total end field to the pair of output waveguides was computed with a one-dimensional overlap integral.

Simulation results predict an optimum excess loss of 0.3 dB, with 0-dB unbalance for a perfectly symmetric device. A 0.2-µm lateral misalignment in the output junction will cause a 0.06-dB extra excess loss, and 0.1-0.2 µm in the inpuct junction will cause an extra excess loss of 0.07-0.16 dB. As each lobe of the resultant field at the end of the MM section is nearly even symmetric, the impact of the junction misalignments on the unbalance is estimated very low.

A Beam Propagation Method (BPM) simulation of the device was performed, and the results are shown in Figure 4. It can be seen that the incoming power is equally divided into two equal lobes, which will excite the fundamental modes of the output waveguides.

Experiments and Discussion The devices were designed and fabricated for operation at 1.52-µm wavelength in a $SiO_2/Al_2O_3/SiO_2$ rib-type waveguide structure on a silicon substrate, as shown in Fig. 3. In order to prevent light from leaking into the substrate, a SiO_2 buffer layer is first thermally grown on the (110) Si substrate. An Al_2O_3 guiding film is then deposited by rf sputtering. The channel waveguides are generated by an Argon-beam milling etching step. A SiO_2 cover layer is sputtered on top of the etched Al_2O_3 film. A final annealing treatment is applied that reduces the waveguide attenuation to about 0.3 dB/cm [4].

Two series of MM Power Splitters were realized. The first series with optimum designed values of W_{MM}=5.2 µm, L_{MM}=21 µm and a junction gap of 1.4 µm, the second series with W_{MM}=6.8 µm, L_{MM}=32 µm and a gap of 2.4 µm. In order to test experimentally the sensitivity to these process parameters, a number of devices were fabricated with both dimensions varying in a range of ±0.3 µm, in steps of 0.1 µm. The tolerance to asymmetry was tried out by purposely introducing a lateral misalignment of 0.1-0.2 µm in the input and output junctions on some devices.

Measurements were carried out by coupling in light with a prism coupling technique to the input waveguide and recording the light intensities of both output waveguides on an IR video camera. The video signals were digitized and processed by a computer.

Figure 5 shows the experimental results obtained for the first series (devices with W_{MM}=5.20 µm and L_{MM} ranging from 20.7 to 21.3 µm). An average excess loss of 1.0 dB and a 0.15-dB unbalance were measured for both series. Unbalances better than 0.1 dB were measured for 40% of all devices.

Conclusions Modal interference in a multi-moded section has been applied to achieve low-loss equi-phase balanced optical power splitting with ultra-short devices. Simulations were performed for $SiO_2/Al_2O_3/SiO_2$ and InP/InGaAsP/InP waveguide structures, indicating that 0.3-dB excess loss and unbalances better than 0.1 dB can be obtained with very short devices. Experiments were carried out in 20-µm long Si-based devices at 1.52-µm wavelength demonstrating excess losses around 1.0 dB and unbalances better than 0.15 dB.

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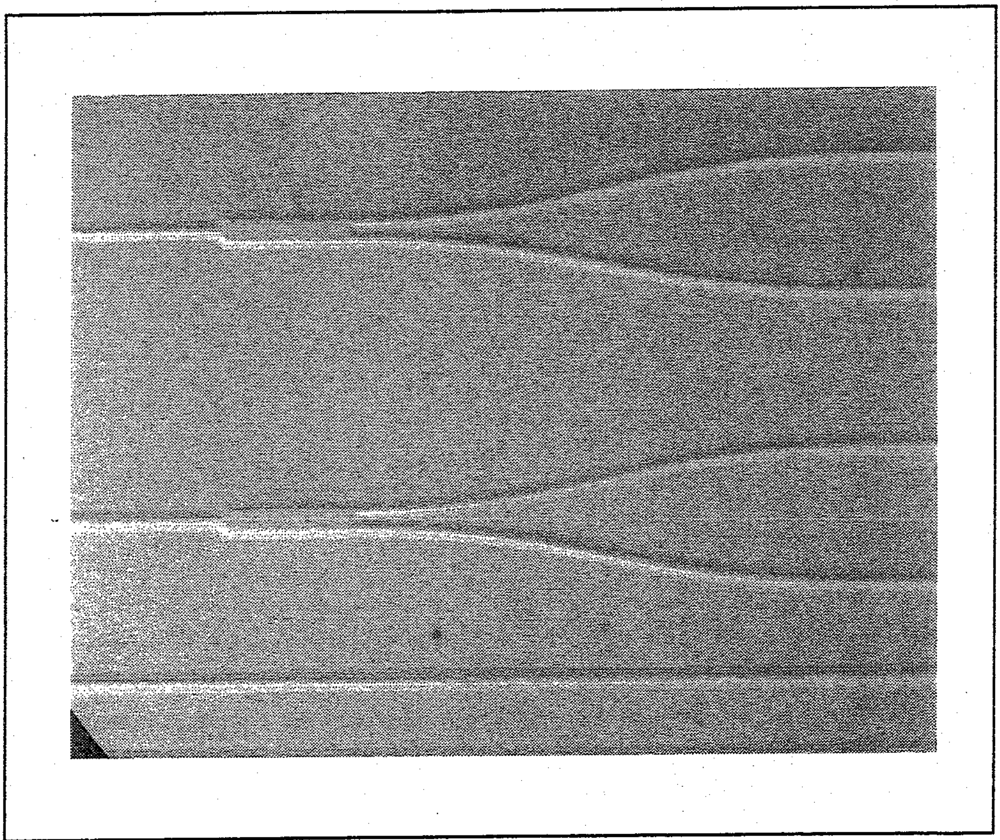

Microscope photograph (×400) of the Si-based realized devices.

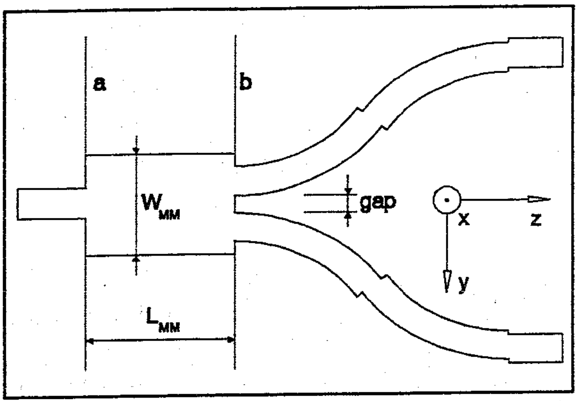

Figure 1. *Top view of the Multi-Mode Power Splitter.*

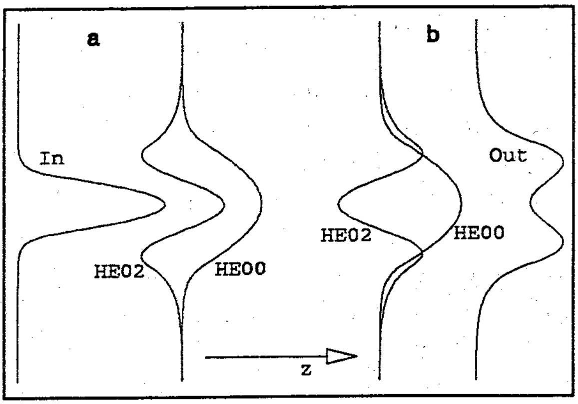

Figure 2. *z-axis evolution of the mode amplitudes in the MM section.*

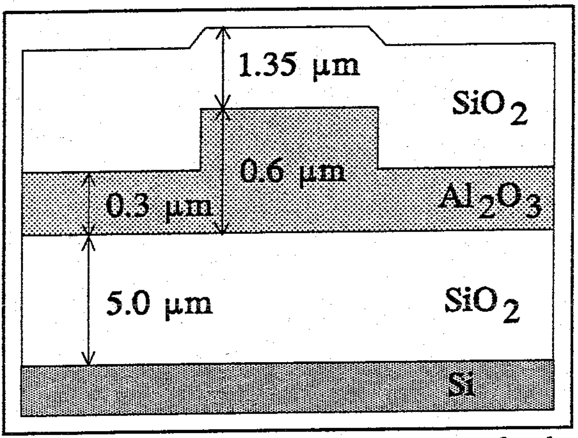

Figure 3. *Cross-section view of the $SiO_2/Al_2O_3/SiO_2$ rib-type waveguide structure.*

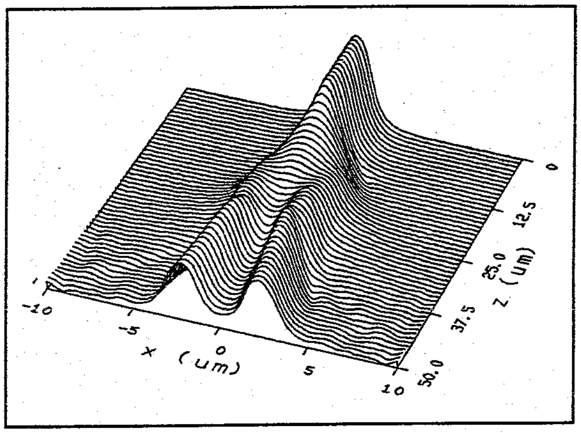

Figure 4. *BPM calculations.*

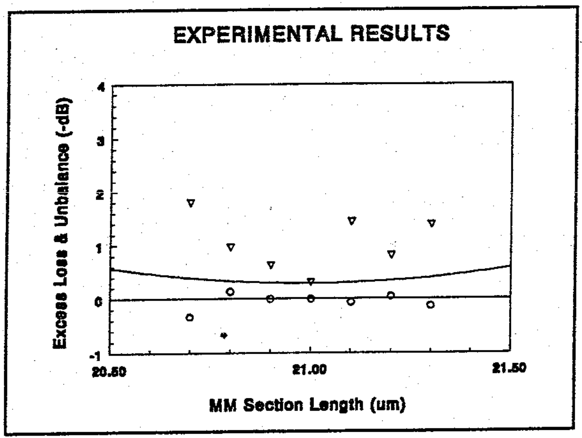

Figure 5. *Simulated and measured excess loss and unbalance. Solid line is simulated excess loss, (▿) are measured excess losses and (○) are measured unbalances.*