Low Secondary Electron Yield Carbon Coatings for E-cloud Mitigation in Modern Particle Accelerators

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Motivation
- Electron Cloud Build-Up
- SPS-U: Super Proton Synchrotron Upgrade
- New solution!? → Amorphous Carbon Coating

Experiments
- Experiments in the lab: Thin Film Coatings + SEY measurements
- Implementation in the SPS: Coatings + E-cloud experiments
- Ageing observation of a-C coating: in the lab + in the SPS

Applications and Conclusions
- Application on the dipole magnets in the SPS
- Summary
Outline

1 Motivation
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3 Applications and Conclusions
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In the beam pipe of high-energy proton or positron particle accelerators, an ‘Electron Cloud’ can be generated:

- by residual gas ionization.
- by photoemission from synchrotron radiation.
- by subsequent secondary electron emission via a beam-induced multipactoring process.

The electron cloud leads to:

- dynamic pressure rise (electron stimulated desorption).
- transverse emittance blow-up (bunch expansion).
- thermal load in cryogenic vacuum systems.
- fast or slow beam losses.
The goal of this work

SPS-U: make the SPS able to deliver the above nominal beams to LHC and reach maximum luminosity.

Find a solution to eliminate e-cloud in the SPS, which

- can be implemented in the present SPS-dipoles
- does not require bake-out
- is robust against air venting (maintenance, installation...)
- has a long life time

The condition to avoid e-cloud in SPS dipoles with nominal LHC beam is (G.Rumolo et al.)

\[ \delta_{max} < 1.3 \]
Possible remedies for the electron cloud in the beam pipe:

- Low Secondary Electron Yield (SEY) thin-film coatings
- surface conditioning
- clearing electrodes
- chamber with grooves or slots

Ti-Zr-V film coating (implemented in straight sections of LHC) have $\delta_{\text{max}} = 1.1$ after activation at temperature higher than 180°C (24h).
But they cannot be applied to the SPS because the SPS magnet vacuum chambers are not bakeable.

TiN works well under the effect of photon conditioning in situ.
But no photons in the SPS.
Which material to start with:

**Known facts**
- For air exposed stainless steel, Cu and Al $\delta_{\text{max}} > 2$.
- In the periodic system, elements with fewer electrons (on the left side) $\Rightarrow$ lower SEY.
- Insulators have high SEY (electrons escape from deep layers).
- 'Beam scrubbed' surfaces are covered by more carbon (at least Cu and StSt).

**Try Carbon, which has few electrons**
- SEY of graphite is much lower than diamond, so try to make graphite-like coatings.
- Graphite is not very reactive, should be less affected by air exposure.
- Graphite-like Amorphous Carbon (a-C) Thin Film Coating.
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Surface morphology by SEM (Scanning electron microscope)

Amorphous Carbon Coating: DC magnetron sputtering

The SEM images of a-C coatings

Thicknesses from 50 nm to 1500 nm.

Variation of surface roughness with substrate coating temperatures.
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The SEM images of a-C coatings
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Variation of surface roughness with substrate coating temperatures.
SEY $\delta$ is calculated as:

$$\delta = \frac{I_c}{I_c + I_s}$$

- $I_c$: collector current.
- $I_s$: sample to ground current.
- $I_p$: $I_c + I_s$, the primary electron current (PE).

The electron dose during the measurement is calculated to be below $1 \times 10^{-6}$ C/mm$^2$. 

**Experimental setup for SEY measurement**

Electron gun

<table>
<thead>
<tr>
<th>Electron collector</th>
<th>Sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>$I_p$</td>
<td>$I_s$</td>
</tr>
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$\delta = \frac{I_c}{I_c + I_s}$
The SEY as a function of PE

P: power, p: pressure

- Measured directly after extraction from the deposition chamber and transfer to the SEY apparatus through air.
- The precision of the presented SEY values is estimated to ±0.03.
- $\delta_{max}$ is between 0.9 and 1.1 and $E_{max} = 300$ eV. (not sensitive to coating parameters as pressure, power.)
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Numbers of the coatings. Total: 90 samples
Coating for the Electron Cloud Monitor in the SPS

Electron cloud monitor (ECM) in SPS

- B-field
- Coated liner: magnetron sputtering
- Proton beam
- Magnet chamber
- E-cloud current: 48 strips spaced 1.5 mm
Coating for the Electron Cloud Monitor in the SPS

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Coating for the Electron Cloud Monitor (ECM)

- Dipole C-magnet
- Coated liner inside the dipole
- In the SPS
- The multi-strip detector
- B-field
- Proton beam
- Magnet chamber
- E-cloud current
  - 48 strips spaced 1.5 mm
**Electron Cloud Monitor (ECM)**

- Normalized EC v.s time, measured by ECM in the SPS.
- 3-4 batches of nominal LHC beam. \((1.15 \cdot 10^{11} \text{ protons/bunch})\)

![Normalized e–cloud from the MD runs](image)

**SEY measurements in the lab.**

- Normalized \(\log_{10}(\text{ElectronCurrent}/\text{IntFBCT})\)

![Normalized electron current signal](image)

**Observe!**

- EC signal is \(10^4\) higher on StSt than a-C.
- Low SEY \(\Rightarrow\) Low electron current signal.
Ageing observation under different conditions in the lab

3 identical a-C samples have been stored in different conditions and compared after 1 month.

- By storing the sample in desiccators, the ageing seems to be suppressed completely.
- A weak correlation between the O content and the SEY can be seen in this sample.
- 1 month in air, still below the threshold value for the SPS, $\delta_{\text{max}} = 1.3$. 
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![Graph showing ageing observation](image)
Ageing observation under different conditions \textit{in the lab}

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![Graph showing the changes in O content and $\delta_{\text{max}}$ over time]
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![Graph showing O content and $\delta_{\text{max}}$ over time in different storage conditions.](image)
Ageing observation of a-C in the SPS

One a-C coated liner has been tested during 3 Machine Development (MD) Runs with 3-4 batches of nominal LHC beam accelerated to 450 GeV/c.

- Vertical unit: nC/10^{10} protons per bunch
- The a-C coated liner was kept in the SPS for more than one year operation. (more than 2 months of venting, maintenance, installation...)
- No sign of ageing in the SPS.

![Normalized e-cloud from the MD runs](image_url)
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Inspection of one a-C liner extracted from the SPS

- One a-C coated liner has been tested during 5 Machine Development (MD) Runs in 2009, with 3-4 batches of nominal LHC beam accelerated to 450 GeV/c.
- Inserted in SPS in March 2009, and extracted in February 2010 and inspected.
Inspection of one a-C liner extracted from the SPS

- One a-C coated liner has been tested during 5 Machine Development (MD) Runs in 2009, with 3-4 batches of nominal LHC beam accelerated to 450 GeV/c.
- Inserted in SPS in March 2009, and extracted in February 2010 and inspected.
Inspection of one a-C liner extracted from the SPS

- One a-C coated liner has been tested during 5 Machine Development (MD) Runs in 2009, with 3-4 batches of nominal LHC beam accelerated to 450 GeV/c.
- Inserted in SPS in March 2009, and extracted in February 2010 and inspected.

![SEY measurements in the lab](chart.png)

- a–C coated liner: before insertion $\delta = 0.92$
- a–C coated liner: inspection after 1 year $\delta = 0.96$
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- Microwave transmission measurements detected e-cloud related signal in the coated and uncoated magnets. by S. Federmann et al (Poster ID: TUPEA076)
- Dynamic pressure rise used to monitor the behavior of the coated and uncoated magnets. by C. Yin Vallgren et al (Poster ID: TUPD048)
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Magnetron sputtered a-C film is a potential solution to eliminate e-cloud.

especially in an un-bakeable accelerator as SPS.

Future activities:
- Study of ageing with storage in different atmospheres.
- Modifying the coating system in order to find a solution to coat the dipole magnets with the best quality of a-C coating.

More details can be found in *Low Secondary Electron Yield Carbon Coatings for Electron-cloud Mitigation in Modern Particle Accelerators* and *Amorphous Carbon Coatings for the Mitigation of Electron Cloud in the CERN SPS* by Christina Yin Vallgren et al (WEOAMH03, TUPD048).
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Thanks

Many thanks to all the members of the SPS-U Study team handed by E. Shaposhnikova!

Thanks for your attention! and Questions
Backup Slide
Cylindrical configuration (Lab samples)
Different coating configurations were used:

- Cylindrical tube with graphite rod as shown (for lab measurements)
- Liner in tube with 4 graphite rods (for e-cloud monitors, will be explained later)
- Multi-electrode geometry in MBB magnets (for SPS dipoles)

Different discharge gases (Ne, Kr, Ar) and different coating parameters (Temperature of substrate, discharge gas pressure, power) can be used.