Tunable ion flux density and its impact on AlN thin films deposited in a confocal DC Magnetron Sputtering System

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Outline

- Motivation & Introduction

- Results
  - Part A: Plasma Analytics
  - Part B: Thin Film Properties

- Conclusion
Motivation

- Plasma analytics
- Plasma control
- Control of thin film growth through plasma conditions

Magnetic Configuration of Single Magnetron

Side View

Type I

Balanced

Type II


Ref: CAPST, Sungkyunkwan University, Suwon, South Korea
Magnetic Configuration of Single Magnetron

- Plasma extended towards substrate
- Interaction of growing film with plasma


Ref: CAPST, Sungkyunkwan University, Suwon, South Korea
Confocal Dual Magnetron Sputtering

Closed Field

Open Field

Magnetrons (unbalanced)
Confocal Dual Magnetron Sputtering

a) Closed Field

b) Open Field

Magnetrons (unbalanced)
Confocal Dual Magnetron Sputtering

Substrate

Magnetrons (unbalanced)

Closed Field

Open Field

07.03.2017
Plasma Analytics Setup

<table>
<thead>
<tr>
<th>In Situ Coil</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>150</td>
</tr>
<tr>
<td>L</td>
<td>58 cm</td>
</tr>
<tr>
<td>R</td>
<td>8.8 – 12.2 cm</td>
</tr>
<tr>
<td>(</td>
<td>B_{\text{max}}</td>
</tr>
</tbody>
</table>
Plasma Analytics Setup

**Plasma Analytics**

- ‘Substrate Holder’
- Langmuir Probe
- Calorimetric Probe
- ‘Thermocouple’

<table>
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<td>N</td>
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<tr>
<td>L</td>
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<tr>
<td>R</td>
</tr>
<tr>
<td>$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Confocal DCMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\phi = \phi_{\text{Ar}}$</td>
</tr>
<tr>
<td>$P_{1,2}(\text{Al})$</td>
</tr>
<tr>
<td>$d_{\text{target} \to \text{substrate}}$</td>
</tr>
</tbody>
</table>
Plasma Analytics
I – Substrate Holder

- Enhancement of ion flux for both configurations
- Ion flux is the sum of ion flux from individual guns

<table>
<thead>
<tr>
<th>B_z = 0 G</th>
<th>B_z = 45 G</th>
</tr>
</thead>
<tbody>
<tr>
<td>Closed</td>
<td>Open</td>
</tr>
</tbody>
</table>

Single MS

- open
- closed

Dual MS
Plasma Analytics
II - Langmuir Probe

Closed Field

Open Field

Graphs showing ion current versus position for closed and open field conditions.
Local increase of ion flux density by more than one order of magnitude
Plasma Analytics
III – Calorimetric Probe

Closed Field

Open Field

Energy flux density (mW/cm²)

Energy flux density (mW/cm²)
Plasma Analytics
III – Calorimetric Probe

Local increase in energy flux density by more than one order of magnitude.

Almost identical spatial profiles to ion current density.
Plasma Analytics
IV – Temperature

Open Field, $I_{coil} = -24A$

<table>
<thead>
<tr>
<th>$I_{coil}$ [A]</th>
<th>Temperature [°C] (open field; $P_{1,2}(Al) = 200W$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>$T_{outer}$</td>
</tr>
<tr>
<td>116</td>
<td>108</td>
</tr>
<tr>
<td>-24</td>
<td>259</td>
</tr>
</tbody>
</table>
Motivation

Why Aluminum Nitride?

- **Hard** (around 20 GPa)
- **Wide bandgap** semiconductor (6.2 eV)
- **Optically Transparent** (400-800 nm)
- **Piezoelectric** (5.15 pm/V for $d_{33}$)

http://www.crystal-n.com
**AIN Thin Film Properties**

**Setup**

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**Reactive Confocal DC Magnetron Sputtering**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ar:N₂</td>
<td>15:12</td>
</tr>
<tr>
<td>Pressure</td>
<td>5 μbar</td>
</tr>
<tr>
<td>Power</td>
<td>200 W (10W/cm²)</td>
</tr>
</tbody>
</table>

**Varied Parameters**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ion to Neutral Ratio</td>
<td>1 ↔ 44</td>
</tr>
<tr>
<td>Ion Current Density</td>
<td>1.5 ↔ 70 A/m²</td>
</tr>
<tr>
<td>Temperature</td>
<td>100 ↔ 500 °C</td>
</tr>
</tbody>
</table>
AlN Thin Film Properties

- **Stochiometric films**
  Metal non-metal ratio not affected by ion bombardment

- **Oxygen** incorporation reduced for higher plasma densities

Explanation:

Higher reactivity of N\(_2\) in plasma environment

- **No Ar implantation** through increased ion bombardment (<0.07 at%, RBS+ERDA)

Low energy ion bombardment!

[1] Zhi-Ye Qiu et al. (2014), DOI: 10.1093/rb/rbu007
(almost) all samples show preferred (002)-orientation
AI N Thin Film Properties

Ion Bombardment of growing film

columnar, porous  dense

$T \, [^\circ C]$  $j_{ion} \, [A/m^2]$
Conclusions

- Variation of ion flux density with additional magnetic field in confocal DCMS.
  - $j_{\text{ion}}$ tunable over more than one order of magnitude
  - Considerable influence on temperature

- Comparison of influence of Ion Bombardment and Temperature on AlN thin film growth
  - (002) orientation: $100 ^\circ \text{C} < T < 500 ^\circ \text{C}$
    - $1 < j_{\text{ion}}/j_{\text{neutral}} < 30$
  - Stress: tensile $\rightarrow$ compressive with increasing $j_{\text{ion}}$
  - Microstructure: columnar, porous $\rightarrow$ dense with increasing $j_{\text{ion}}$