Comparison of photodesorption yields using synchrotron radiation of low critical energies for electrodeposited copper and aluminum surfaces

J. Gómez-Goñi,
Dept. de Física Aplicada a las Tecnologías de la Información,
EUIT de Telecomunicación,
Universidad Politécnica de Madrid
&
CERN LHC/VAC Division
Outline

- Introduction
- Experimental setup
- Electrodeposited copper & Aluminum
  - Influence of critical energy
  - Influence of dose
  - Influence of treatment
  - Influence of material processing
- Photoelectron production
- Conclusions
## LHC parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>[TeV]</td>
<td>7.0</td>
</tr>
<tr>
<td>Dipole field</td>
<td>[T]</td>
<td>8.4</td>
</tr>
<tr>
<td>Luminosity</td>
<td>[cm(^{-2}) s(^{-1})]</td>
<td>(10^{34})</td>
</tr>
<tr>
<td>Injection energy</td>
<td>[GeV]</td>
<td>450</td>
</tr>
<tr>
<td>Circulating current/beam</td>
<td>[A]</td>
<td>0.54</td>
</tr>
<tr>
<td>Bunch spacing</td>
<td>[ns]</td>
<td>25</td>
</tr>
<tr>
<td>Particles per bunch</td>
<td></td>
<td>(10^{11})</td>
</tr>
<tr>
<td>Beam lifetime</td>
<td>[h]</td>
<td>22</td>
</tr>
<tr>
<td>Luminosity lifetime</td>
<td>[h]</td>
<td>10</td>
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<tr>
<td>Energy loss per turn</td>
<td>[keV]</td>
<td>6.7</td>
</tr>
<tr>
<td>Critical photon energy</td>
<td>[eV]</td>
<td>44.1</td>
</tr>
<tr>
<td>Photon Flux</td>
<td>[ph m(^{-1}) s(^{-1})]</td>
<td>(1\times10^{17})</td>
</tr>
<tr>
<td>Total radiated power per beam</td>
<td>[kW]</td>
<td>3.6</td>
</tr>
</tbody>
</table>
LHC Dipole layout

Cross Section of LHC Dipole

Vacuum Vessel
Beam Pipe
Heat Exchanger Pipe
Superconducting Coils
Iron Yoke (COLD MASS, 1.9K)
Shrinking Cylinder / HE II - Vessel
Radiative Insulation
Support Post

He 50K 20 bar
LHC beam screen layout
Experimental Setup

- Ti Sub Pump
- + Ion Pump
- Conductance
- B.A. Gauge
- Gate Valve
- Test Chamber
- Photon Beam
- Photoelectron Probe
- EPA Ring
- Collimator
- Gate Valve
- Valve
- Turbo Pump
- Rotary Pump
- Ti/IP
- VG
- Gate Valve
- RGA
- EPA Ring
- Test Chamber
Experimental details

- **Synchrotron radiation**
  - Bending magnet
  - Collimator 7.8 x 7.8 mrad
  - Photon energies below 4.2 eV attenuated
  - 11 mrad incidence

- **Vacuum**
  - Conductance of 72.5 $\ell$ s$^{-1}$ for N$_2$
  - Gas analyser and vacuum gauge calibrated
  - H$_2$O was not calibrated

- **Photoelectrons**
  - 200 mm long, 1 mm diameter stainless steel wire along the axis
  - Photoelectron currents at + 1kV
SR critical energy

- Median of power distribution

\[ \frac{W_l}{2} = \int_{0}^{E_c} \frac{dN_g}{dE_g} E_g dE_g \]

\[ E_c = \frac{3 \hbar c \gamma^3}{2r}, \text{ where } \gamma = \frac{E}{(m_0 c^2)} \]

For electrons \( E_c \) (eV) = \( 2.22 \times 10^{-6} \frac{E^3 \text{(MeV)}}{r \text{(m)}} \)

For protons \( E_c \) (eV) = \( 3.59 \times 10^{-16} \frac{E^3 \text{(MeV)}}{r \text{(m)}} \)
Synchrotron radiation

Photon flux into 0.1% dE/E bandwidth (Photons s⁻¹)

Photon energy (eV)

194 eV
45 eV

V. Baglin et al, CERN
Vac. Tech. Note

ASEVA Summer School July 1999

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**Electroplated copper: Cleaning**

- **Special electroplated copper (Flühmann AG)**
  - Stainless steel chamber chemically cleaned by
    - perchloroethylene vapour at 121°C,
    - alkaline detergent at 65°C
    - cold demineralized water
    - drying in a vacuum oven at 150°C.
  - Covered by 0.1 µm Ni + 0.2 µm Au + 100 µm Cu
  - Reversed pulse current with smooth surface finishing

- **CERN electroplated copper**
  - No cleaning, unbaked
  - Flash of Ni and 100 µm Cu
Aluminum: Cleaning

- **Aluminum**

- **Anticorodal Al (ISO Al-Si1-Mg-Mn 6082)**
- **Chemically cleaned by:**
  - perchloroethylene vapour at 121°C,
  - alkaline detergent at 65°C
  - cold demineralized water
  - drying in a vacuum oven at 150°C.
Electroplated copper: Influence of critical energy (I)

Flühmann Electroplated Cu
As received

Desorption Yield (molecules/photon)

Critical Energy (eV)

H₂
CH₄
H₂O
CO
CO₂
Electroplated copper: Influence of critical energy (II)

CERN Electroplated Cu
As received

Desorption Yield (molecules/photon)

Critical Energy (eV)

- $H_2$
- $CH_4$
- $H_2O$
- CO
- $CO_2$
Aluminum: Influence of critical energy (I)

Desorption Yield (molecules/photon) versus Critical Energy (eV) for Unbaked Al.

- H₂
- CH₄
- H₂O
- CO
- CO₂
Aluminum: Influence of critical energy (II)

Desorption Yield (molecules/photon)

Critical Energy (eV)

Baked Al

- H₂
- CH₄
- H₂O
- CO
- CO₂
Aluminum: Influence of critical energy (III)

Desorption Yield (molecules/photon) vs. Critical Energy (eV)

- Baked Al
- EPA
- DCI

Graph showing desorption yield as a function of critical energy for different species:
- $H_2$
- $CH_4$
- $H_2O$
- CO
- $CO_2$
OFHC Copper: Influence of critical energy

Photodesorption Yield (mol/photon) vs. Critical Energy (eV)

- H₂
- CH₄
- CO
- CO₂

EPA
BNL
DCI

OFHC Cu (baked)
Stainless steel: Influence of critical energy

Photodesorption Yield (mol/photon) vs Critical Energy (eV)

- SS 316 L+N (baked)
- EPA
- BNL
- DCI

Chemical species:
- $\text{H}_2$
- $\text{CH}_4$
- CO
- $\text{CO}_2$
 Dependence of yields on critical energy

\[ \eta \text{ (molec/ph)} = C \ E_c^\alpha \text{ (eV)} \]

<table>
<thead>
<tr>
<th>Exponent ( \alpha )</th>
<th>( \text{H}_2 )</th>
<th>( \text{CH}_4 )</th>
<th>( \text{CO} )</th>
<th>( \text{CO}_2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>St. Steel</td>
<td>-</td>
<td>1.0</td>
<td>0.92</td>
<td>0.96</td>
</tr>
<tr>
<td>OFHC Cu</td>
<td>0.74</td>
<td>0.94</td>
<td>1.01</td>
<td>1.12</td>
</tr>
<tr>
<td>Flu Cu</td>
<td>1.12</td>
<td>1.12</td>
<td>1.18</td>
<td>1.07</td>
</tr>
<tr>
<td>CERN Cu</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Baked Al</td>
<td>1.21</td>
<td>1.32</td>
<td>1.18</td>
<td>1.16</td>
</tr>
<tr>
<td>Unbaked Al</td>
<td>1.4</td>
<td>2.2</td>
<td>1.7</td>
<td>1.9</td>
</tr>
</tbody>
</table>
Electroplated copper: Influence of dose (I)

Fluhmann Electroplated Cu

\( E_c = 63.5 \, \text{eV} \quad \text{As received} \)

- \( LHC \ 3h \)

Desorption Yield (molecules/photon) vs. Dose (photons m\(^{-1}\))

- \( \text{H}_2 \)
- \( \text{CH}_4 \)
- \( \text{H}_2\text{O} \)
- \( \text{CO} \)
- \( \text{CO}_2 \)
Electroplated copper: Influence of dose (II)

Flühmann Electroplated Cu

$E_c = 63.5 \text{ eV}$

Molecules desorbed (ML)

Dose (photons m$^{-1}$)

$H_2$

$\text{CH}_4$

$H_2O$

CO

$\text{CO}_2$

$LHC 3h$

Dose (photons m$^{-1}$)
Electroplated copper: Influence of dose (III)

Desorption Yield (molecules/ photon) vs Dose (photons m⁻¹)

- As received
- \( E_c = 51.2 \text{ eV} \)
- CERN Electroplated Cu

Species:
- \( \text{H}_2 \)
- \( \text{CH}_4 \)
- \( \text{H}_2\text{O} \)
- \( \text{CO} \)
- \( \text{CO}_2 \)

LHC 3h
Electroplated copper: Influence of dose (IV)

Desorbed Molecules (ML) vs. Dose (photons/m)

- $H_2$
- $CH_4$
- $H_2O$
- CO
- $CO_2$

CERN electroplated Cu

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Electroplated copper: decay after long exposure

CERN electroplated Cu
Decay after long exposure

Relative Ion Current (a.u.)

Time (s)

- $\text{H}_2$
- $\text{CH}_4$
- $\text{H}_2\text{O}$
- $\text{CO}$
- $\text{CO}_2$

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Electroplated copper: Influence of treatment

Desorption Yield (molecules/photon)

- Unbaked
- Baked
- Pre-baked
- Ar dischar

After $1 \times 10^{21}$ ph/m

- $H_2$
- $CH_4$
- $H_2O$
- CO
- $CO_2$

Flühmann Electroplated Cu

$E_c = 63.5$ eV
Electroplated Cu: Comparison of treatments

<table>
<thead>
<tr>
<th></th>
<th>Baked</th>
<th>Unbaked</th>
<th>Pre-Baked</th>
<th>Glow discharged</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{H}_2$</td>
<td>1</td>
<td>6.6</td>
<td>1.9</td>
<td>1.02</td>
</tr>
<tr>
<td>$\text{CH}_4$</td>
<td>1</td>
<td>8.9</td>
<td>1.5</td>
<td>1.2</td>
</tr>
<tr>
<td>$\text{H}_2\text{O}$</td>
<td>1</td>
<td>885</td>
<td>22</td>
<td>11.1</td>
</tr>
<tr>
<td>$\text{CO}$</td>
<td>1</td>
<td>6.4</td>
<td>3.1</td>
<td>1.4</td>
</tr>
<tr>
<td>$\text{CO}_2$</td>
<td>1</td>
<td>2.7</td>
<td>3.4</td>
<td>1.04</td>
</tr>
</tbody>
</table>
Aluminum: Influence of treatment

Aluminum

$E_c = 63.5$ eV

Desorption Yield (molecules/photon)

Unbaked Baked 150°C

$H_2$, $CH_4$, $H_2O$, $CO$, $CO_2$
## Aluminum: Comparison of treatments

<table>
<thead>
<tr>
<th></th>
<th>Baked</th>
<th>Unbaked</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{H}_2$</td>
<td>1</td>
<td>8.6</td>
</tr>
<tr>
<td>$\text{CH}_4$</td>
<td>1</td>
<td>5.8</td>
</tr>
<tr>
<td>$\text{H}_2\text{O}$</td>
<td>1</td>
<td>7970</td>
</tr>
<tr>
<td>CO</td>
<td>1</td>
<td>11.3</td>
</tr>
<tr>
<td>$\text{CO}_2$</td>
<td>1</td>
<td>9.8</td>
</tr>
</tbody>
</table>
Electroplated copper: Influence of material processing

As received samples

$E_c = 194$ eV

Desorption Yield (molecules/photon)

- $H_2$
- $CH_4$
- $H_2O$
- CO
- $CO_2$

Flühmann Cu

CERN Cu
Aluminum: Photoelectron Yields vs critical energy

Critical Energy (eV)

Photoelectron Yield (elec/ph)

Unbaked Al

Baked Al

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All materials studied: Photoelectron Yields vs $E_c(II)$

- Fluhmann Cu
- SS 316 LN
- Unbaked Al
- Baked Al
- RollBonded Cu as received (1)
- RollBonded Cu air baked (1)
- CERN plated Cu (1)

(1) V. Baglin et al, CERN Vac. Tech.

Critical Energy (eV) vs Photoelectron Yield (elec/ph)
**Dependence of photoelectron yield with critical energy**

\[ I_{pe} \text{ (elec/ph)} = A \ E_c \text{ (eV)} + B \]

<table>
<thead>
<tr>
<th>Material</th>
<th>A</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>St. Steel</td>
<td>$4 \times 10^{-4}$</td>
<td>$3 \times 10^{-2}$</td>
</tr>
<tr>
<td>Flu Cu</td>
<td>$4 \times 10^{-4}$</td>
<td>$2 \times 10^{-2}$</td>
</tr>
<tr>
<td>Baked Al</td>
<td>$1.2 \times 10^{-3}$</td>
<td>$4 \times 10^{-2}$</td>
</tr>
<tr>
<td>Unbaked Al</td>
<td>$1.3 \times 10^{-3}$</td>
<td>$4 \times 10^{-2}$</td>
</tr>
</tbody>
</table>

\[ I_{pe} \text{ (elec/ph)} = C \ E_c^2 \text{ (eV}^2\text{)} + A \ E_c \text{ (eV)} + B \]

<table>
<thead>
<tr>
<th>Material</th>
<th>C</th>
<th>A</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>St. Steel</td>
<td>$-2 \times 10^{-6}$</td>
<td>$1.0 \times 10^{-3}$</td>
<td>$1 \times 10^{-2}$</td>
</tr>
<tr>
<td>Flu Cu</td>
<td>$-9 \times 10^{-7}$</td>
<td>$6.0 \times 10^{-4}$</td>
<td>$1 \times 10^{-2}$</td>
</tr>
<tr>
<td>Baked Al</td>
<td>$-4 \times 10^{-6}$</td>
<td>$2.2 \times 10^{-3}$</td>
<td>$8 \times 10^{-3}$</td>
</tr>
<tr>
<td>Unbaked Al</td>
<td>$-3 \times 10^{-6}$</td>
<td>$2.2 \times 10^{-3}$</td>
<td>$9 \times 10^{-3}$</td>
</tr>
</tbody>
</table>
Aluminum: Pressure rise vs photoelectron yields

Specific Pressure Rise (Torr mA⁻¹ GeV⁻¹) vs Photoelectron Yield (elec/ph)

- Unbaked Al

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Aluminum: Pressure rise vs photoelectron yields (II)

Specific Pressure Rise (Torr mA⁻¹ GeV⁻¹)

Photoelectron Yield (elec/ph)

Baked Al
Electrodeposited copper: Pressure rise vs photoelectron yields

Photoelectron Yield (elec/ph)

Specific Pressure Rise (Torr mA⁻¹ GeV⁻¹)

+ Fluhmann Cu

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Stainless steel: Pressure rise vs photoelectron yields

Specific Pressure Rise (Torr mA⁻¹ GeV⁻¹)

Photoelectron Yield (elec/ph)

SS 316 LN

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Dependence of specific pressure rise on photoelectron yield

\[ \frac{\Delta P}{I_B E_B} \text{ (Torr mA}^{-1} \text{ GeV}^{-1}) = A I_{pe} \text{ (elec/ph)} + B \]

<table>
<thead>
<tr>
<th>Material</th>
<th>A</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>St. Steel</td>
<td>$4 \times 10^{-9}$</td>
<td>$-1 \times 10^{-10}$</td>
</tr>
<tr>
<td>Flu Cu</td>
<td>$7 \times 10^{-8}$</td>
<td>$-1 \times 10^{-9}$</td>
</tr>
<tr>
<td>Baked Al</td>
<td>$1 \times 10^{-8}$</td>
<td>$-4 \times 10^{-10}$</td>
</tr>
<tr>
<td>Unbaked Al</td>
<td>$4 \times 10^{-8}$</td>
<td>$-1 \times 10^{-10}$</td>
</tr>
</tbody>
</table>
Conclusions

- Desorption yields are linear with critical energy in the range studied (10 to 200 eV)
- Initial yields are reduced with different treatments:
  - In situ bakeout
  - Bakeout before installation
  - Ar + O₂ glow discharge
- Yields for specially electroplated copper of the same order than for normal copper electroplating
- Cleaning effect with dose at low critical energies
- Almost linear relation between photoelectron yields and critical energies
- Almost linear relation between specific pressure rise and photoelectron yields
Acknowledgements

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