Effects of NH$_3$ as a Catalyst on the Metalorganic Chemical Vapor Deposition of Al$_2$O$_3$

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Motivation for Research

- Need for increased circuit density
  - Fitting more transistors on each wafer

- Physical limit of SiO₂
  - High leakage current
  - Reliability
  - Boron penetration

- Finding a new dielectric
  - SiO₂ κ = 3.9
  - Need a higher κ dielectric

\[ C = \kappa \varepsilon_0 A/t \]
  - C - capacitance
  - κ - dielectric coefficient (or relative permittivity)
  - \( \varepsilon_0 \) - permittivity of free space (8.85*10⁻³ fF/μm)
  - A - area of capacitor
  - t - thickness of the dielectric

http://www.hpc.unm.edu/~acpineda/research/movies/movies.html
Why $\text{Al}_2\text{O}_3$ as a possible dielectric?

- Positive characteristics
  - $\kappa = 9$
  - Thermodynamically stable in contact with Si
  - Very stable, robust
  - High band gap (9 eV)
  - It can combined with other high k dielectric material

- Experiment with $\text{NH}_3$
  - Hope that it will
    - Increase the deposition rate of $\text{Al}_2\text{O}_3$
    - Decrease deposition temperature
    - Decrease amount of impurities in film
Set Up of Experiment

- Cut 2 cm x 2 cm silicon wafers

Cleaning procedure
- Ultrasonic cleaning- loosens particles (1 min)
- Distilled water- removes particles (3 min)
- 4:1 \( \text{H}_2\text{SO}_4/\text{H}_2\text{O}_2 \)- remove organic material (15 min)
- Distilled water (3 min)
- 49% HF- remove native silicon oxide (15 sec)
- Distilled water (3 min)
- Dry with nitrogen

http://www.imps.co.uk/imps%2013-11-03/index_act.htm
Metal Organic Chemical Vapor Deposition

Reaction conditions
- Deposition temperature: 100, 200, 300, 400, and 500°C
- Deposition pressure: 0.7-0.8 torr

Diagram of the deposition process:
- Oxygen (O₂) and Argon (Ar) flow to the reactor.
- Precursor and Ammonia (NH₃) are added to the reactor.
- Heating Element maintains the desired temperature.
- Wafer is placed in the reactor.
- Vacuum Pump ensures a controlled environment.
- Venting system.
Analysis Techniques

- Ellipsometric Spectroscopy
  - Thickness

- X-Ray Photoelectron Spectroscopy (XPS)
  - Stoichiometry, Composition

- Fourier Transform Infrared Spectroscopy (FTIR)
  - Composition
Comparing the Results

Deposition temperature (°C)

Al₂O₃ Deposition rate (nm/cycle)

- without NH₃
- with NH₃

Graph showing the deposition rate of Al₂O₃ as a function of deposition temperature with and without NH₃.
XPS Analysis

XPS Survey for film catalyzed with NH₃ at 200C

Binding Energy (eV)

- No Etch
- 600 Etch
XPS Analysis: Stoichiometric

<table>
<thead>
<tr>
<th>O/Al ratio</th>
<th>Sample1</th>
<th>Sample3</th>
<th>Sample2</th>
<th>Sample4</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>No NH₃</td>
<td>NH₃</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature (°C)</td>
<td>300</td>
<td>200</td>
<td>300</td>
<td>200</td>
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<tr>
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<td>1.619</td>
<td>1.671</td>
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<td>300 sec Etch</td>
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<td>1.540</td>
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<td>600 sec Etch</td>
<td>1.472</td>
<td>1.479</td>
<td>1.560</td>
<td>1.534</td>
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</tbody>
</table>

From 2006 experiments

- 2004 experiments by A. Roy Chowdhuri and C.G. Takoudis
  - Stoichiometric ratio of O/Al was 2.0 ± 0.1
FTIR Analysis

- **NH₃**
  - 2900-3600 cm⁻¹

- C-H stretching
  - 2800-3000 cm⁻¹

- O-Al-O bending
  - 690 cm⁻¹

- O-Al stretching
  - 598 cm⁻¹

- O=Al
  - 1345 cm⁻¹
Conclusions and Future Work

- NH₃ raised the deposition rate in the temperature range of 200-300°C

- Without Ammonia
  - Absorption controlled until 300°C
  - Reaction controlled after 300°C

- With Ammonia
  - Reaction controlled from 100-300°C
  - At 100°C ammonia gets absorbed therefore less TMA is absorbed results in lower Al₂O₃ deposition rate

- Purity of the film was not compromised

- Continue to perfect use of NH₃ in the deposition of Al₂O₃
References

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