Investigation of Complex Oxides for Solid State Electronics

Jenna Bovaird, Prathamesh Nagnoor, Aaron Peng, Mark Wang

Principal Investigator: Dr. Susanne Stemmer
Mentor: Kaveh Ahadi
Silicon Transistors Face Sizable Complications

- **Electron Flow**
- **Substrate**
- **Gate**
- **Insulator**
- **Output (Conventional Current)**
- **Input (Conventional Current)**
- **Gate Leakage**
- **Switch Leakage**
- **N-Type Transistor (Uses Electrons)**

Intended path of travel
Thin Film Oxides are the Answer to Silicon’s Problem

Displays  Solar Cells  Power Electronics
The Crystal Structure of Strontium Titanate is More Versatile
Studying Functional Thin Films Begins with Synthesis

Clean substrate

Electron-Beam Vapor Deposition (E-Beam)
E-Beam Deposition Aides in Substrate Heat Absorption

Vacuum

Substrate

Vaporized Tantalum

E-beam

Solid Tantalum Sample

Electrons (Not visible)
Oxide Thin Film is Grown Using Molecular Beam Epitaxy

Clean substrate

Electron-Beam Vapor Deposition (E-Beam)

Molecular Beam Epitaxy (MBE)
MBE Process Requires High Temperatures and Low Pressures

Oxide Layer

Tantalum Layer

Substrate

20 nm
500 µm
350 nm

Oxide Layer
Substrate
Tantalum Layer
Detecting Structural Imperfections Follows Coating

1. Clean substrate
2. Electron-Beam Vapor Deposition (E-Beam)
3. Molecular Beam Epitaxy (MBE)
4. Ellipsometry
Ellipsometry Detects Structural Imperfections

- Light source
- Polarizer
- Oxide Layer
- Tantalum Layer
- Substrate
- Detector
- Change in Angle
- Change in Intensity

Parameters:
- $\Theta_{i}$
- $\Theta_{r}$
- 20 nm
- 500 µm
- 350 nm
Data Resembles Ideal SrTiO$_3$ Thin Film Curve

- Refractive Index ($n$)
- Proportionality to Absorption ($K$)
Hall Measurements Electrical Properties

- Clean substrate
- Electron-Beam Vapor Deposition (E-Beam)
- Molecular Beam Epitaxy (MBE)
- Hall measurements
- Ellipsometry
Quantifying the Electrical Efficacy of the Thin Film

<table>
<thead>
<tr>
<th>Measurements</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volumetric Charge Density (cm(^{-3}))</td>
<td>How much charge is packed per cubic cm</td>
</tr>
<tr>
<td>Mobility (cm(^2)V(^{-1})s(^{-1}))</td>
<td>Ability to flow through the semiconductor</td>
</tr>
<tr>
<td>Charge</td>
<td>What current carrier is being used</td>
</tr>
</tbody>
</table>
Creating a Functional Thin Film Requires Trial and Error

1. Clean substrate
2. Molecular Beam Epitaxy (MBE)
3. Electron-Beam Vapor Deposition (E-Beam)
4. Ellipsometry
5. Hall measurements
6. Data Analysis
SrTiO$_3$ Continues to Show Promise

<table>
<thead>
<tr>
<th>Measurements</th>
<th>SrTiO$_3$ (290 K)</th>
<th>Si (290 K)</th>
<th>SrTiO$_3$ (2 K)</th>
<th>Si (2 K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volumetric Charge</td>
<td>4.70 x 10$^{20}$</td>
<td>8.72 x 10$^9$</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Density (cm$^{-3}$)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mobility (cm$^2$V$^{-1}$s$^{-1}$)</td>
<td>5.2</td>
<td>1.4 x 10$^3$</td>
<td>5.0 x 10$^4$</td>
<td>1 x 10$^3$</td>
</tr>
<tr>
<td>Charge</td>
<td>N-Type</td>
<td>Usage</td>
<td>Usage</td>
<td>Usage</td>
</tr>
<tr>
<td></td>
<td>Dependent</td>
<td>Dependent</td>
<td>Dependent</td>
<td>Dependent</td>
</tr>
</tbody>
</table>
Thank You to...

Center for Science and Engineering Partnerships
Mentor: Kaveh Ahadi
SIMS Coordinator: Mary Alice Callaghan
Super Mentors: Dean Morales and Stephanie Mendes
RAs: Rachel Alvelais, Stephen Chih, Marine Marnasyan, and Joseph Sanz