Low temperature deposition of thin passivation layers by plasma ALD

Bernd Gruska, SENTECH Instruments GmbH, Germany

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SENTECH in brief

Private company founded in 1990
Located in Berlin, Germany

New building since 2010
60 employees
ISO 9001 certificated

Business fields
Thin Film Metrology
Metrology for PV
Plasma Process Technology
Atomic Layer Deposition
SENTECH in brief

Located in Berlin-Adlershof, Germany’s largest science and technology park
Application experts at SENTECH

- Processing of customer samples
- Device demonstrations
- User training

Application fields:

- R & D
- Quality control
- Photovoltaic
- Low damage etching
- Low temperature deposition
- Nano patterning
- Nano films
- 3D deposition
Plasma Process Technology

- RIE, ICP-RIE
- PECVD, ICPECVD
- Cluster tools
- ALD / PEALD
- SENTECH laser end point monitor
Spectroscopic ellipsometers
SENresearch for R&D and quality control

Wide spectral range
Highly flexible

SENDURO 200/300
SENDIRA
SE 850 DUV
Low temperature deposition processes

Applications of low temperature deposition processes

• Passivation of organic materials (OLEDs) \( (T_D \leq 80^\circ C) \)
• Isolation of interconnects on small gap compound semiconductors \( (T_D \leq 100-200^\circ C) \)
• Passivation of pn-structures (mesas) of compound semiconductors \( (T_D \leq 200^\circ C) \)
Low temperature deposition processes

Deposition methods

- Inductively coupled plasma enhanced chemical deposition (ICPECVD)
- Plasma enhanced atomic layer deposition (PEALD)
Low temperature deposition processes

ICPECVD
SI 500 D
ICP planar plasma source
RT-400°C
Gasses:
SiH4, O2, NH3, N2, H2, CH4
Films:
:SiO2, SiNx, SiOxNy, a-Si, SiC
Growth rate: 30-50 nm/min
Conformality:~0.7:1
Low ion energy, <10 eV
Main properties of ICPECVD films

MOS barrier
ICPECVD: SiOₓ, T = 260°C
nᵦ = 1.469
Nₛₛ = 0.2*10¹¹ cm⁻² eV⁻¹
Eᵦ = 8.6 MV/cm
r = 1.1*10¹⁸ Ohm cm
Low temperature deposition processes

Atomic Layer Deposition

- Complete control of deposition process in a nanometer scale
- Conformal coatings into high aspect ratio structures
- Pin-hole and particle free depositions
- Low temperature deposition by plasma enhanced ALD
- PEALD removes water as precursor
- Wide range of chemistry for film deposition
Atomic Layer Deposition of Al₂O₃

ALD cycle using TMA and water vapor:
1) TMA chemisorption
2) Purging step
3) Water chemisorption
4) Purging step

Applications:
ALD Al₂O₃ films have been investigated in different applications, such as:
- Charge-recombination layers in solar cells [1]
- Diffusion barriers in organic electronics [2]
- Gate dielectrics in transistors [3, 4]
- Passivation layers in Li-Ion batteries [5]
SENTECH SI ALD LL System
Specifications

Substrate size
- up to 8”

Substrate temperature
- 400° (up to 600 °C optional)

Reactor wall temperature
- 150°C (optional 200°C)

Precursor lines
- up to 4 separate inlets
  - direct draw or bubble line
  - 200°C heated
  - heater jacket for container

Gas lines
- up to 7

Plasma source
- true remote CCP source
  (option)

In-situ diagnostic
- SENTECH ellipsometer
- QMS, QMC

Options
- TMP with isolation valve
- Ozone line,
- Glove box
- Clusterable to other process modules
SENTECH SI ALD LL System

System software

- User-friendly, based on SENTECH plasma system software
- Special tool for operating ALD-pulses
- Reliable remote field controller (RFC)
- Manual and automatic operation
SENTECH SI ALD LL System

In-situ analysis

Optional available:
- Ellipsometry (laser, spectroscopic)
- Mass Spectrometer (QMS)
- Quartz Crystal Microbalance (QCM)

Applications:

<table>
<thead>
<tr>
<th></th>
<th>LE, SE, QMC</th>
<th>LE, SE, QMC</th>
<th>SE</th>
<th>QMC, QMS</th>
<th>QMS</th>
<th>QMS</th>
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<td>Growth</td>
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<td>Resistivity</td>
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<td>Chamber conditions</td>
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<td>Precursor behavior</td>
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</table>
SENTECH SI ALD LL System
In-situ analysis by laser ellipsometry
SENTECH SI ALD LL System

Key features of SI PEALD LL

Flexible system architecture
- A wide range of processes and applications

Thermal and plasma enhanced processing
- Plasma source can be separated from the system

True remote plasma source
- Substrate outside of the plasma generation region

In-situ diagnostic capability
- SENTECH ellipsometers, QMS ...

Rugged design and small footprint
- System can be connected to cluster tool
- L x W x H: 1800 x 680 x 1840 mm²
Properties of ALD Al$_2$O$_3$ films
Thermal ALD on 8" Wafer, thickness and R.I uniformity

Layer thickness

<table>
<thead>
<tr>
<th>Layer thickness: 8&quot; Wafer</th>
<th>49,9nm (± 1,2%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sigma</td>
<td>0,283nm</td>
</tr>
<tr>
<td>Growth rate</td>
<td>0,8 Å/cycle</td>
</tr>
<tr>
<td>Substrate temperature</td>
<td>200°C</td>
</tr>
<tr>
<td>n (@632,8 nm)</td>
<td>1,639 (± 0,15%)</td>
</tr>
<tr>
<td>Cycle time</td>
<td>2 s</td>
</tr>
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</table>

TMA + H$_2$O:
Properties of ALD $\text{Al}_2\text{O}_3$ films
Plasma enhanced ALD on 8" Wafer, thickness and R.I. uniformity

Layer thickness

Refractive index

TMA + $\text{O}_2$-Plasma:

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
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<tbody>
<tr>
<td>Layer thickness: 8&quot; Wafer</td>
<td>26.8 nm ($\pm$ 1.6%)</td>
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<tr>
<td>Sigma</td>
<td>0.232 nm</td>
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<tr>
<td>Growth rate</td>
<td>1.1 Å/cycle</td>
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<tr>
<td>Substrate temperature</td>
<td>200°C</td>
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<tr>
<td>$n$ (@632.8 nm)</td>
<td>1.642 ($\pm$ 0.58%)</td>
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<tr>
<td>Cycle time</td>
<td>10.5 s</td>
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</table>
Properties of ALD Al₂O₃ films

Linearity of growth

- Al₂O₃ film thickness shows linear dependence on the number of cycles in ALD and PEALD.

- PEALD provides a higher growth rate of 1.2 Å/cycle compared to ALD. The growth rate in ALD amounts 0.8 Å/cycle.

<table>
<thead>
<tr>
<th>Process parameter</th>
<th>ALD</th>
<th>PEALD</th>
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</thead>
<tbody>
<tr>
<td>Substrate temperature (°C)</td>
<td>200</td>
<td>200</td>
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<tr>
<td>Process pressure (Pa)</td>
<td>12</td>
<td>20</td>
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<tr>
<td>Plasma power (W)</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>Growth rate (Å/Cycle)</td>
<td>0.8</td>
<td>1.2</td>
</tr>
<tr>
<td>Cycle time (s)</td>
<td>4</td>
<td>8</td>
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</tbody>
</table>
Properties of ALD Al₂O₃ films

Conformality

18 nm ALD-Al₂O₃ @ 80 °C

21 nm PEALD-Al₂O₃ @ 80 °C

1) 3D resist structures were prepared on Si-Wafers* and coated with ALD and PEALD Al₂O₃ at 80°C substrate temperature.
2) Prepared samples were treated with O₂-plasma to remove resist and examined with REM*.

Very good conformality to 3D structures

*) Thanks to Dr. Hübner, IPHT-Jena, Germany, for preparing the 3D structures and doing the REM-measurement.
Properties of ALD Al$_2$O$_3$ films
Low temperature deposition of Al$_2$O$_3$ by PEALD
Properties of ALD Al$_2$O$_3$ films

Chemical information

XPS

IR spectroscopy
IR ellipsometer
SENDIRA

Impurities, methyl groups
Summary

- Outstanding features of SI PEALD-systems:
  ⇒ Flexible system configuration for a wide range of processes and applications
  ⇒ True remote plasma CCP source
  ⇒ In-situ control by ellipsometry
  ⇒ Rugged design and small footprint

- Process results:
  ⇒ Thermal and plasma enhanced deposition: very good uniformity
  ⇒ Thermal and plasma enhanced deposition: very good conformality
  ⇒ Incorporation of methyl groups at low temperature depositions

Outlook

Process optimization based on IR ellipsometry, in-situ laser ellipsometry
Thank you for your attention

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