Ultra-compact Grating-based 2x2 Beam Splitter for Miniature Photonic Integrated Circuits

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Abstract: A novel, InGaAsP/InP ultra-compact grating-based beam splitter that has less than 1.8dB of loss has been fabricated. The beam splitter exhibits 50/50 splitting with a length of less than 25µm for 1555nm wavelength

1. INTRODUCTION

Compact beam splitters have attracted considerable interests during the last few decades. There has been an ever-increasing demand for photonic integrated circuits, analogous to their electronic counterparts, to be small in size and also achieve high data rates and low losses. Moreover, in some applications with optical feedback circuits, such as the optical phase-locked loops in [1], the system stability greatly relies on ultra-short loop delays. Conventional directional couplers and MMI-based beam splitters, usually a few hundred microns or even millimeters in length, cannot meet the compactness requirements. Other advanced technologies such as photonic crystals [2] and air trenches [3] can be used to construct beam splitters with ultra compactness within submicron order; however, their performance is sensitive to the processing, and they are usually hard to fabricate with large throughput.

A grating-based beam splitter proposed in this paper has the advantage of (1) meeting the short delay requirement with a length less than 25 µm, (2) having well-established processes for robust fabrication and large throughput, and (3) being compatible with existing integrated platforms. Another point worth mentioning is that the total footprint of a splitter includes not only the central splitting region but also connecting waveguides between the splitter and other components e.g. phase modulators and photo detectors in our case. As is typically the case with these devices, the final footprint of our compact beam splitter is limited by the pad layout and beam separation issues, hence is usually dominated by the connecting lengths. Therefore, the grating-based beam splitter is a very desirable solution for circuits that require compactness without a trade-off in the fabrication complexity.

2. DESIGN

The splitter is designed by using the 2-D, quasi-free space, and two-wave interference method. The schematic diagram and FDTD simulations [4] are shown in Figure 1. The incoming guided light from each side first diverges out in the quasi-free space region without reaching its waveguide boundary, and is divided by a Bragg grating section into transmitted and reflected waves. Here, a grating period of 245 nm for the Bragg condition has been used. The goal for our grating-based beam splitter is to have an equal splitting ratio, low loss, and high degree of interference between the two waves.

In the case of large incident angles and wide grating regions, signal distortions and resulting degradation of interference are typically observed due to the oblique incidence and the finite widths of both gratings and input

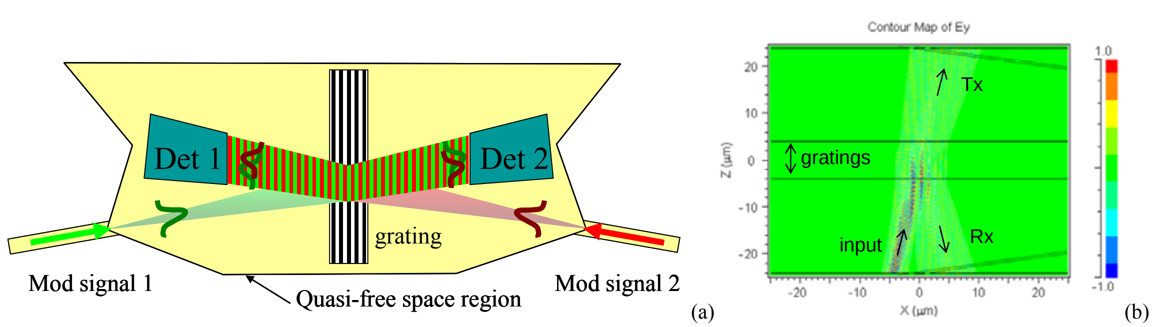

FIGURE 1. (a) Schematic diagram of grating-based beam splitter. Waveguide boundary is far away from the diverged beams in quasi-free space region. Green and red colors represent two input signals from modulators. (b) FDTD simulation shows 50% splitting ratio.

beams. Therefore, a small angle of 10° and a large coupling coefficient achieved by deep etching, which allows a short grating length, are desirable. However, perturbation theories cannot be applied to splitters using deeply etched gratings. The possibility of low scattering loss with high reflectivity has been theoretically proven in [5]. In order to minimize the scattering loss and to provide more uniform interference, a grating depth which extends completely through the slab waveguide layer is required.

3. DEEP GRATING FABRICATION

The gratings are first patterned with holographic exposure, and then transferred to an 800Å SiO_2 hard mask layer using ICP CHF_3 etching. Methane/hydrogen/argon (MHA)-based reactive ion etching (RIE) is generally used in InP-based materials. However, deeply etched profiles with high aspect ratios usually suffer from polymer deposition and methyl radical undercut. It is known that the presence of oxygen within the MHA RIE process is beneficial for preserving the etch profile and enabling sufficient etch depth. In this work, we adopt a hybrid fabrication method [6] in which the continuous addition of oxygen is present during the etching steps (0.5/4/20/10sccm O_2:MHA, 60mTorr, -450V), and also in which oxygen ashing steps (40sccm, 125mTorr, -200V) are cyclically applied until the desired etch depth is reached. The small amounts of continuous oxygen prevent lateral overgrowth, and cyclic oxygen plasma helps clean up any polymer accumulated during etching. Subsequently a cladding layer of 2 μm InP is regrown on top of the etched grating grooves. As shown in Figure 2 (a), the gratings are almost completely etched through the slab waveguide layer to achieve high index contrast and the absence of apparent air vacancies implies a low void-stimulated scattering loss.

4. RESULTS AND CONCLUSIONS

The grating-based beam splitter performance is characterized by measuring the photocurrents of the two photo detectors for transmitted and reflected. Two examples are shown in Figure 2 (b) and (c). These splitters have grating lengths of 10 μm and 25 μm and the peak reflections at Bragg wavelength of 47% and 66% respectively. As expected, the peak reflections are larger for longer gratings. The total measured insertion loss for the devices is between 1 and 1.8 dB for the wavelength range shown in Fig 2 (b) and (c). It includes the propagation loss in the quasi-free space region and the grating scattering loss.

In this paper, we have fabricated a novel, ultra-compact grating-based beam splitter with low scattering loss and splitting ratio close to and greater than 50%. The physical dimensions of our ultra-compact beam splitter, including two 350 μm phase modulators, two 100 μm photo detectors, 90 μm splitter regions (grating and connection waveguides) and all the electrical pads for wire-bonding, are less than 850 μm x 350 μm.

5. REFERENCES

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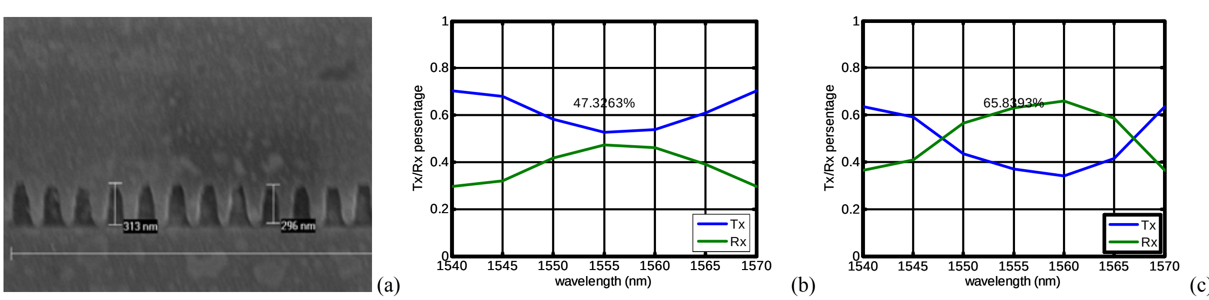

FIGURE 2. (a) SEM picture of the fabricated gratings after regrowth. The vertical waveguide layer is revealed by a selective wet etch. (b) Beam splitter with grating length = 10μm and peak reflection of 47%. (c) Beam splitter with grating length = 25μm and peak reflection of 66%.