Development of a LFLE Double Pattern Process for TE Mode Photonic Devices

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May 9, 2017
Introduction and Motivation

Silicon Photonics Geometry, TE vs TM, Double Pattern vs Single Pattern
**Silicon Photonics Geometry**

Silicon waveguide thickness and width are chosen such that only a single TE and TM mode are confined.

At 1550 nm wavelength:
- Thickness – 220 nm
- Width – 500 nm

TE Mode vs TM Mode

Photonic devices take advantage of optical tunneling of the evanescent field to couple energy from one waveguide to another.

TM Mode contains a larger amplitude evanescent field allowing coupling over larger distances.

## Double Pattern vs Single Pattern (Using i-line Lithography)

<table>
<thead>
<tr>
<th>Mode</th>
<th>Minimum Feature Size Possible</th>
<th>Minimum Feature Separation Possible</th>
</tr>
</thead>
<tbody>
<tr>
<td>Double Pattern</td>
<td>~250 nm</td>
<td>~100 nm</td>
</tr>
<tr>
<td>Single Pattern</td>
<td>~300 nm</td>
<td>~300 nm</td>
</tr>
</tbody>
</table>
Process Development

Proposed Litho-Freeze-Litho-Etch Process
Obtain SOI Wafer (2000 nm SiO$_2$) (220 nm a-Si)

RCA Clean

Apply BARC (65 nm)

Wafer Pre-processing – Cleaning, BARC Application
Coat, Pattern, and Develop OiR-620 Positive Photoresist Image

1. Apply Positive Resist (300 nm)
2. Expose Resist
3. Develop Positive Resist

Diagram:
- Positive Resist: a-Si, SiO2, Silicon
- Exposed Resist: a-Si, SiO2, Silicon
UV Cure of OiR-620 Positive Photoresist Image

- **UV Cure**

- **Flood Expose**
  - 250 nm Source
  - 140°C
  - 7 min

250nm UV Light Source

- a-Si
- SiO2
- Silicon
- Hotplate
Coat, Pattern, and Develop NLOF-2020 Negative Photoresist Image

1. Apply Negative Resist (600 nm)
2. Expose Resist
3. Develop Negative Resist
RIE Etch of BARC, ICP Etch of a-Si, Photoresist Strip
Final Device Profile – TE Mode Waveguide

- Silicon
- SiO₂
- 2000 nm
- a-Si
- 500 nm
- 220 nm
- ~200 nm
- 500 nm
Process Development

UV Cure DOE – Impact of Exposure Time and Temperature on UV Cure Process
Experimental Setup

• Study the effects of exposure time, exposure temperature, room temperature, and humidity on the area of cured photoresist remaining after processing of the second layer of photoresist
• Apply and develop OiR-620 photoresist without exposure
• UV cure the first layer
• Apply and develop NLOF-2020 photoresist without exposure
• Measure area of remaining OiR-620 photoresist
### Design Matrix and Area of Cured Photoresist

<table>
<thead>
<tr>
<th>Exposure Time</th>
<th>130°C</th>
<th>135°C</th>
<th>140°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 minutes</td>
<td>46.94</td>
<td>2876.6</td>
<td>3093.4</td>
</tr>
<tr>
<td>7.5 minutes</td>
<td>131.40</td>
<td>2519.4</td>
<td>3119.0</td>
</tr>
<tr>
<td>8 minutes</td>
<td>90.38</td>
<td>2506.6</td>
<td>3139.5</td>
</tr>
<tr>
<td>8.5 minutes</td>
<td>1148.10</td>
<td>2633.7</td>
<td>3598.6</td>
</tr>
<tr>
<td>9 minutes</td>
<td>993.80</td>
<td>3026.1</td>
<td>3198.1</td>
</tr>
</tbody>
</table>
Method of Analysis

• Least Squares Regression

• Examined three predictor variables:
  1. Exposure Temperature (Continuous)
  2. Exposure Time (Continuous)
  3. Humidity (Continuous)

• Using one response variable
  1. Area of cured photoresist in cm²

• Regression Model:
  Area = -1832 + 0.59*Time + 15.76*Temp – 901.64*Humidity
Process Development
Engineering Design Mask
Design Mask Overview

Photonic Design Variations:
1. Ring Width
   - 500 nm
   - 520 nm
   - 540 nm

2. Waveguide Width
   - 500 nm
   - 515 nm
   - 530 nm

Photonic Design Variations:
1. Grating Duty Ratio (space:line)
   - 0.40
   - 0.50
   - 0.60

2. Waveguide to Ring Gap
   - 150 nm
   - 175 nm
   - 200 nm
   - 225 nm
   - 250 nm

Grating
Dutv Ratio  0.40  0.50  0.60

TE Mode
Experimental Results

Initial Lithography Results
Compound Photoresist Image
Affect of Pitch and Duty Ratio on Photoresist Image

<table>
<thead>
<tr>
<th>Duty Ratio (space:line)</th>
<th>0.40</th>
<th>0.50</th>
<th>0.60</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pitch (nm)</td>
<td>640</td>
<td>675</td>
<td>710</td>
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</table>
# Affect of Pitch and Duty Ratio on Photoresist Image

<table>
<thead>
<tr>
<th>Duty Ratio (space:line)</th>
<th>Pitch (nm)</th>
<th>745</th>
<th>780</th>
<th>815</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.40</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.50</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.60</td>
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</tbody>
</table>
Experimental Results

Initial Etch Results
Ring Resonator – Post Etch SEM
Conclusions

Conclusions Drawn from Final Results
Conclusions

• Obtained successful results from experimental process:
  • Minimum obtained feature size ~150 nm
  • Minimum obtained feature separation - ~100 nm
• Developed a working UV cure process using readily obtained positive and negative tone resists
• Developed a working LFLE process that can be refined to fabricate working TE mode photonic devices
• Created a two layer engineering design mask adequate for future work
Future Work

Outline of Possible Future Work
Outline of Possible Future Work

• Lithography optimization for SOI wafer
  • Account for changes in stack reflectivity
  • Separate optimization for positive and negative layers

• Optical Proximity Correction (OPC) mask design
  • Corrections for bulging in ring to wave guides gap
  • Corrections for fine pitch grating couplers

• Etch Recipe Optimization for compound resist image
References

Works Referenced
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