THIN FILM COATINGS TO SUPPRESS ELECTRON MULTIPACTING IN PARTICLE ACCELERATORS


CERN - Vacuum Surfaces and Coatings group

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THIN FILM COATINGS TO SUPPRESS ELECTRON MULTIPACTING IN PARTICLE ACCELERATORS

- Motivation
- Non Evaporable Getter (NEG) coatings
- Carbon coatings
- Summary and future work
**MOTIVATION**

*Electron clouds are created in accelerators when bunches of positive charge accelerates the stray electrons already floating in the tube towards the walls, producing secondary electrons that are again accelerated by the next bunch, resulting in electrons multiplication bunch after bunch.*

**UNDESIRABLE EFFECTS:** emitance blow up, thermal loads, pressure rises, beam losses, rise of detector’s background.

**CURES:** clearing electrodes (pull electrons with a polarized electrode), trap electrons with an axial magnetic field, limit electron multiplication by reducing the **Secondary Electron Yield (SEY)** of the walls of the beam pipe.

**Reduction of SEY by coating the internal surface of the beampipes.**
Motivation to develop NEG coating

Long Straight Sections (LSS) of the Large Hadron Collider (LHC)

- $e$-cloud threshold $\delta_{\text{max}} = 1.3$
- Bakeable Beampipes ($T > 180^\circ\text{C}$)
Motivation to develop NEG coating

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Motivation to develop Carbon coatings

*Upgrade the Super Proton Synchrotron (SPS)*

To feed the LHC with 25 ns bunch spaced beam

- e-cloud threshold $\delta_{\text{max}} = 1.3$
- Non Bakeable Beampipes
NEG COATINGS

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T = RT

Secondary electrons

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**high SEY** $\delta_{\text{max}} \sim 2$
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**Native oxide layer**

**High SEY** \( \delta_{\text{max}} \sim 2 \)

**Heating in vacuum**

Oxide dissolution -> activation
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\[ T = T_{\text{activation}} \]

[Diagram showing temperature changes and oxide dissolution]

- **T = RT**
- Secondary electrons
- Native oxide layer: high SEY $\delta_{\text{max}} \sim 2$
- Heating in vacuum: Oxide dissolution $\rightarrow$ activation
- Metallic surface

[Diagram showing different states of oxide layers]
NEG COATINGS

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In addition: **activated NEG surface pumps most of the gas species in UHV**.
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Ti-Zr-V NEG can be activated at 180°C for 24h (or 250°C for 2 hours)

Typical thickness about 1~2 µm.
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![Typical thickness about 1~2 µm.](image)

![Graph showing secondary electron yield vs. primary electron energy for different activation temperatures.](graph)
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![Graph showing secondary electron yield vs. primary electron energy](image)

- **SEY_{LHC}=1.3**
- as received
- after 2h @ 120°C
- after 2h @ 160°C
- after 2h @ 200°C
- after 2h @ 250°C
NEG COATINGS

Large scale production for the LHC and experiments by DC Cylinder Magnetron sputtering (DCCM) from a target of Ti, Zr and V wires (more than 1300 chambers)
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Large scale production for the LHC and experiments by DC Cylinder Magnetron sputtering (DCCM) from a target of Ti, Zr and V wires (more than 1300 chambers).

Fully industrialized process. So far, no e-cloud in the NEG coated parts of the LHC.
CARBON COATINGS

SPS dipole: 6.5 m, ~16 tons, non bakeable, Radioactive, >700 magnets to be coated.

Why carbon? Because graphite has low SEY and is not very reactive.

Why sputtering? Because it favours sp2 hybridization in C-C bonds.

How to do it?... Two possible scenarios:

1) **Coat new beampipes**: disassemble the magnets, insert coated beampipes, re-assemble magnets. **Easy for coating process** ( < 0.5M USD)
   **Expensive to disassemble/re-assemble**: 17M USD

2) **Coat actual beampipes** inside the magnets. **Difficult for coating process**
   **Cheaper**: 4M USD (coating < 0.5M USD)
**CARBON COATINGS**

**Scenario 1) coat new beampipes:** the coating setup.

The coating is done by DC Cylindrical Magnetron sputtering (DCCM) in the solenoids used for the NEG.

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**Beampipes for the main SPS dipoles**

**For MBB magnet**
- 3'805 mm x 1'320 mm
- Thickness: 1.5 mm

**For MBA magnet**
- 3'805 mm x 1'320 mm
- Thickness: 2 mm
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Beampipes for the main SPS dipoles

- Thickness: 1.5mm
- For MBB magnet
- CERN 2009-2010

Housing vacuum chamber for coating purposes
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![Diagram of beampipes and graphite targets]
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Scenario 1) coat new beampipes: the coating setup.

The coating is done by DC Cylindrical Magnetron sputtering (DCCM) in the solenoids used for the NEG.

- Ne pressure $8 \times 10^{-2}$ mbar
- Power 400 Watt / meter of cathode
- Target bias -650 V
- Substrate temperature 300°C
- Magnetic field 180 Gauss
Scenario 1) coat new beampipes: characterization in laboratory.

SEY measured in laboratory
CARBON COATINGS

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SEY measured in laboratory

![Graph showing SEY measurement over energy of primary electrons (in eV)]
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\( \delta_{\text{max}} \) seems to correlate with the gas impurities in the plasma at the end of the sputtering process.

Water is possibly related with ageing.
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SEY measured in laboratory

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water is possibly related with ageing

![Graphs showing SEY measurements and \( \delta_{\text{max}} \) correlation with gas impurities for different conditions, including initial, 4 months in air, 12 months in air, and 12 months in dessicator.](image-url)
Scenario 1) coat new beampipes: tests in the SPS

Electron-Cloud Monitors
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Set-up: carbon coated liners with strip detector in 1.2K Gauss field
Beam: 2-3 batches, 72 proton bunches, 25 ns spacing, 450 GeV

![Graph showing log(e-cloud/IntFBCT) vs time with data points and labels for Stainless steel reference, NEG activated, DCCM Carbon.]

- Stainless steel reference
- NEG activated $\delta_{\text{max}} = 1.10$
- DCCM Carbon $\delta_{\text{max}} = 0.95$
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E-cloud signal for carbon is 4 orders of magnitude below that for stainless steel.
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Electron-Cloud Monitors

Several liners coated with carbon and tested during MD runs with LHC type beam

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<td>StSt (Ref)</td>
<td>1 year (5 MD runs)</td>
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<td>1.5 years (9 MD runs)</td>
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<td>3 months (2 MD runs)</td>
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Negligible ageing (accuracy of SEY measurements +/- 0.03)

E-cloud signal for carbon is 4 orders of magnitude below that for stainless steel.
CARBON COATINGS

Scenario 1) coat new beampipes: tests in the SPS

Set-up: carbon coated liner with strip detector in 1.2K Gauss field
Beam: 2-3 batches, 72 proton bunches, 25 ns spacing, 450 GeV

Electron-Cloud Monitors in SPS
Several liners coated with carbon and tested during MD runs with LHC type beam

Ready for industrialization
More tests required to validate the carbon coating

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Negligible ageing
(accuracy of SEY measurements +/- 0.03)
**CARBON COATINGS**

Scenario 2) coat actual beampipes: coating techniques being explored

DC magnetron using permanent magnets: good results on 30 cm prototype: $\delta_{\text{max}} = 0.96$, 0.98 after 3 months in air. 2 meter ready to be tested. If ok go for 7 meter.
CARBON COATINGS

Scenario 2) coat actual beampipes: coating techniques being explored

DC hollow cathode: good results on 30 cm prototype: $\delta_{\text{max}} = 0.96, 0.99$ after 1 month in air. 2 meter in fabrication. If ok go for 7 meter.
Summary and Future work

Thin film coatings are effective to suppress e-cloud

For bakeable \((T>180^\circ\text{C})\) beampipes: NEG coatings are reliable and fully industrialised.

For unbakeable beampipes: Carbon coatings enters the last phase of development / validation.

understand ageing process, role of plasma contaminants and substrate temperature during film growth. Do more tests in the SPS with real dipoles.

Coat new chambers for SPS (scenario 1): technology ready to be industrialized.

EXPENSIVE TO DISASSEMBLING / REASSEMBLING DIPOLES.

Coat the actual SPS chambers (scenario 2): promising results on small prototypes; go for 7 meter. Tests on e-cloud monitors and real dipoles will follow.

If carbon coatings are chosen to suppress e-cloud in the SPS, the whole 6 km of the machine will be coated.

THANK YOU
Summary and Future work

Thin film coatings are effective to suppress e-cloud

For **bakeable** (T>180°C) beampipes: NEG coatings are reliable and fully industrialised.

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understand **ageing process**, role of **plasma contaminants** and **substrate temperature** during film growth. Do more tests in the **SPS with real dipoles**.

Carbon coatings of new chambers for SPS (scenario 1): technology **ready** to be industrialized. **EXPENSIVE**.

Carbon coatings of actual chambers for SPS (scenario 2): **promising results** on small prototypes; go for 7 meter. Tests on **e-cloud monitors** and **real dipoles** will follow.

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