ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-TUPMP019

VACUUM PERFORMANCE OF THE NEG-COATED CHAMBER FOR U#19 AT PF-RING

Y. Tanimoto†, T. Nogami, X.G. Jin, M. Yamamoto, R. Takai, T. Honda,
High Energy Accelerator Research Organization (KEK), Tsukuba, Japan

Abstract

At the Photon Factory storage ring (PF-ring) in KEK, a new APPLE-II type elliptically polarizing undulator U#19 was installed in October 2018. The U#19 vacuum chamber is 4.1 m in length, and the beam channel with a 15×90 elliptical profile and two cooling-water channels alongside were formed by extrusion of A6060-T6 aluminum alloy. The inner surface of the beam channel is coated with a Ti-Zr-V non-evaporable getter (NEG) thin film, as it has a high effective pumping speed and a low photon stimulated desorption (PSD) yield. After the installation of the U#19, the NEG coating was activated at 160 ºC for 48 hours. As a result, the pressures in the neighboring chambers reached as low as 10^{-8} Pa. The conditioning of the vacuum chambers with irradiation of Synchrotron radiation (SR) evolved as favorably as expected by Synrad+ and Molflow+ coupled simulations, leading to a smooth recovery of the beam lifetime. Vacuum performance of the NEG-coated chamber was assessed by static and dynamic pressure measurements. The properties of the NEG film were characterized by surface analyses.

INTRODUCTION

Since 2005 when the PF-ring underwent the straight-section upgrade [1], 12 insertion devices in total (8 in-air and 4 in-vacuum) have been renewed or newly installed. In late 2018, as a successor to the revolver type multi-undulator Rev#19, an APPLE-II type elliptically polarizing undulator U#19 [2] was installed and commissioned successfully.

The U#19 employed a NEG-coated vacuum chamber because the NEG coating is capable of providing two essential vacuum properties [3]: 1) a highly effective pumping speed especially in a long and narrow chamber, and 2) an extremely low PSD yield [4], by which the conditioning time can be reduced. The U#19 chamber is the first NEG-coated chamber at PF-ring, and this experience also bears an implication toward exploiting the advantages of the NEG-coating technology at future SR light sources in Japan. Throughout this activity, we also expect to establish an effective activation procedure for a long NEG-coated chamber in actual accelerator environment, as well as to accumulate practical experiences in a long-term operation.

In the design of the U#19 vacuum system, vacuum properties affected by SR irradiation were carefully considered. In order to confirm that the vacuum performance of the U#19 chamber should be as high as those of other conventional undulators, the conditioning behavior of the PSD outgassing was estimated by the Synrad+ and Molflow+ coupled simulations [5].

The characterization of the NEG film itself is also essential because the crystal structure closely affects its vacuum performance [6,7]. For this purpose, surface analyses were performed on a sample coupon coated together with the U#19 chamber.

NEG-COATED VACUUM CHAMBER

The U#19 has four movable magnet arrays, each of which measures 3740 mm in length, and their vertical minimum gap is 24 mm. To be housed in the U#19, the vacuum chamber, made of extruded A6060-T6 aluminum alloy, has external dimensions of H20×W290×L4100. Figure 1 shows the cross-sectional profile of the U#19 chamber. The beam channel has a 15×90 elliptical profile with a tolerance of ±0.15 mm. Two cooling-water channels alongside the beam channel are to remove an SR heat load of 340 W from the 2.5 GeV, 450 mA electron beam. According to the Synrad+ simulation, one cooling-water channel takes out a direct SR power of 300 W and the other a reflected and scattered SR power of 40 W.

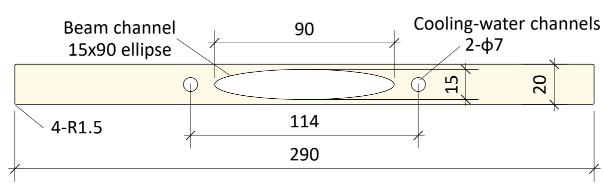

Figure 1: Cross-sectional profile of the U#19 chamber.

On the both ends of the chamber, DN160CF flanges, made of aluminum/stainless-steel explosion-bonded clad material (Asahi Kasei BACLAD™), were machined and TIG-welded. In order to avoid direct SR irradiation on stainless steel, the upstream flange is shadowed by a photon absorber upstream, and the downstream flange has a 2 mm wider opening.

The Ti-Zr-V NEG thin films were deposited by SAES Getters S.p.A. on the elliptical beam channel and on a sample coupon with film thicknesses ranging from 1.0 to 2.0 μm.

SURFACE ANALYSES

As the vacuum performance of a Ti-Zr-V NEG film correlates closely with its crystal structure, surface analyses were performed on a sample film deposited on a silicon substrate.

Microscopic images of the NEG film were taken with JEOL JSM-7900F field emission scanning electron microscope (FE-SEM). Figure 2 (a) shows a surface morphology, revealing that the film consists of fine grains of 10~20 nm. These fine grains and increased grain boundaries are considered to play a key role in elevating oxygen diffusivity during activation. Figure 2 (b) is a cross sectional view of

† yasunori.tanimoto@kek.jp

ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-TUPMP019

the NEG film, which depicts a columnar structure smoothly grown during the magneton sputtering. Although the substrate is different, this implies that the film has a high sticking probability and a high sorption capacity [8,9].

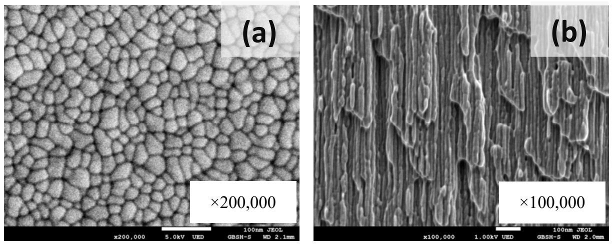

Figure 2: FE-SEM images of the NEG film. (a) top surface and (b) cross section.

Typical film thickness measured by FE-SEM was 1.5 µm, and the composition ratio measured by the attached energy-dispersive X-ray spectroscopy (EDS) was Ti 34.7, Zr 27.9, and V 37.4 (at%). The average crystallite size analyzed by X-ray diffraction (XRD) was as fine as 1.6 nm. All of these surface analyses confirm that the NEG film has a fine crystal structure favorable to high pumping properties and low temperature activation.

VACUUM PERFORMANCE

Pumping Properties

The 4.1 m long U#19 chamber is installed in the straight section between the bending magnets B18 and B19, where a free length of 4.8 m is available between the sector valves. Each end of the U#19 chamber is connected to a short transition chamber equipped with a 300 L/s turbo molecular pump (TMP), an ULVAC PST-200AX2 noble gas capable sputter ion pump (SIP), a SAES Z200 NEG pump, a Bayard-Alpert gauge (BAG), and photon absorber(s). An INFICON C100M residual gas analyzer (RGA) is installed only in the upstream (B18 side) chamber.

Prior to the NEG-coating activation, the uncoated parts were baked at 200 ºC for 44 h, during which the NEG coating was kept at 80 ºC. After degassing the vacuum components and activating the Z200 NEG pump, the NEG coating was activated at 160 ºC for 48 h, during which the Z200 NEG was kept at 200 ºC.

The pressures around the U#19 reached $1\sim4\times10^{-8}$ Pa in two days. Then, the pumping performance of the NEG coated chamber was investigated by a systematic on/off test of the SIPs and BAGs.

Figure 3 shows the changes of the mass spectra under four different SIP conditions. In this test, the two BAGs were switched off. US and DS denote the installed locations; upstream and downstream, respectively.

In one comparison when the SIP-DS at the far end was switched off while the SIP-US was off (red vs. green), a large increase of CH_4 in m/z 12–16 was observed, followed by small increases of C_2H_6 (ethane) or C_2H_4 (ethylene) in m/z 25–30 and Ar in m/z 40&20. The fact that only such inert gases for NEGs were transmitted across the U#19 chamber can be a piece of evidence that the NEG coating was well activated.

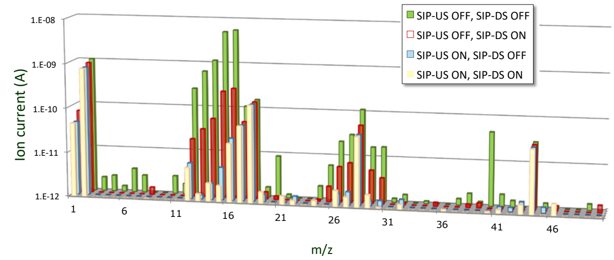

Figure 3: Comparison of RGA spectra in the SIP on/off test.

PSD Outgassing and its Conditioning

The evolution of the pressure profile in the U#19 section was estimated by the Synrad+/Molflow+ simulations, and the result was shown in Fig. 4. In Molflow+, the NEG coating was assumed to have a sticking probability of 0.01 for CO.

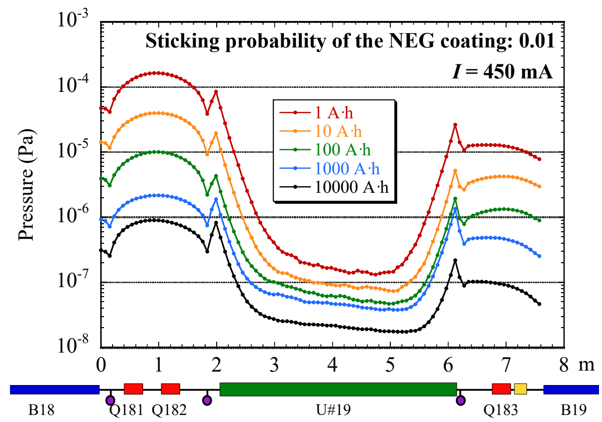

Figure 4: Estimated evolution of the pressure profile in the U#19 section.

The PSD data applied to this simulation are shown in Fig. 5, where the PSD yields of the four major materials actually used in the U#19 section are plotted as a function of the photon dose. The PSD data for NEG coating, copper, and stainless steel were obtained experimentally on a dedicated beamline BL-21 at PF, and the data for aluminum was obtained from observations during the commissioning of the SuperKEKB LER [10].

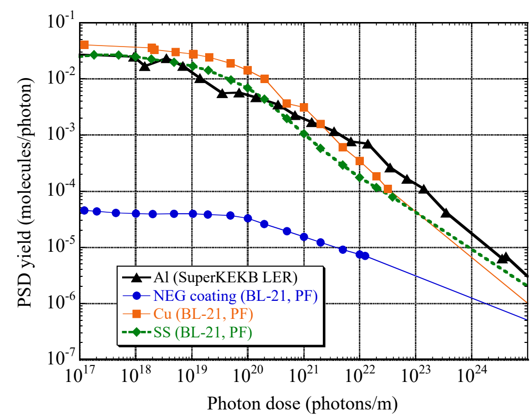

Figure 5: PSD yields of the four major materials actually used in the U#19 section.

ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-TUPMP019

Figure 6 shows the observed and simulated total pressures as a function of the integrated current (beam dose). The surface conditioning has progressed slightly faster than expected, and correspondingly, the beam lifetime has recovered smoothly during the commissioning (reduced beam lifetimes are observed in hybrid-mode operations).

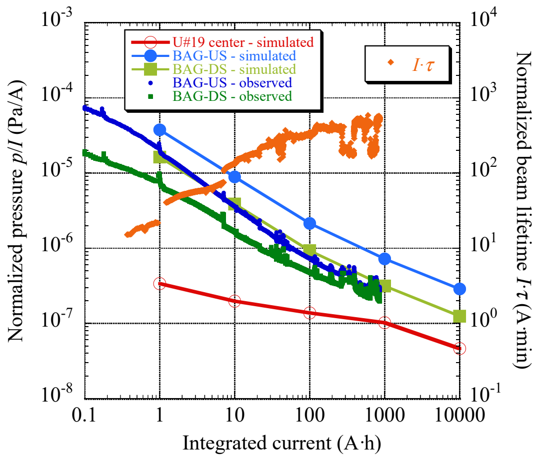

Figure 6: Progress of the U#19 vacuum chamber conditioning by SR (simulation vs. observation) and the recovery of the beam lifetime.

Figure 7 compares the conditioning behaviors with some undulators previously installed in the PF-ring. In this graph, only the SGU#01 vacuum system is based on titanium sublimation pumps (TSP), so the flushing/saturating cycles are prominent. Since only the U#19 doesn't have any gauge installed inside the undulator, the estimation of the normalized pressure at the U#19 center is also plotted (red solid line). This suggests that the U#19 chamber provided the highest performance at the early stage of the commissioning. Based on these comparisons, we conclude that the U#19 chamber has a vacuum performance comparable to or higher than the other undulators.

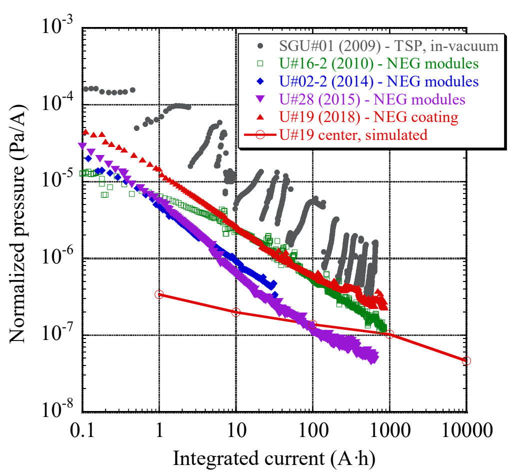

Figure 7: Conditioning behaviors of typical undulator vacuum chambers during each commissioning period.

The PSD conditioning curves of five dominating gas species are plotted in Fig. 8. Similar to the PSD data experimentally obtained on the NEG-coated sample tubes [4], H_2 and CO highly dominate the PSD outgassing. In the accelerator environment, however, the CH_4 partial pressure is lower compared to the experimental result. CH_4 could have been pumped by the SIPs installed in the storage ring. No evidence of CH_4 pumping by the NEG coating through electron beam ionization [11] has been observed at PF-ring.

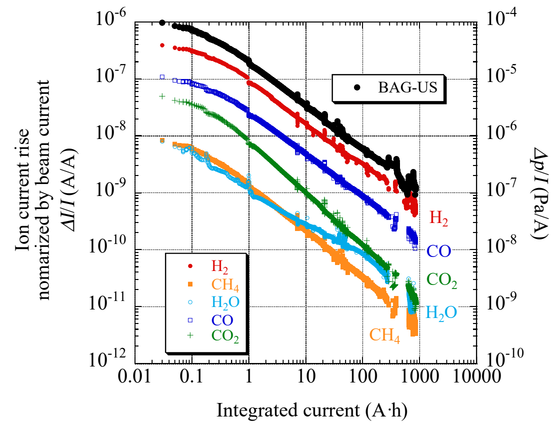

Figure 8: PSD conditioning curves for the five dominating gas species.

CONCLUSIONS

The U#19 NEG-coated vacuum chamber has been successfully installed and commissioned at PF-ring.

The surface analyses performed on the NEG-coated sample indicate that the deposited film is capable of a low-temperature activation, as the film has a fine crystal structure, as well as desirable composition and thickness.

The pumping properties after the activation were investigated by the measurements of the ultimate pressure and the residual gas composition changes in the SIP on/off test. These results demonstrate that the NEG coating was well activated in the actual accelerator environment.

The PSD outgassing and its conditioning behaviors were also investigated. The good agreement with the Synrad+/Molflow+ simulation results indicates that the modeling in the simulations is satisfactorily accurate and that the NEG coating had a CO sticking probability of 0.01 or higher throughout the commissioning period.

ACKNOWLEDGEMENT

The authors would like to thank Dr. Enrico Maccallini of SAES Getters S.p.A., Mr. Carlo Belliero of SAES RIAL Vacuum S.r.l., and their colleagues for providing the high-performance NEG-coated chamber.

REFERENCES

[1] T. Honda *et al.*, "Commissioning of the PF Ring after the Reconstruction for the Straight-sections Upgrade", AIP Conference Proceedings 879, 87 (2007). doi:10.1063/1.2436012

[2] K. Tsuchiya, M. Adachi, T. Shioya, S. Eguchi, Y. Tanimoto, and R. Kato, "Construction of an elliptically polarizing Undulator (U#19) at the Photon Factory", AIP Conference Proceedings 2054, 030010 (2019). doi:10.1063/1.5084573

ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-TUPMP019

[3] C. Benvenuti *et al.*, “Vacuum Properties of TiZrV Non-Evaporable Getter Films”, Vacuum 60, 57 (2001). doi:10.1016/S0042-207X(00)00246-3

[4] M. Ady, P. Chiggiato, R. Kersevan, Y. Tanimoto, and T. Honda, “Photodesorption and Electron Yield Measurements of Thin Film Coatings for Future Accelerators”, in *Proc. 6th Int. Particle Accelerator Conf. (IPAC'15)*, Richmond, USA, May 2015, pp. 3123-3125.

[5] Synrad+ and Molflow+ are Monte Carlo codes developed at CERN by R. Kersevan and M. Ady. website: cern.ch/molflow

[6] C. Benvenuti *et al.*, “Influence of the Elemental Composition and Crystal Structure on the Vacuum Properties of Ti–Zr–V Nonevaporable Getter Films”, J. Vac. Sci. Technol. A 19, 2925 (2001). doi:10.1116/1.1414122

[7] P. Chiggiato and P. Costa Pinto, “Ti-Zr-V Non-Evaporable Getter Films: From Development to Large Scale Production for the Large Hadron Collider”, Thin Solid Films 515, 382 (2006). doi:10.1016/j.tsf.2005.12.218

[8] C. Benvenuti, P. Chiggiato, P. C. Pinto, A. Prodromides, and V. Ruzinov, “Influence of the Substrate Coating Temperature on the Vacuum Properties of Ti-Zr-V Non-Evaporable Getter Films”, Vacuum 71, 307 (2003). doi:10.1016/S0042-207X(02)00755-8

[9] O. B. Malyshev *et al.*, “Influence of deposition pressure and pulsed dc sputtering on pumping properties of Ti–Zr–V non-evaporable getter films”, J. Vac. Sci. Technol. A 27, 521 (2009). doi/10.1116/1.3112623

[10] Data provision by Prof. Y. Suetsugu of KEK.

[11] R. Kersevan, “Calibrated Leak Experiment at ID6, ESRF” (2004). *unpublished*