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Variable split ratio multimode interference couplers using multimode waveguide holograms

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The recent advances of micro and nano fabrication technologies have allowed the realization of highly complex patterns on planar light-wave circuits (PLCs). Coupling the new fabrication capability with the rapid advance of computing power, it is now possible to calculate and fabricate a refractive index distribution as a hologram on a waveguide. We have demonstrated a new class of devices using multimode waveguide holograms (MWHs) to implement passive variable split ratio 2×2 multimode interference (MMI) couplers. Traditionally, different device geometries are required to generate different split ratios. In these devices, surface relief holograms are used to obtain arbitrary split ratios in components with fixed footprints as shown in Fig. 1. These computer generated diffractive patterns mix and transform the guided modes of multimode structure to generate desired outputs. This is highly beneficial to the integration with other integrated optical components. This methodology provides a versatile technical platform for the development of the future generation integrated optical components and an opportunity to perform highly multi-disciplinary research in system integration for applications in areas ranging from optical communications to optical interconnects, ultrafast signal processing, and sensing.

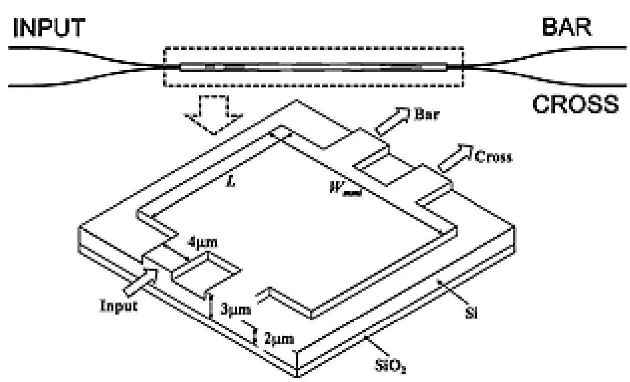
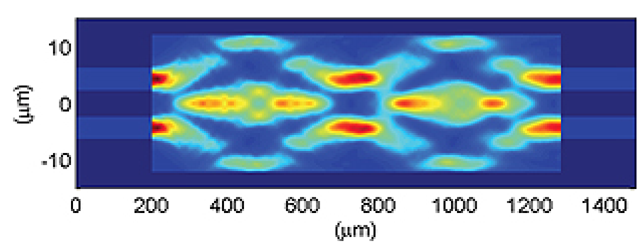


Fig. 1 Schematic of the application of multimode waveguide hologram on fixed footprint 2×2 multimode interference couplers.

First, we performed numerical simulation using the wide-angle beam propagation method (WA-BPM) to verify our theoretical calculations (Fig. 2). The simulation results showed perfect agreement with our matrix theory (Fig. 3). We also showed that the advantages of MMI based devices in fabrication



tolerance and bandwidth were retained in these newly proposed devices. For applications, these MMI couplers can be used to precisely adjust the coupling ratio between waveguides and micro-resonators, where the typical evanescent wave coupling scheme requires very high fabrication tolerances. On the other hand, the proposed device design could be easily integrated with nonlinear optical materials. Kerr-type material can be incorporated into the designed structure to enable active control of the split ratio, thus leading to the realization of all-optical switches.

Fig. 2 Multimode waveguide hologram obtained by the wide-angle beam propagation method (WA-BPM).

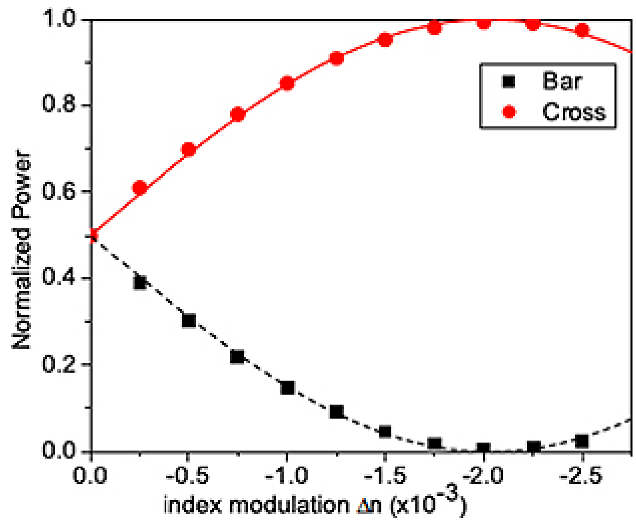


Fig. 3 Split ratios obtain by numerical simulations (dots) and the matrix theory (curves).

For device fabrication, we demonstrated the first experimental results on the fabrication and characterization of power splitters on SOI with identical footprints but different split ratios. Devices based on the silicon-on-insulator (SOI) platform were fabricated for their compatibility and ease of integration with the silicon CMOS technology. The fabrication required multiple lithographic steps to pattern and align the MWH layer and the MMI layer. First, we patterned global alignment marks on the SOI chip using the electron beam (e-beam) lithography and a reactive ion etching (RIE) system. The MWH was aligned to the global marks, patterned using the same e-beam system, and transferred to Si with the same RIE. The MMIs were patterned and aligned to the CGPH layer via the global marks using a contact aligner and transferred to Si with the same RIE system.

Devices with different etch depth and hologram length were fabricated. Devices were probed by coupling a tunable CW laser into the inputs. The device output was measured with an optical power meter. Tapered fibers were used to couple light in/out of the devices. The MMI without MWHs functioned as a 50:50 power splitter as designed. As predicted by the theoretical calculations and numerical simulations, the power splitting ratio of fixed-footprint 2×2 MMI couplers could be varied by changing the MWH etch depth and the MWH length as shown in Fig. 3. We also simulated the abrupt steps used in the fabrication and compared the results with the experiment. The simulation and the experiment showed very good agreement.

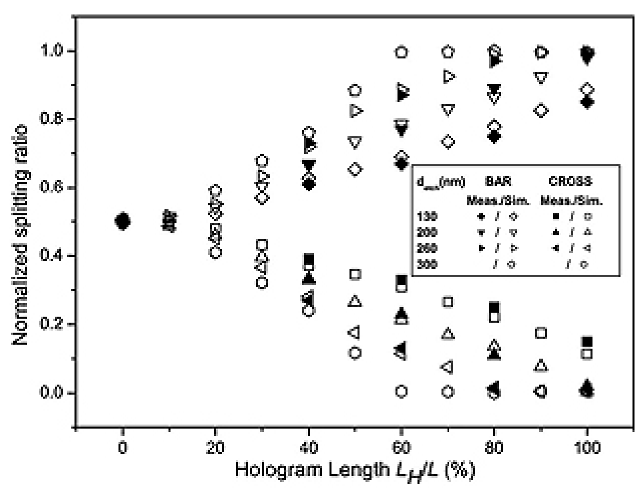


Fig. 4 Device characterization results (Meas.) agree with numerical simulation results (Sim).

We demonstrated, for the first time, a new class of power splitters using MWHs on 2×2 MMI couplers with fixed footprint in SOI. These devices allow a free selection of the splitting ratio while maintaining a fixed device dimension.