The current dependency of the compound sputtering yield

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Dedicated Research on Advanced Films and Targets
The importance of $Y_C$

Technological viewpoint:

- It determines the deposition rate in the poisoned mode

Academical viewpoint:

- It determines the shape and width of the hysteresis curve
Method of Reactive gas consumption

Steady state gas balance equation

\[ q_{in} = q_p + q_s + q_t \]

Gettered by the pump

Compound formation
Method of Reactive gas consumption

Direct relation between reactive gas consumption and compound sputtering yield

\[ q_{\text{cons}} = q_s + q_t = \frac{z}{2} I_{\text{ion}} Y_c \]

(assuming every sputtered particle forms stoichiometric compound)
How to measure the consumption?

Pressure gauge vs. Mass spectrometer

$$q_{cons} = q_{in} - \frac{P_{r, on} S_r}{k_B T}$$

Measure $P_{r, on}$!

But...

$$P_{r, on} = P_{tot, on} - (P_{Ar, on})$$

$P_{Ar, on}$ is unknown
How to measure the consumption?

Pressure gauge vs. Mass spectrometer

Perform calibration

Determine $q_{\text{cons}}$

$$q_{\text{cons}} = \frac{P_{\text{cons,RGA}}}{a}$$

$P_{r,\text{RGA}} = aq_r + b$
The current dependency of $Y_{\text{AlO1.5}}$

Experimental conditions:

- $S = 3 \text{ l/s}$
- $P_{\text{Ar}} = 0.5 \text{ Pa}$
- $f_{\text{O2}} = 0.2$

$$\text{Target or substrate property?}$$
The current dependency of $Y_{AlO1.5}$

Reactive gas consumption $\rightarrow$ Target + substrate
Conventional weight loss $\rightarrow$ Solely target

Qualitative but no quantitative agreement
Influence of redeposition

Region of effective growth adds weight!

Exclude redeposition

Influence of redeposition

Good agreement!

Method of reactive gas consumption is quantitative

Current dependency is a target related
Increased time-resolution

Poison target at $f_{O_2} = 0.2$

Switch of discharge
And wait certain time

Switch discharge back on at $f_{O_2} = 0.2$
and start measurement

<table>
<thead>
<tr>
<th>$P_{O_2}$ (mbar)</th>
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<tbody>
<tr>
<td>2.6</td>
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<tr>
<td>2.7</td>
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<td>2.8</td>
</tr>
<tr>
<td>2.9</td>
</tr>
<tr>
<td>3.0</td>
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<td>3.1</td>
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discharge on

discharge off

off time: 3600 s
discharge current: 0.05 A
Increased time-resolution
Increased time-resolution

Is this dynamical behavior real?
Sputtering cleaning experiments give information about initial target behavior.


Measure cleaning time:

Calculate $Y$: $t_{ct} \propto \frac{d}{Y}$

(With fixed thickness $d = 2$ nm)

Diagram showing the relationship between off time (s) and sputtering yield (AlO$_{1.5}$/ion).
The current dependency of Y

Possible explanations:

• Change in target surface topography (roughness)

  Aif et al., Surface and Coatings Technology 324 (2017)

• Texturing on the surface

  Depla D. Magnetrons, reactive gases and sputteiring (2017)
The current dependency of Y

Possible explanations:

- Change in target surface topography (roughness)
- Texturing on the surface
- Implantation and diffusion of reactive gas atoms

Dose effects
(cannot explain influence of off time)
Hypothesis: retention and diffusion

During reactive sputtering, (reactive) gas atoms are implanted

Without diffusion, the concentration of retained gas scales as $n_r \sim 1/Y$

(radiation enhanced) diffusion regulates the actual amount of gas


Janssens et al., Surface Science 601 (2007)
Hypothesis: retention and diffusion

Low current density $\implies$ Retained gas diffuses out
High current density $\implies$ Retained gas gets sputtered

Beshenkov et al., Technical Physics 47 (2002)

During the off time, the gas is able to diffuse out...

... but the refilling does not scales linearly with the current due to the duality

$Y \leftrightarrow n_r$
Conclusion

• A new method to determine the compound sputtering yield based on reactive gas consumption is introduced.

• The method is quantitative and has a high time-resolution.

• The compound sputtering yield shows a current dependency.

• A hypothesis on reactive gas implantation, retention and sputtering/diffusion is postulated.
Acknowledgements

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