Low-loss and High Contrast Silicon-on-Insulator (SOI) Arrayed Waveguide Grating

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Abstract: We report high-extinction and low-loss 40-channel x 100-GHz arrayed waveguide grating (AWG) fabricated on silicon-on-insulator using high quality etching condition resulting in < 0.8 dB/cm loss and low phase errors.

OCIS codes: (080.1238) Array waveguide devices; (230.7370) Waveguides.

1. Introduction

Recently, there has been significant interest in sub-micron low-loss optical waveguide structures to facilitate highly-integrated dense silicon photonics applications including optical interconnects, on-chip WDM systems, and RF photonics [1-5]. Sub-micron waveguides allow for micro-meter sized bend radius to form compact device designs such as arrayed-waveguide gratings, Mach-Zehnder interferometers, and ring resonators in integrated photonics. The primary source of scattering loss is due to sidewall roughness and can be estimated from the mean square roughness and correlation function along with the field distribution and waveguide geometry [4]. The sidewall roughness is a consequence of the ensuing fabrication process such as photoresist lithography and plasma dry etching. In this paper, we report the conditions for sub-0.8dB/cm waveguide loss and excellent AWG extinction ratio in excess of ~15dB using CMOS compatible optical lithography and plasma dry etching processes.

2. Fabrication and Experiment

We designed SOI rib waveguides with a height of 500-nm, etch depth of 250-nm for various waveguide widths of 1.0-µm, 1.5-µm, 2.0-µm, 2.5-µm, and 3.0-µm. The dimensions were fabricated with 6° SOITEC wafers with a 500-nm top silicon layer and a 3-µm thick BOX. The waveguide structures were first patterned by 250nm optical lithography using a DUV ASML 5500/300 stepper with a KrF light source. A focus-exposure matrix was performed to obtain an optimized exposure dose of 21mJ/cm2 on 420nm thick Rohm Haas UV210-0.6 photoresist and then developed in MF-26A for one minute. Afterwards, the photoresist was reflowed at 158°C for 2 minutes to eliminate any standing wave effect and roughness of the resist. The silicon waveguides are then dry etched with a Lam TCP etcher and HBr/O2 plasma.

Table 1: HBr plasma based TCP etch recipe

<table>
<thead>
<tr>
<th></th>
<th>Oxide Etch</th>
<th>Si Etch</th>
<th>Si Overetch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure (mtorr)</td>
<td>13</td>
<td>12</td>
<td>80</td>
</tr>
<tr>
<td>TCP RF (watt)</td>
<td>200</td>
<td>300</td>
<td>100</td>
</tr>
<tr>
<td>Bias RF (watt)</td>
<td>40</td>
<td>150</td>
<td>150</td>
</tr>
<tr>
<td>Electrode Gap (cm)</td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>HBr (sccm)</td>
<td>0</td>
<td>150</td>
<td>100</td>
</tr>
<tr>
<td>CF₄ (sccm)</td>
<td>100</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>He Clamp (sccm)</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Time (sec)</td>
<td>10</td>
<td>vary</td>
<td>10</td>
</tr>
</tbody>
</table>

Figure 1: Cross section of Si waveguide profile for different HBr/O2 content: (a) 99/1 (b) 97/3 (c) 95/5 and (d) sidewall roughness of HBr/O2 (99/1) plasma dry etching. All experiments are done with TCP RF=300W and Bias RF=150W.

Figure 2: Optimized pure HBr waveguide etch of (a) waveguide cross section (b) fabricated 40-channel-100GHz AWG. Table I: Details of pure HBr etch recipe steps for low-loss, high contrast AWG response.
Fig. 1 illustrates the effect of waveguide cross-section and sidewall roughness due to HBr/O$_2$ plasma dry etching. The HBr/O$_2$ plasma etch results in the formation of a passivation layer on the sidewalls which can give significant slopes with angles greater than 12° and pronounced notching at the foot of the waveguide. The HBr/O$_2$ plasma etch results in the formation of a passivation layer on the sidewalls which can give significant slopes with angles greater than 12° and pronounced notching at the foot of the waveguide. However isotropic etching can be achieved by using a pure HBr etch which reduces the passivation layer by exposing the silicon atoms to Br radicals [2, 3]. Fig. 2 (a) shows an improved cross-section without significant sidewall sloping and excessive foot notching. The waveguide roughness is very similar to that shown in Fig. 1(d) and the optimized etch conditions are detailed in table1 resulting in an etch rate of 200nm/min.

3. Results

The waveguide losses were evaluated using two methods. The first involved the fabry-perot method which involved a tunable swept laser. The polarization of the source output was set to excite the TE mode by using an in-line polarization controller and polarizer. The light was coupled into the waveguides using an anti-reflection coated lensed fiber. The output light was collected by using another lensed fiber and the output spectrum was measured.

Waveguide widths of 3.0μm, 2.5μm, 2.0μm, 1.5μm, and 1.0μm were fabricated and the losses respectively were 0.711dB/cm, 0.787dB/cm, 0.858dB/cm, 0.947dB/cm, 0.990dB/cm. Facet power reflections for various waveguide widths using 3D-FDTD are 42.2%, 41.5%, 40.0%, 37.5%, and 31.7% respectively for the listed waveguide above and are used in fabry-perot loss equation: $L\ [dB/cm] = (-1/L)n[1 - (R_1 R_2)^{1/n}]$, Further proof of low loss is evidenced by the measured spectral response of a fabricated 40 channel AWG with 100GHz spacing. The relatively high 3dB loss shown in figure 4 is due to a 2mm long AWG output waveguide section that has a 700nm waveguide width. The average channel crosstalk is approximately -15dB indicating low-loss, low-phase error, and high contrast performance.

4. References