1. Introduction

Recently, optical wiring has been extensively studied due to its inherent no RC-delay in metal wiring. Therefore, the light waveguide is expected to be integrated on Si LSI.

In this study, waveguide structure, which is able to be integrated on Si LSI, is examined. As a substrate, silicon on insulator (SOI) is used, which is widely put to practical use in advanced LSI's. Examined structures are those with bend and MOS ones with aluminum gate as a reflective material.

While, an optical modulator of MOS structure was proposed by the authors based on free carrier absorption [1]. Recently, an MOS modulator based on permittivity change was successfully proposed [2].

2. Experimental

The SOI waveguides are fabricated on {110} SOI wafer. Thickness and resistivity of the SOI layer are 1.4 µm and 10 Ω-cm, respectively. BOX layer is 1.0-µm in thickness. Two kinds of waveguide structures are investigated as shown Fig. 1. Those are formed by TMAH anisotropic etching or ECR dry etching. In case of TMAH, {111} side walls are delineated vertically because the etch rate of {110} to {111} exceeds 130 [3], as shown in Fig. 2.

Fig. 1 Two kinds of waveguide structures: (a) air / SOI and (b) Al / 50-nm thick SiO₂ / SOI.

3. Results and Discussion

I) Loss Measurement for Six Bend Shapes

Propagation characteristics at 1.55-µm wavelength are measured by six bends, already shown in Fig. 2. The results are shown in Fig. 3. While, simulation is done for these structures using FDTD with PROLOG simulator. An example is shown in Fig. 4 for No. 4 bend. Evaluated values are summarized in Table 1 on an assumption that absorption in straight portion is equal for six bends.

Fig. 2 Characterized six bends delineated with TMAH etchant.

Fig. 3 Propagation characteristics for six bend shapes at 1.55-µm wavelength.

Table 1 Evaluated absorption coefficient and transmission for six bend shapes.

<table>
<thead>
<tr>
<th>Bend Shapes</th>
<th>Measured Values</th>
<th>FDTD Simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Absorption Coefficient (α/µm)</td>
<td>Transmission</td>
</tr>
<tr>
<td>No.1</td>
<td>0.15</td>
<td>0.21</td>
</tr>
<tr>
<td>No.2</td>
<td>0.15</td>
<td>0.19</td>
</tr>
<tr>
<td>No.3</td>
<td>0.15</td>
<td>0.16</td>
</tr>
<tr>
<td>No.4</td>
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<td>0.22</td>
</tr>
<tr>
<td>No.5</td>
<td>0.15</td>
<td>0.08</td>
</tr>
<tr>
<td>No.6</td>
<td>0.15</td>
<td>0.06</td>
</tr>
</tbody>
</table>
2) Structure Dependence of Propagation Loss

Figure 5 indicates the propagation difference for air clad or Al/50-nm thick SiO$_2$ clad, and sidewalls etched by TMAH or ECR.

The total optical loss may be affected by six factors such as (1) free carrier absorption, (2) sidewall roughness, (3) bend shape (4) coupling loss at input and output sections, (5) absorption by aluminum, and (6) optical mode, as shown in Fig. 6, in waveguide.

Fig. 5 The comparison of propagation characteristics among three different structures.

(a) Air-clad waveguide etched by TMAH.

(b) Air-clad waveguide etched by ECR.

(c) Al/SiO$_2$-clad waveguide etched by TMAH.

*Smaller output power for 20-µm width may be caused by smaller input power due to poor coupling.

Fig. 6 Infrared microscope output patterns of 1.55-µm infrared light for 100-µm wide and 30-µm wide SOI waveguides.

To summarize the results, evaluated absorption coefficients are illustrated in Fig. 7. It is very obvious that Al electrode causes propagation loss due to free carrier in the electrode. Based on the results and simulation of reflection of plane wave, it is estimated that certain free carrier concentration gives optimum propagation, shown in Fig. 8 in case of ITO (Indium-Tin-Oxide).

4. Conclusion

Integrated SOI waveguide structures are investigated in this study. Although highly reflective metal layer is expected to be suitable, light loss is given rise to with Al. Therefore, it is simulated that there exists optimum carrier concentration for maximum propagation. ITO may be suitable for its flexibility to choose the concentration.

Furthermore, light propagation mode should be considered to make accurate simulation in wider waveguide in particular.

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