CONTINUED STUDY ON PHOTOELECTRON AND SECONDARY ELECTRON YIELDS OF TIN AND NEG (Ti-Zr-V) COATINGS AT THE KEKB POSITRON RING

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Abstract

The photoelectron and secondary electron yields of a TiN coating and a NEG (Ti-Zr-V) coating on copper have been studied so far by using the KEK B-Factory (KEKB) positron ring. Recently, test chambers with these coatings were installed at a straight section of the ring, where the irradiated photon density was considerably smaller than that at an arc section in the previous experiments. The number of electrons around beams in the NEG-coated and the TiN-coated chambers were clearly smaller as compared to those of the uncoated copper chamber by the factors of 2–3 and 3–4, respectively. The evaluated maximum SEY (δ_{max}) for the TiN coating and the NEG coating and the copper were in the ranges of 0.8–1.0, 1.0–1.15, and 1.1–1.25, respectively. As an application of the simulation, δ_{max} values and the effective photoelectron yield including the geometrical effect were also estimated for copper chambers with one or two antechambers.

INTRODUCTION

One of the most critical problems in current and future high-luminosity colliders is the electron cloud instability (ECI) in positron and proton rings [1]. A promising method to suppress the ECI is to apply a coating with a low secondary electron yield (SEY) to the inner surface of the beam duct. We have been focusing on a TiN coating and a NEG (Ti-Zr-V) coating, and investigating the effect of their SEYs on the electron cloud formation by using the KEKB positron ring (Low Energy Ring, LER) [2, 3]. In the previous experiments, the test chambers with these coatings were installed at an arc section. The number of electrons around the beams was measured using an electron current monitor, and compared with each other. Based on a simulation, furthermore, the photoelectron yield (PEY, η_e) and the maximum SEY (δ_{max}) of these surfaces were estimated.

As a continuation to the previous studies, the PEY and the SEY of a TiN coating and a NEG coating were investigated in the same manner at a straight section of the LER, where considerably less direct photons were irradiated. It was expected that the effect of SEY would become evident by reducing the photoelectrons. The evaluations of the η_e and δ_{max} of these surfaces were also attempted. Furthermore, the simulation was applied to estimate η_e and δ_{max} for copper beam chambers with one or two antechambers [4]. The antechamber scheme is said to be effective in reducing the effect of photoelectrons.

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EXPERIMENT

Test Chambers

The test chambers had a length of 1.35 m and a diameter of 94 mm. The TiN coating onto a test chamber was performed at Brookhaven National Laboratory (BNL), New York. The coating conditions were almost the same as those in the case of the arc section [3]. The NEG coating onto the test chamber was performed by SAES Getters SpA., Italy. The compositions were determined as Ti = 28%, Zr = 28%, and V = 44% and the thickness was approximately 1.1 µm [5]. Before the installation into the LER, all the test chambers were baked at 150°C for 24 h.

The test chambers were located approximately 86 m downstream of a bending magnet at the end of an arc section, as shown in Fig. 1. The energy of the positron beam was 3.5 GeV, and the critical energy of the synchrotron radiation (SR) was 5.8 keV. The line density of the direct photons was approximately 3.3 × 10^{12} photons s^{-1} m^{-1} mA^{-1}, and the incident angle was approximately 0.6 mrad. A photon mask, which was located just upstream of the test chamber, blocked most of the direct photons; however, the scattered and widely spread SR could hit the chamber.

An electron current monitor was attached at the bottom of the center pumping port of the test chamber [2, 3]. A negative voltage (V_r) of –1000 V was generally applied to the repeller. The measured electron current reflects the average number of electrons just around the beams.

The copper (uncoated) chamber and the TiN-coated chamber were not baked after the installation. The NEG-coated chamber, on the other hand, was baked up to 200°C for 2 h after the installation in order to activate the

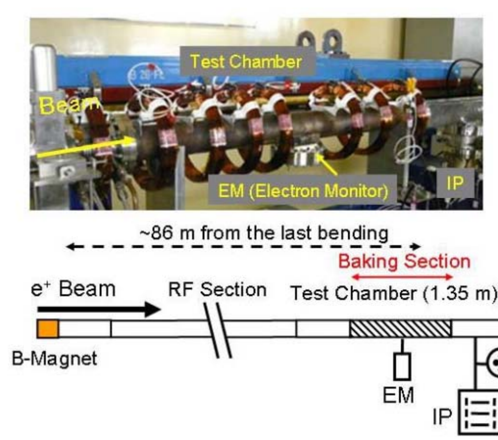

Figure 1: Test chamber installed at a straight section. "EM" and "IP" denote an electron monitor and an ion pump, respectively.

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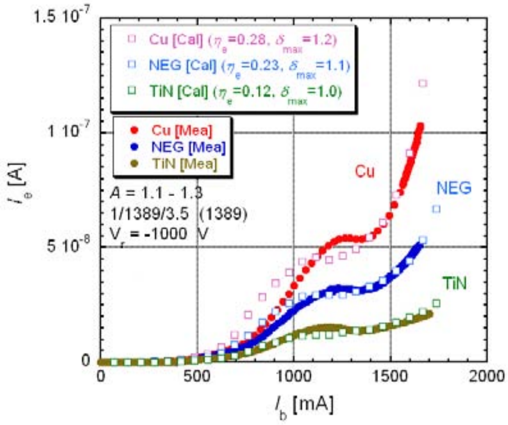

Figure 2: Behaviors of measured and calculated I_e against I_b using the estimated η_e and δ_{max} values.

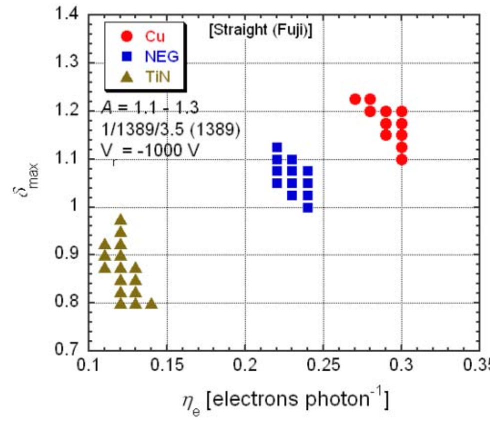

Figure 3: Estimated δ_{max} and η_e for the uncoated copper, NEG-coated, and TiN-coated chambers obtained from curve fitting for the case of Fig. 2.

NEG coating *in situ*. [6]. The pressure during the measurement was on the order of 10^{-7} Pa. No magnetic field was applied to the test chamber this time.

Measurement

The electron currents (I_e [A]) were measured for beam currents up to approximately 1700 mA (1389 bunches). A typical bunch filling pattern was 1/1389/3.5, which means one train of 1389 bunches with an average RF-bucket spacings of 3.5 (i.e., a mixture of three and four RF-bucket spacings), where one RF-bucket spacing corresponds to 1.97 ns.

A typical behavior of I_e against the beam current (I_b) is plotted in Fig. 2 (solid circles) for the TiN-coated, NEG-coated, and uncoated copper chambers (V_r = –1000 V). The I_e value for the TiN-coated chamber was clearly lower than that for the copper chamber by a factor of 3–4. The effect of the TiN coating was clearly observed as in the case of the arc section [3]. However, a significant difference from the previous experiment was that I_e for the NEG-coated chamber was also specifically lower than that for the copper chamber by a factor of 2–3. For other bunch fill patterns, although the behavior of I_e with respect to I_b was different, the order of the intensity of I_e for the TiN-coated, NEG-coated, and copper chambers was the same.

Estimation of η_e and δ_{max}

Based on the simulation, the η_e and the δ_{max} of the TiN coating, the NEG coating, and the copper were estimated in a manner similar to the previous study [2, 3]. However, in the present experiment, the estimation of η_e from the I_e values at a low current (ex. <100 mA) was unfortunately difficult because the I_e values were significantly small to be measured due to the small photon density. Therefore, as a first-order approximation, the η_e values for the TiN coating, the NEG coating, and the copper were assumed to be similar to those of the previous study with a photon incident angle of 8 mrad, that is, approximately 0.14, 0.24, and 0.28, respectively. In fact, the ratios of I_e for these surfaces at I_b = 500–600 mA almost corresponded to the ratios.

The δ_{max} and η_e values estimated by curve fitting for the case in Fig. 2 are presented in Fig. 3. The fitting focused on the I_e value at the high beam current region, that is, I_b > 1400 mA, where the secondary electrons play a significant role. The estimated δ_{max} values for the TiN coating, NEG coating, and copper were in the ranges of 0.8–1.0, 1.0–1.15, and 1.1–1.25, respectively. The results, together with those obtained in the previous experiments are summarized in Table 1 [2, 3]. The δ_{max} values were almost in agreement with those reported so far after sufficient electron bombardment [1]. Note that the photon density of 1 × 10^{13} photons s^{-1} m^{-1} mA^{-1} was required in the simulation to set the scale factor (A) around one, which was larger than the geometrically expected one by a factor of 3. That will be explained by considering the shallow incidence angle of photons (0.6 mrad) and also scattering from the upstream long straight

Table 1: Summary of η_e and δ_{max} obtained from Experiments So Far

	η_e ($\eta_{e\text{-eff}}$[1])			δ_{max}		
	TiN	NEG	Cu	TiN	NEG	Cu
Circular chamber [2, 3][2]	0.13–0.15	0.22–0.27	0.28–0.31	0.8–1.0	1.0–1.1	1.1–1.3
Circular chamber[3]	0.11–0.14[4]	0.22–0.24[4]	0.27–0.30[4]	0.8–1.0	1.0–1.15	1.1–1.25
Chamber with one antechamber[2]	-	-	0.008[1,5]	-	-	1.2
Chamber with two antechambers[3]	-	-	0.04[1,5]	-	-	1.2

1) Effective η_e including the geometrical effect of antechambers. 2) Experiment at an arc section. 3) Experiment at a straight section. 4) The η_e values obtained in the experiment with a photon incident angle of 8 mrad was used as a first approximation, and then photon density was assumed to be 1 × 10^{13} photons s^{-1} m^{-1} mA^{-1}. 5) The η_e value of 0.28 was assumed for the side wall of the antechambers.

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section.

Although the δ_{max} values of the copper and NEG coatings were almost the same as in the previous experiment [2, 3], the I_e values for the NEG coating were clearly lower than those of the copper in the present case. This can be attributed to the small amount of photons in this experiment; a small number of photoelectrons could elucidate the difference of SEY between the copper and the NEG coating.

The fitted I_e values are also plotted in Fig. 2 (outline squares) along with the measured values, where the scale factor (A) was in the range 1.0–1.3. Each curve has a bump around I_b =1000–1200 mA. The bump position is determined by the timing of the acceleration of electrons due to successive bunches, and changes by the bunch fill patterns [2, 3]. The observed shapes and positions of the bumps in the I_e curves were almost the same as those of the calculated ones; however, they were not exactly coincident with each other. The shapes and positions depended on not only δ_{max} but also the initial energy of the emitted secondary electrons and the radius of beam chambers. On the other hand, the slope of I_e in the higher I_b region depended almost only on δ_{max}, which is one reason of utilizing I_e at high I_b to estimate the δ_{max} values.

APPLICATION TO CHAMBERS WITH ANTECHAMBERS

The studies on the coating so far indicate that the benefit of a surface with a low SEY is lost in the presence of abundant photoelectrons. One way to reduce the number of photoelectrons is to utilize a beam duct with antechambers. Test chambers with one or two antechambers have also been studied using the LER [4]. The diameter of the beam channel was 94 mm, and the half-apertures was 112 mm. The height and the depth of the antechamber were 18 mm and 65 mm, respectively.

The test chamber with two antechambers on both sides as shown in Fig. 4, for example, was installed into the wiggler section, where the SR struck both the sides. The direct photon density at the position of the electron monitor was about 8×10^{14} photons m^{-1} s^{-1} mA^{-1} and the incident angle was 14 mrad. The critical energy was 6.1 keV.

The measured I_e with respect to I_b is presented in Fig. 5 (solid circles), where the bunch fill pattern was 1/1389/3.5 and V_r = –1000 V. The $\eta_{e\text{-eff}}$ and δ_{max} values were estimated again using the simulation, where $\eta_{e\text{-eff}}$ denotes the photoelectron yield (η_e) that includes the geometrical effect of the antechamber. The square data in the figure are the calculated I_e for $\eta_{e\text{-eff}}$ = 0.04 and δ_{max} = 1.2, where η_e = 0.28 was again assumed as a PEY at the side wall of the antechamber. The $\eta_{e\text{-eff}}$ value was lower than that expected from the simple circular chamber (~ 0.3) by a factor of approximately 7. The similar results were obtained for the test chambers with one antechamber. The results obtained for the test chambers with antechambers are also summarized in Table 1.

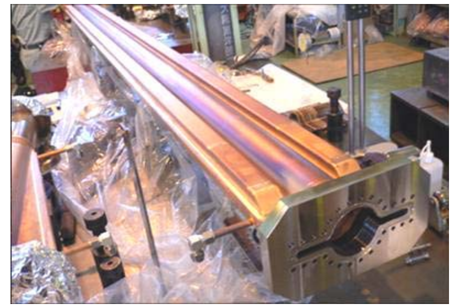

Figure 4: Test chamber with two antechambers on both sides.

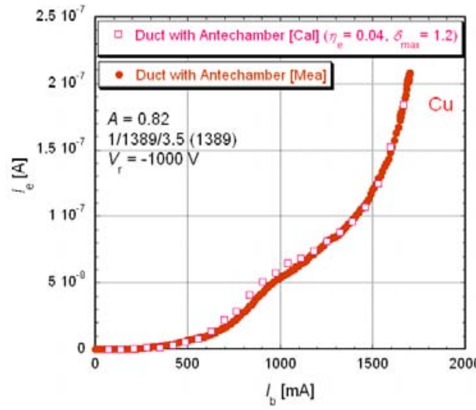

Figure 5: Behavior of measured and calculated I_e against I_b for a chamber with two antechambers.

FUTURE PLAN

Based on the experiments and the simulations so far, a test using a TiN coated beam chamber with antechambers is planed, which is the best solution at present. The test chambers will be installed in the LER soon, and the electron density in the chambers will be studied again.

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