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TiZrV non-evaporable getter coating for ultra-high vacuum systems

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Non-Evaporable Getter (NEG) coating, composed of ternary mixture of Ti, Zr, and V, has been widely applied in particle accelerator vacuum systems, providing desirable properties such as highly effective pumping speeds and extremely low Photon Stimulated Desorption (PSD) yields. Since these vacuum properties are linked to the microstructure and surface conditions of the film, surface analysis methods such as SEM, XPS, XRD, etc are essential for characterization of the NEG coating. As this technology is also demanded for application to general Ultra-High Vacuum (UHV) systems, a compact NEG-coating device utilizing magnetron sputtering with a TiZrV alloy target is being developed.

1. Introduction

TiZrV NEG coating was originally developed at the European Organization for Nuclear Research (CERN) in late 1990s for the vacuum system of the Large Hadron Collider [1] . By coating the inner walls of long beam pipes with NEG, native outgassing sources can be converted into a vacuum pump, and thus low vacuum pressures of 10^{-8}–10^{-9} Pa are effectively achieved.

NEG coating can be activated at 180 ºC for 24 hours, during which a surface oxide layer dissolves in the film by diffusion. The activated surface can provide pumping speeds of about 0.4 L/s/cm^2 for H_2 and 5 L/s/cm^2 for CO, and an initial PSD yield of the order of 10^{-5} molecules/photon. Precise measurements of these vacuum properties under various conditions are essential for designing the accelerator vacuum systems.

2. Pumping properties

NEG coating adsorbs gas molecules except for inert gas species such as noble gases and methane through reaction of chemisorption, so the pumping properties of the NEG coating is characterized by a sticking probability, typically 0.01 for H_2 and 0.4 for CO [2].

Since the standard method to assess the pumping speed using an ISO or Fischer-Mommsen dome cannot be applied to long NEG-coated pipes, a dedicated method called the transmission method is instead used to measure the sticking probability across the pipe. Test gas is injected from one end of the pipe and the ratio of the pressures of two ends indicates the sticking probability on the inner wall of the pipe with the help of a Monte Carlo simulation (Fig. 1).

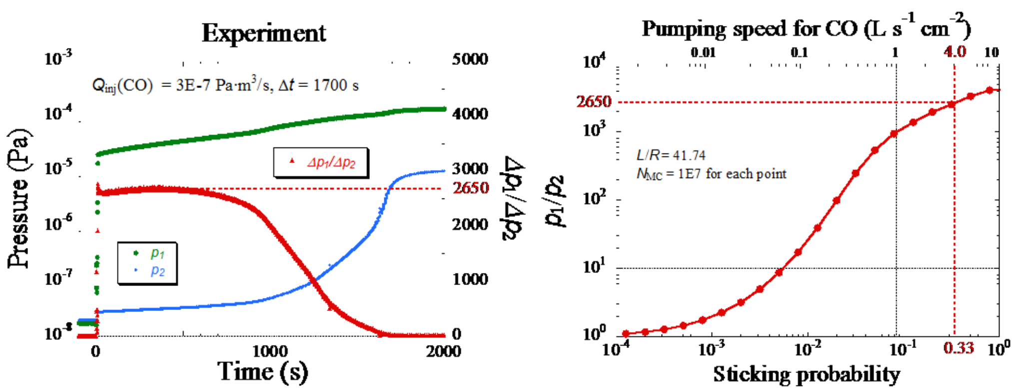

Figure 1. Pumping speed measurement by transmission method: (left) changes in vacuum pressures at both ends during CO gas injection and (right) sticking probability and pumping speed measured with the help of Monte Carlo simulation.

There are two kinds of capacities in NEG coating: surface and bulk. The surface capacity is a pumping capacity until full saturation of the surface, typically one monolayer, and depends on the roughness of the film, for example, 7×10^{14} molecules/cm^2 for a smooth surface and 7×10^{15} molecules/cm^2 for a rough surface [3].

The bulk capacity is a maximum solubility of oxygen in the film, in other words, a film lifetime after the cycles of air exposures and activations. In general, a thicker film gives a higher bulk capacity; for example, 10 cycles are possible for a 1 µm thick film. A very thin layer of Pd can be deposited on the NEG coating to prevent the surface from oxidization, which is effective to prolong the film lifetime [4, 5].

The favorable vacuum properties of the NEG coating are ascribed to fine and columnar structures of the film as shown by the SEM images in Fig. 2. Fine grains of 10~20 nm form a porous film, and the columnar structure facilitates the oxygen diffusion during activation.

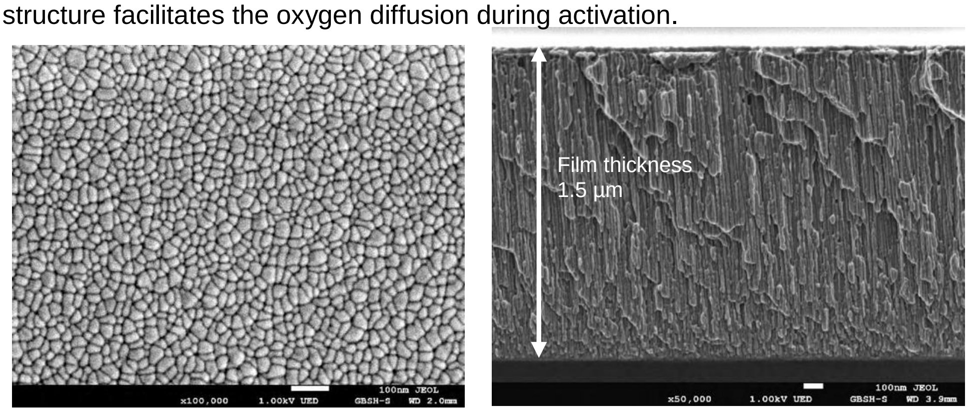

Figure 2. SEM Images of the TiZrV NEG coating: (left) surface morphology and (right) cross section.

3. PSD yield

In the vacuum systems of high energy electron accelerators for Synchrotron Radiation (SR) source, outgassing is dominantly caused by PSD from the inner walls of the beam pipes, as a consequence of irradiation by direct or scattered SR emitted from electron beams. Activated NEG coating exhibits a PSD yield of as low as 10^{-5} molecules/photon, which is about two orders of magnitude lower than those of uncoated surfaces [6, 7]. This advantageous property of the NEG coating significantly shortens the accelerator operations for vacuum chamber conditioning that often takes several months.

As shown in Fig. 3, we have been systematically measuring the PSD yields of NEG coating under various conditions with the aim to adopt the obtained data into the vacuum system designs for current and future accelerators [8, 9].

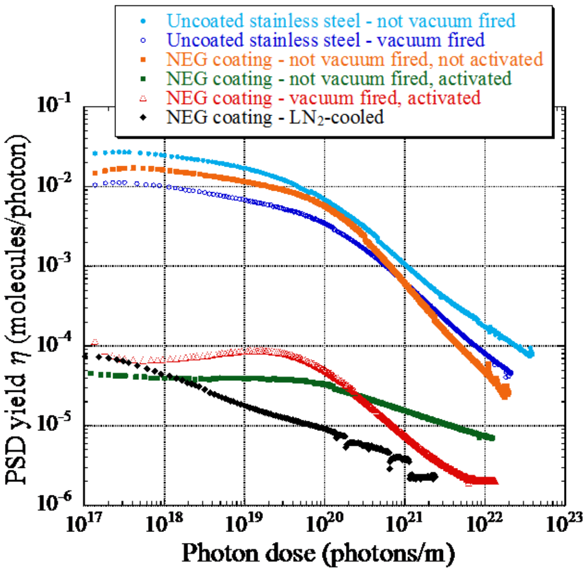

Figure 3. PSD yields and their conditioning behaviors of various surfaces and conditions. Activated NEG coatings exhibit significantly low PSD yields from the initial stage of conditioning.

4. Compact NEG-coating device

There has been an increasing demand for expanding the range of applications because the desirable characteristics of NEG coating are expected to improve performance of general UHV devices such as electron microscopes. At present, however, TiZrV NEG coating has not been easily applied to outside the accelerator field because the original coating method is suitable for long beam tubes; TiZrV twisted wire is usually used as a sputter target and a cylindrical solenoid magnet is necessary to establish a DC magnetron sputtering condition (Fig. 4 left).

To expand the range of applications these conventional techniques need to be modified, and we have been developing a compact, flange mountable NEG-coating device that utilizes a cylindrical TiZrV alloy target and a permanent magnet array inserted in the target cylinder (Fig. 4 right).

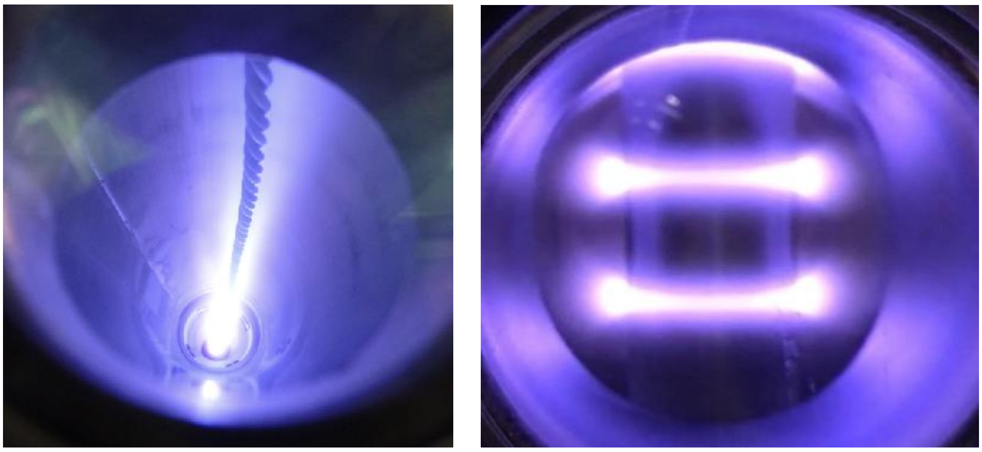

Figure 4. NEG film depositions by magnetron sputtering: (left) conventional method using a TiZrV twisted wire target and (right) compact NEG-coating device using a TiZrV alloy target.

5. Summary

Since the original invention by CERN more than 20 years ago, NEG coating has been employed in many particle accelerators as it can provide highly effective pumping speeds and extremely low PSD yields. In parallel, fundamental research activities to improve the performance have been extensively carried out worldwide. There has also been an increasing demand for expanding the range of applications because such desirable characteristics of NEG coating are expected to improve performance of general UHV devices such as electron microscopes.

References

[1] C. Benvenuti *et al.*, *Vacuum* **1999**, 53, 219–225.
[2] C. Benvenuti *et al.*, *Vacuum* **2001**, 60, 57–65.
[3] P. Chiggiato and P. Costa Pinto, *Thin Solid Films* **2006** 515 382–388.
[4] C. Benvenuti *et al.*, *Vacuum* **2004**, 73, 139–144.
[5] X.G. Jin, T. Uchiyama, Y. Tanimoto, T. Honda, *J. Vac. Sci. Technol. B* **2021** 39, 064202.
[6] P. Chiggiato and R. Kersevan, *Vacuum* **2001**, 60 (2001) 67–72.
[7] M. Ady, P. Chiggiato, R. Kersevan, Y. Tanimoto, and T. Honda, "Photodesorption and Electron Yield Measurements of Thin Film Coatings for Future Accelerators", 6th International Particle Accelerator Conference (IPAC2015), Richmond, USA, **2015**, 3123–3126.
[8] Y. Tanimoto *et al.*, "Vacuum Performance of the NEG-coated Chamber for U#19 at PF- ring", 10th International Particle Accelerator Conference (IPAC2019), Melbourne, Australia, **2019**,1276–1279.
[9] X.G. Jin, Y. Tanimoto, T. Uchiyama. T. Honda, *Vacuum* **2023**, 207, 111671.