Low-loss TiO$_2$ planar waveguides for nanophotonic applications

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Outline

Introduction: TiO$_2$ for nanophotonic applications

Deposition of TiO$_2$ films

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Conclusion
Introduction

Applications of TiO$_2$ thin films:
Introduction

Applications of $\text{TiO}_2$ thin films:

- Photocatalysis
- Solar cells
- Reflective coatings
- Dielectric layers
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- Photocatalysis
- Solar cells
- Reflective coatings
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- Nanophotonics
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Why TiO$_2$ films for nanophotonics?
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Potential applications:
Photonic crystals, nonlinear optics, passive devices, active devices
Introduction

Challenges:

\( \text{TiO}_2 \) has several phases: amorphous, anatase, brookite, rutile.

These phases result in a wide range of properties (refractive index, birefringence, nonlinearity, loss).
Introduction

Goal:

Exploit TiO$_2$ as a material for nanophotonic devices for real-world applications.

Requirements:

- Low losses
- Scalable technology
- Small dimensions
Deposition of TiO$_2$ Films

Reactive Sputtering
Deposition of TiO$_2$ Films

Reactive Sputtering

- Excellent uniformity
- Large parameter space for control of film properties
- Multiple targets: potential for doping
- Compatible with Silicon Technology

Deposition of TiO$_2$ Films
Deposition of TiO$_2$ Films

Process Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Range</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>20–600</td>
<td>°C</td>
</tr>
<tr>
<td>Pressure</td>
<td>2–5</td>
<td>mTorr</td>
</tr>
<tr>
<td>Power</td>
<td>100–200</td>
<td>W</td>
</tr>
<tr>
<td>Total Flow</td>
<td>40–60</td>
<td>sccm</td>
</tr>
<tr>
<td>O$_2$ Flow %</td>
<td>2–33</td>
<td>%</td>
</tr>
</tbody>
</table>
Results

Film Characterization Methods

Structure: scanning electron microscopy (SEM)
Composition: X-ray photoelectron spectroscopy (XPS)
Crystalline phase: Raman spectroscopy
Optical properties: ellipsometry and prism coupling
Results

Structure

Cross-section

Surface

Stoichiometry confirmed via XPS measurements.
Results

Phase

![Graph showing Raman shift intensity](image)
Results

Phase

![Graph showing Raman shift vs. intensity with peaks at 300 cm⁻¹ and 520 cm⁻¹ for Si, at 20 °C.](image)
Results

Additional peak observed for films deposited at $T > 300^\circ C$
Results

Phase

Results
Dispersion

![Graph showing the relationship between refractive index and wavelength (nm) at 20 °C and 350 °C. The refractive index decreases as the wavelength increases.]
Results

Propagation Loss
Results

Propagation Loss

![Graph showing propagation loss with intensity on the y-axis and propagation distance on the x-axis. The graph compares the intensity at different temperatures: 20 °C and 350 °C. The inset image shows a TiO\textsubscript{2} waveguide with guided light.](image-url)
Results

Propagation Loss

![Graph showing intensity vs. propagation distance with data points for 0.4 dB/cm, 3.5 dB/cm, and 20 °C, 350 °C. Image of TiO₂ waveguide with guided light shown as inset.](image)
## Results

### TiO$_2$ Film Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Amorphous Films</th>
<th>Anatase Polycrystalline Films</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature (°C)</td>
<td>20</td>
<td>350</td>
</tr>
<tr>
<td>Deposition rate (nm/hr)</td>
<td>100</td>
<td>16</td>
</tr>
<tr>
<td><em>Refractive index</em></td>
<td>2.35</td>
<td>2.43</td>
</tr>
<tr>
<td><em>Loss (dB/cm)</em></td>
<td>0.4</td>
<td>3.5</td>
</tr>
</tbody>
</table>

* At $\lambda = 826$ nm
Conclusion

We have developed a method for depositing amorphous and anatase TiO$_2$ thin films with low losses.

These high-index thin films will be used for nanophotonics applications over a wide wavelength range.
Acknowledgements

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