Investigation of the O\textsuperscript{-} emission during reactive magnetron sputtering.

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Partially Funded by the FWO-Flanders

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Idea

Energy Mass distribution

Conclusions

planar

rotatable

Amount

Direction

Influence

Vd

Vp

Ar

+e

M

O

Ar^+

O_2

2

MO

x

y

e^-

M

O
negative ions with an energy \( \sim V_d \) have been observed by many authors for different systems:

\[
\begin{align*}
\text{Power mode:} & \quad \text{Target:} & \quad \text{Reactive gas:} \\
\text{DC, RF, Pulsed DC} & \quad \text{metallic, compound} & \quad \text{O}_2, \text{H}_2\text{S}
\end{align*}
\]

Energy, direction, and amount?

Experimental + Model/Simulation
Energy of ions

Y or Al

M$^+$

O$^-$

P(Ar) 0.4 Pa
P(O$_2$) 0.04 Pa

8 cm

Mass spec

2: S. Mahieu and D. Depla: APL 90 (2007) 121117
Can we simulate the energy distribution?
Simulation of energy distribution

Initial position, energy and direction

Collision with background gas, new energy, direction

Initial position: simulation of discharge (e⁻ trajectory MC code or PIC/MC) gives racetrack and energy of Ar⁺ ions bombarding the target


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Simulation of energy distribution

Initial position, energy and direction

Collision with background gas
new energy, direction

Initial energy and direction: simulation of collision cascade in
the target with SRIM (don’t forget to correct for the surface
binding energy)

1: Stopping Range of Ions in Matter

Free download: www.srim.org
Simulation of energy distribution


$$\lambda = -\lambda_m \ln(RN)$$

$\lambda_m$ depends on regime (speed of particle compared to energy of background gas)
Simulation of energy distribution

Initial position, energy and direction

Collision with background gas
new energy, direction

Energy of sputtered Y particles

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Simulation of energy distribution

Negative O⁻ ions: two remarks:
- Surface binding energy for oxide from Malherbe et al.
- Additional acceleration over discharge potential

Simulation of energy distribution

Mass distribution of negative ions

Not only $O^-$, but also $O_2^-$, $MO^-$, $MO_2^-$
Direction of negative $O^-$ ions

Idea
Energy
Mass distribution
Direction
planar
rotatable
Amount
Influence
Conclusions
Direction of negative O\(^-\) ions

-30°  -20°  -10°  0°  10°  20°  30°

Al target
P(Ar) 0.4 Pa
P (O\(_2\)) 0.04 Pa
Vd 290V
Id 0.25 A
8 cm
Direction of negative O\(^-\) ions

Can we simulate this?

Y target
P(Ar) 0.4 Pa
P (O\(_2\)) 0.04 Pa
Vd 185 V
Id 0.25 A
8 cm
Mass-spec has limited acceptance angle $A$!

SiMTRA allows to simulate amount of $O^-$ at small angle and total amount of $O^-$. 

Direction of negative O$_-$ ions

**Al**

$V_d = 290$ V

**Y**

$V_d = 185$ V

- Al: $V_d = 290$ V
- Y: $V_d = 185$ V

- 'O exp'
- 'O SiMTRA'
- 'O/Y SiMTRA (a.u.)'
- 'magnetron'

- 0°: 10°
- 20°: -30°
- -20°: -10°
- -30°: 30°
Direction of negative $O^-$ ions
Direction of negative $O^-$ ions

Al

$V_d = 290 \, V$

Y

$V_d = 185 \, V$

'I O exp'  'O SiMTRA'  'O/Al SiMTRA (a.u.)'

'magnetron'  'O SiMTRA 180°'
**Direction of negative O\(^-\) ions**

Al target
P(Ar) 0.4 Pa
P (O\(_2\)) 0.04 Pa
Vd 220V
Id 0.25 A
Direction of negative O\textsuperscript{-} ions
Influence of oxygen flow

Only high energy negative ions when target is poisonned.
Amount of high energy O$^-$ ions

13 different metallic targets

$$\text{Sum} = \gamma(O^-)$$

$$N(O) = I^+ Y_{tot} \frac{z}{1 + z}$$

$$\text{MO}_z$$

Ion induced O$^-$ emission $\approx \gamma(O^-)/N(O)$

1: S. Mahieu and D. Depla: APL 90 (2007) 121117
Ion induced O⁻ emission is related to ISEE of oxide

\[ V_d = \frac{2^{-1/2} \eta d \varepsilon \varepsilon_r}{W} \]

1. S. Mahieu and D. Depla: APL 90 (2007) 121117
Amount of high energy O\textsuperscript{−} ions

Ion induced O\textsuperscript{−} emission is related to ISEE of oxide

Reason:
Probability to sputter a negative ion is related the work function \( \phi \)

\[
P = k \exp\left( \frac{E_{ea} - \phi}{\varepsilon_N} \right)
\]

ISEE is related to the bulk modulus and thus probably also to the work function \( \phi \) (see talk D. Depla)

Influence of O-ions

Deposition of AlO_x and YO_x on semi-circle. Substrate is grounded Si + native oxide

Characterisation with ellipsometer and XRD

Conclusions
Influence of O$^-$ ions: optical properties AlO$_x$ on Si

\[
\begin{align*}
\lambda k_{max} & \quad \lambda n_{max} \\
< n >_{\lambda,380} & \quad \ldots \text{model}
\end{align*}
\]
Influence of O⁻ ions: optical properties AlOₓ

Al₂O₃ on Si

Refractive index of 125 nm Al₂O₃ on Si decreases with O⁻ bombardment
Influence of O\textsuperscript{−} ions: XRD YO\textsubscript{x}

\[ I_{\text{tot}} = \frac{A_{222}}{I_{222}} + \frac{A_{400}}{I_{400}} + \frac{A_{440}}{I_{440}} + \frac{A_{622}}{I_{622}} \]

\( A_{\text{hkl}} \) is peak area in \( \theta/2\theta \) for hkl plane
\( I_{\text{hkl}} \) is intensity factor

Crystallinity decreases with O\textsuperscript{−} bombardment
Conclusions

The energy distribution of negative ions can be simulated with SiMTRA.

A striking difference in angular distribution of high energy O⁻ ions for planar and rotating cylindrical magnetrons.

Can be simulated with SiMTRA.
Conclusions

The amount of high energy negative ions is related to ISEE and $\phi$ of sputtered material.

Selected film properties are shown to be related to the amount of high energy $O^-$ ions.
THANK YOU

Thanks to:
-IWT Flanders and FWO Flanders for financial support

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