History and potential of Non Evaporable Getter (NEG) technology

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OUTLOOK

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Evaporable and Non Evaporable Getters

Getters are materials capable of chemically adsorbing gas molecules (by chemisorption). To do so, their surface must be clean.

Chemisorption (surface pumping)

- Limited to 1 monolayer (~$10^{15}$ molecules/cm$^2$)
- Reactive gases are pumped: CO, O$_2$, H$_2$O, N$_2$, H$_2$, CO$_2$
- Noble gases and methane are not pumped.

Diffusion (bulk pumping)

- Very large capacity!
- At room temperature only H$_2$ diffuses
- Other reactive gases require higher temperature

Pedro Costa Pinto, WAMAS, CERN, November 2013
Evaporable and Non Evaporable Getters

Getters are materials capable of chemically adsorbing gas molecules (by chemisorption). To do so, their surface must be clean.

Getters can be classified by the way the clean surface is obtained:

- **Evaporable Getters**
  - In situ deposition of a fresh getter film (under vacuum)

- **Non Evaporable Getters** (NEG)
  - Diffusion of the oxide layer into the bulk (usually by heating in vacuum)
Getter pumping was reported for the first time in 1858 by Plucker. When working with gas discharges in vacuum he noticed that “certain gases react with the cathode and the platinum deposited in the walls”.

By the 1940s, industrialization of evaporable getters for vacuum tubes. (first phosphorous and then barium alloys). => reliability of electronics.
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1966 The Total Yield Flash Getter extended the life of color tv tubes from 300 to 10 000 hours. (SAES Getters)
1979 SAES Getters launches a Non Evaporable Getter (NEG) in form of strip. (developed with CERN for the Large Electron Positron collider).

LEP
~27 km
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Cross section of the LEP dipole vacuum chamber
NEG technology at CERN

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1998 Low activation temperature NEG coatings, (Ti-Zr-V), developed at CERN for the LHC.

Cristoforo Benvenutti
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1998 Low activation temperature NEG coatings, (Ti-Zr-V), developed at CERN for the LHC.

Cross section of the LHC warm dipole vacuum chamber
NEG technology at CERN

Known NEG technologies require very high activation temperatures (>> 350°C): Zr, Ti, Zr-Al, Ti-Al, Zr-V-Fe, Th-Ce-Al) (usually as sintered powders or compressed in strips, pellets, rings).

CERN goal: find a NEG with low activation temperature (compatible with technical materials used for UHV: <400°C for stainless steel, <250°C for Cu, <200°C for Al).

More than 20 materials were investigated by combining 2 or 3 of these elements in the form of thin films. (Produced by DC Magnetron Sputtering.)
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NEG technology at CERN

The Ti-Zr-V NEG coating can be activated at 180°C for 24 hours.

Crystallographic structure (XRD)

The Ti-Zr-V NEG coating can be activated at 180°C for 24 hours.
NEG technology at CERN

Vacuum properties 1: pumping speed versus coverage.

Smooth (coated at 100°C)

Rough (coated at 300°C)
NEG technology at CERN

Vacuum properties 2: ageing (recovery after air venting)

**Number of heating/venting cycles**

- **200°C**
- **250°C**
- **300°C**
- **350°C**

**Heating duration**: 24 hours unless otherwise indicated.

**Beam pipe diameter**: 80 mm

**H$_2$ sticking probability**

- **TiZrV/St. Steel**
- **5 μm thick**

**H$_2$ pumping speed** [l s$^{-1}$ m$^{-1}$]

- **10**
- **10$^2$$^-$
- **10$^3$$^-$
NEG technology at CERN

Anti electron multipacting properties 1: low Secondary Electron Yield (SEY).

![Graph showing SEY as a function of primary electron energy for different temperatures.](image)

- As received
- After 2h @ 120°C
- After 2h @ 160°C
- After 2h @ 200°C
- After 2h @ 250°C

SEY_{LHC} = 1.3
NEG technology at CERN

At CERN, 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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Potential of NEG coatings

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Potential of NEG coatings

Applications of NEG coatings other than in particle accelerators:

- Low SEY
- RF devices
- Vacuum systems
- Solar panels
- MEMS
- Lightning devices
- Particle accelerators
- Photo multipliers
- X-Ray tubes
- X-Ray image intensifiers

Vacuum, Surfaces & Coatings Group
Technology Department

Pedro Costa Pinto, WAMAS, CERN, November 2013
Summary and future

Due to their pumping properties, getters and NEGs became unavoidable in vacuum sealed devices.

The development of particle accelerators pushed the development of NEGs with low activation temperature and in the form of thin film coatings.

The anti electron multipacting properties, (low SEY), of NEG coatings became of major importance for positive particle accelerators and can potentially be applied to waveguides and RF devices.

These coatings are applied in more and more accelerators but also in other technology devices (solar panels, MEMS, X-Ray imaging, etc)

Future developments targets lowering the activation temperature (150°C), deposition in small aperture devices (beam pipes) and integration in new assembly techniques.
Thank you for your attention.
Introduction to CERN

CERN European Organization for Nuclear Research: supplies particle accelerators and detectors to the scientific community to probe the fundamental structure of the universe.

Switzerland (Geneva) / France
Why do we need NEG and Carbon coatings

- Vacuum required to minimize interaction of particles with the residual gas.

- Long beam pipes $\Rightarrow$ low conductance $\Rightarrow$ requires distributed pumping.

- To avoid electron multipacting, the internal walls of the beam pipes must have Low Secondary Electron Yield (SEY).
Why do we need NEG and Carbon coatings

Motivation to develop NEG coating

Motivation to develop NEG coating

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

- Low pressure in long beam pipes
- Multipacting threshold $SEY_{\text{max}} = 1.3$
- Bakeable Beampipes ($T > 180^\circ \text{C}$)
Why do we need NEG and Carbon coatings

**Motivation to develop NEG coating**

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

- Low pressure in long beam pipes
- Multipacting threshold $SEY_{\text{max}} = 1.3$
- Bakeable Beampipes ($T < 350^\circ \text{C}$)

**Motivation to develop Carbon coatings**

*Upgrade the Super Proton Synchrotron (SPS)*

- Multipacting threshold $SEY_{\text{max}} = 1.3$
- Non Bakeable Beampipes
NEG coatings

Getters are materials capable of chemically adsorbing gas molecules. To do so their surface must be clean. For Non-Evaporable Getters a clean surface is obtained by heating to a temperature high enough to dissolve the native oxide layer into the bulk.

\[ T = RT \]

\[ T = T_{activation} \]

\[ T = RT \]

Native oxide layer
- No pumping
- High desorption rates
- High SEY

Heating in vacuum
- Oxide dissolution -> activation

Pumping
- Low SEY

*NEG* pumps most of the gas except rare gases and methane at room temperature.

Pedro Costa Pinto, SVSS’13, Tsukuba, November 2013
NEG coatings

Large scale production for the LHC experiments by DC Cylinder Magnetron sputtering (DCCM) from a target of Ti, Zr and V wires (more than 1300 chambers)
2 Why do we need NEG and Carbon coatings

- Vacuum required to minimize interaction of particles with the residual gas.
- Long beam pipes => low conductance => requires *distributed pumping* instead of localized pumping.
- To avoid electron multipacting, the internal walls of the beam pipes must have *Low Secondary Electron Yield (SEY)*.

![Diagram showing proton bunch, electron, and gas molecule]
NEG coatings

Multipacting properties 2: Electron Multipacting.

- Stainless steel reference $\delta_{\text{max}} = 2.00$
- NEG activated $\delta_{\text{max}} = 1.10$
- DCCM Carbon $\delta_{\text{max}} = 0.95$