The chemical origin of SEY at technical surfaces

Rosanna Larciprete
CNR-Istituto dei Sistemi Complessi, Roma, Italy
and
INFN-LFN, Frascati (RM), Italy

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**Secondary Electron Yield**

Three-step process:

- production of SEs at a depth $z$
- transport of the SE toward the surface
- emission of SE across the surface barrier

The material parameters influencing SEY are:
- penetration depth of the primary electrons,
- stopping power,
- escape depth of the secondary electrons,
- work function - $Z$ number
Spread in the SEY data

Lin et al. SIA 2005, 37 895

the effective SEY of the metal is strongly modified by the surface contamination
X-ray photoelectron spectroscopy

KE = hv - BE - \phi

KE: kinetic energy
\phi: work function
BE: binding energy

C1s
hv = 400 eV
FWHM = 250 meV

hv = 1253.6 eV
FWHM = 0.95 eV
XPS spectroscopy of technical samples

- **Oxygen**
- **Hydrogen**
- **Carbon**
- **Metal**
- **C-O-C**
- **C=O**
- **C-H**
- **C-C sp<sup>3</sup>**
- **C-C sp<sup>2</sup>**

**Diagram:***

- **M-O**
- **M**
- **O-C=O**
- **C=O**
- **C-H**
- **C-O-C**
- **C-C sp<sup>3</sup>**
- **C-C sp<sup>2</sup>**
SEY of technical samples

high SEY
medium SEY
low SEY
SEY of technical samples

Incident beam

Secondary electrons

Bond dissociation: M-O, C-OH, C-O, C=O, C

Electron beam desorption: O₂, H₂O, H₂ CO, CO₂

Bond rearrangement: C → C

sp³ → sp²
SEY of technical samples

incident beam

dissociation of “environmental” molecules → reactions, film growth
co-laminated Cu for LHC beam screen

I=5μA
Q=1.2x10^{-3} C/mm²

SEY decreases also outside the beam spot
co-laminated Cu for LHC beam screen

E=500 eV
I=5\mu A
Q=1.2x10^{-3} \text{ C/mm}^2

- the beam spot but also the surrounding area is modified
- in the beam spot the quantity of surface C increases $\rightarrow$ graphitic film growth
co-laminated Cu for LHC beam screen

\[ \delta_{\text{max}} = 2.2 \]
\[ \delta_{\text{max}} = 1.25 \]
\[ \delta_{\text{max}} = 1.6 \]

Ar\(^+\) sputtering @ 2.2 KV + e beam irradiation @ 500 eV, 10 \(\mu\)A, 15 h, Q=3.6x10\(^{-2}\) C/mm\(^2\)
e\textsuperscript{-} beam induced surface reactions

Cu-O dissociation → oxide reduction

C-H dissociation → sp\textsuperscript{3}→sp\textsuperscript{2} conversion

C-O dissociation → C film growth

the contribution of all electron-induced surface reactions reduces δ\textsubscript{max} from 2.2 to 1.1
co-laminated Cu for LHC beam screen

R. Cimino et al. submitted to PRL
co-laminated Cu for LHC beam screen

R. Cimino et al. submitted to PRL
Stainless steel samples from RICH@BNL

E=500 eV

Intensity (arb. units)

Binding energy (eV)

Primary energy (eV)

δ_{max}=2.2

δ_{max}=1.3

δ_{max}=1.1

δ_{max}=1.05
Al samples from Petra III

D. Grosso et al. submitted to PR-ST
72.5 eV Al metallic
73.4 eV Al bonded to chemisorbed O
73.9 eV tetrahedral Al₂O₃
75.1 eV octahedral Al₂O₃

the minimal partial pressure of H₂O contained in the residual gas is sufficient to hinder the achievement of a stable, clean Al surface.

After prolonged ion bombardment there are still Al atoms bonded to O even in a Al₂O₃ phases

D. Grosso et al. submitted to PR-ST
dissociation of residual gas molecules as $\text{H}_2\text{O}$ and $\text{CO}$ induced at the metal surface by the $\text{e}^-$ beam determines a rapid oxidation of the irradiated area, as well as, although to a lesser extent, of the surrounding region.

D. Grosso et al. submitted to PR-ST
Al samples from Petra III

dramatic enhancement exclusively of the most oxidized Al₂O₃ phase

72.5 eV Al metallic
73.4 eV Al bonded to chemisorbed O
73.9 eV tetrahedral Al₂O₃
75.1 eV octahedral Al₂O₃

D. Grosso et al. submitted to PR-ST
Al samples from Petra III

The SEY variation follows the oxygen content of the Al surface

D. Grosso et al. submitted to PR-ST
Al-O dissociation \( \rightarrow \) oxide reduction

\[ \begin{align*} 
\text{CO} & \rightarrow \text{CO}_2 \\
\text{H}_2\text{O} & \rightarrow \text{H}_2 \\
\text{C-O} & \rightarrow \text{C} \text{ film growth} \\
\text{C-H} & \rightarrow \text{H}_2 \\
\text{sp}^3 & \rightarrow \text{sp}^2 
\end{align*} \]

SEY is determined by the rates of Al oxidation and reduction

\[ \begin{align*} 
\text{2Cu}_2\text{O} + \text{O}_2 & \rightarrow 4\text{CuO} \\
\text{4Cu} + 2\text{O}_2 & \rightarrow 2 \text{ Cu}_2\text{O} \\
\text{2Fe} + \text{O}_2 & \rightarrow 2 \text{ FeO} \\
\text{4Al} + 3\text{O}_2 & \rightarrow 2 \text{Al}_2\text{O}_3 
\end{align*} \]
a-C films
magnetron sputtering @ RT
p(Ar) = 10^{-2} mbar
Δt = 2 min

C film thickness 2-3 nm
the graphitization of the C films corresponds to a lower SEY
Conclusions

The SEY of technical samples is strongly affected by the chemical composition of the surface as the presence and the nature of contaminating adsorbates can heavily modify the effective $\delta_{\text{max}}$ values. This determines the high variation of the experimental values.

For Cu samples electron conditioning at 500 eV reduces the SEY and lowers $\delta_{\text{max}}$ from 2.2 to 1.1. Both direct beam and secondary electrons have a role in the chemical reactions which decrease the SEY.

Similar results were found for stainless steel samples.

On the contrary for Al samples electron conditioning at 500 eV does not succeed in lowering $\delta_{\text{max}}$ below 1.8 (1.5). In this case the composition of the residual gas in the UHV chamber is extremely important in limiting the $e^-$ beam induced oxidation.

For ultrathin C films deposited by magnetron sputtering on copper $\delta_{\text{max}}$ depends on the sp$^3$/sp$^2$ ratio.

The knowledge of the chemical state of a “technical” surface can elucidate the origin of the measured SEY curves and in general provide profitable information for the e-cloud mitigation.
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