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Rib Waveguide to Strip Waveguide Mode Converter Using Local Oxidation of Silicon (LOCOS)

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Abstract:
A mode converter that goes from a rib waveguide to a strip waveguide has been demonstrated. The mode converter contains a 3-D taper fabricated using LOCOS. The demonstrated losses are 0.34 dB per coupler.

Introduction

There has been great interest in developing photonics on a silicon platform, and many components, such as modulators, filters, and detectors have been demonstrated. To achieve single-mode operation and compact designs, these devices are often based around a strip waveguide, roughly 500 nm wide x 220 nm thick. Recently devices with gain have been demonstrated by bonding active III-V material to silicon creating a hybrid III-V/silicon waveguide [1]. These hybrid devices use a thicker (~700 nm) silicon waveguide geometry, often a rib waveguide, which is necessary to achieve proper evanescent coupling between the silicon waveguide and the III-V layers. In order to integrate the hybrid devices to the more typical silicon photonic devices, it is necessary to have a mode converter to connect a thick rib silicon waveguide to a thin strip silicon waveguide.

A common method for connecting waveguides of different thicknesses is a bilevel mode converter [2], which uses a laterally tapered rib waveguide to force the mode down as the waveguide becomes narrower. However, the performance of such a device is limited by how narrow the taper can be made. For a minimum width of 200 nm, the minimum theoretical loss is about 1 dB [2]. A more ideal structure is a 3-D taper, where the waveguide is not only tapered laterally, but also vertically [3]. Such a structure can be challenging to fabricate, but we have developed a simple method using local oxidation of silicon (LOCOS) to create a 3-D taper. Using this method, mode converters with a loss of only 0.34 dB were achieved.

Method

The process for the fabrication of the mode converters is shown in Fig. 1 and Fig. 2. Fig. 1 is a diagram of the cross section of the taper at different points along its length, while Fig. 2 is a top down view of the lithography layers. For the first step, silicon nitride is deposited (by PECVD) on top of a thin layer of thermal oxide (not shown). The silicon nitride is patterned to serve as a barrier for the oxidation as shown. Considerable oxidation occurs under the nitride barrier, creating what is commonly known as a bird’s beak structure in the oxide. The area of the silicon that is under the nitride is consumed both horizontally and vertically creating a 3-D taper. At the fine point of the nitride mask (with a width of 200 nm), the silicon under the mask is completely oxidized. Thus, the taper goes completely and adiabatically from one waveguide structure to the other. The nitride and oxide are then removed using a series of BOE (buffer oxide etch) and hot phosphoric etch steps.
Figure 1. Cross-sectional diagrams of the fabrication of mode converter. The rows 1-3 represent different steps during the fabrication of the mode converter, and the columns a-c represent different parts of the mode converter as indicated in Fig. 2. The steps are: 1) the nitride mask is patterned, 2) a thermal oxide is grown, the nitride and oxide are stripped (not shown), and 3) the final waveguide is patterned.

Figure 2. Top down view of the two lithography steps for the mode converter. The green is the silicon nitride mask, and the blue is the waveguide etch mask. The dashed lines labeled a, b, and c are at roughly the locations shown in Fig. 1.

It should be noted that a wet etch could similarly be used to create a 3-D taper. However, the oxidation process has the important advantages that it is straightforward to precisely control the thickness and shape of the taper, and it creates very smooth structures. After the taper structure is fabricated, the waveguides are patterned using standard lithography and dry etch steps.

Results

For a demonstration of the technique, the rib waveguide was 5000 nm wide by 300 nm high, with a total thickness of 775 nm, and the silicon strip waveguide was 500 nm wide by 215 nm thick. The nitride mask was 100 nm thick on top of 30 nm of oxide. For the LOCOS step, an oxide 1250 nm thick was grown, consuming 560 nm of silicon. Fig. 3 shows cross-sectional SEM images of tapers at various locations. Notice that in the Fig. 3c, there is only a very slight bump in the waveguide as the taper has almost completed the transition to a strip waveguide.
Figure 3. Cross-sectional SEM images of mode converters at different locations. Images a and b roughly correspond to the locations in Figs. 1 and 2. Image c is very close to end of the taper. All the images were taken at an angle of 70°.

Figure 4. Measurement of the loss per coupler.

To determine the loss of the mode converter, several test structures were fabricated with different numbers of mode converters in series. Fig. 4 shows a graph of the transmission of these structures vs. the number of mode converters. The loss per mode converter is measured to be 0.34 dB.

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References:

