The discharge voltage behaviour during reactive sputtering of oxides

R. De Gryse, D. Depla, J. Haemers
Hysteresis behaviour Ti/O$_2$ and Al/O$_2$

Discharge voltage INCREASES on addition of oxygen

Discharge voltage DECREASES on addition of oxygen

Measurements by S. Heirwegh
$V_{\text{discharge}} = \frac{W_0}{\varepsilon_0 \varepsilon_i E \gamma_{\text{ISEE}}}$

$W_0$: effective ionisation energy

$\varepsilon_i$: ion collection efficiency (for magnetron: almost 1)

$\varepsilon_0$: fraction of maximum possible number of ions (for magnetron: almost 1)

$m$: multiplication factor: accounts for ionisation in the sheath

$E$: effective ionisation probability: influenced by electron recapture

$\gamma_{\text{ISEE}}$: ion induced secondary electron emission coefficient

* G. Buyle, “Simplified model for the DC planar magnetron discharge (PhD, UGENT, 2005)
Relationship ISEE/Voltage

- **Inverse of the discharge voltage (x10^-3 1/V)**
  - **ISEE coefficient**

- **Elements**:
  - Ag
  - Al
  - Au
  - Ce
  - Cr
  - Cu
  - Mg
  - Nb
  - Pt
  - Re
  - Ta
  - Ti
  - Y
  - Zr
Measuring scheme

- **Voltage**: 
  - $V_{O_2}$
  - $V_{oxAr}$
  - $V_{Ar}$

- **Status**
  - Argon
  - Oxygen
  - Magnetron

- **Time**
  - $\Delta t$

- **Discharge voltage**
  - Oxygen addition (red)
  - Oxygen removal (blue)

- **Oxygen flow**
  - Ti

- **Graph**
  - Discharge voltage vs. oxygen flow

AIMCAL.org
Results for different metals
ISEE: two groups

High ISEE coefficient

Low ISEE coefficient

See Phelps et al. (Plasma Sources Science and Technology 1999)
At constant current: \[ V_{\text{discharge}} = \frac{W_0}{e_0 i n F_{\text{SE}} E} \]

Energy loss per produced ion – electron pair

M.A. Lieberman, A.J. Lichtenberg, Principles of plasma discharges and materials processing (New York, Wiley)
Calculation of yield

\[
\frac{I}{n_0} = \frac{Y}{\Delta}
\]

\[d = R_p + R_f\] (1)

SRIM (2)
- ion: \(O^+\)
- energy: \(eV_{O2}/2\)
- material: oxide (density, stoichiometry)


(2) SRIM can be downloaded from http://www.srim.org
SRIM sputter yields: calculated based on the surface binding energy following the model of Malherbe et al. (Appl. Surf. Sci. 27 (1986): 355-365)
Hypothesis: Sputter bombardment results in reduction of the oxide which will influence the ISEE coefficient.

Reduction

\[ R = \frac{(M/O)^s}{(M/O)^b} \]
Hypothesis (2)

ISEE coefficient vs O/M ratio

- ISEE coefficient values: 0.11, 0.10, 0.09, 0.08
- O/M ratio values: 1.6, 1.4, 1.2, 1.0, 0.8, 0.6

The graph shows a negative correlation between ISEE coefficient and O/M ratio.
At constant current, during reactive sputtering:

1) Increase or decrease of the discharge voltage can be attributed to a change of the ISEE coefficient due to target oxidation.

2) Strong ion bombardment reduction results in a low ISEE coefficient.

3) A linear relationship between the O/M and the ISEE coefficient has been shown.
Acknowledgements

The authors are indebted to the BEKAERT company for financial support