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Recent studies on photoelectron and secondary electron yields of TiN and NEG coatings using the KEKB positron ring

Y. Suetsugu*, K. Kanazawa, K. Shibata, H. Hisamatsu

Accelerator Laboratory, High Energy Accelerator Research Organization (KEK), 1-1 Oho, Tsukuba, Ibaraki 305-0801, Japan

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Abstract

In order to obtain a method to suppress electron-cloud instability (ECI), the photoelectron and the secondary electron yields (PEY and SEY) of a TiN coating and an 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 the arc section of a previous experiment. The number of electrons around beams was measured by an electron current monitor; this measurement was performed up to a stored beam current of approximately 1700 mA (1389 bunches). For the entire range of the beam current, the electron currents of 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 small photon density, that is, the weak effect of photoelectrons, elucidated the differences in the SEYs of these coatings when compared to the measurements at the arc section. By assuming almost the same PEY (η_e) values obtained in the previous study, the maximum SEY (δ_{max}) for the TiN and NEG coatings and the copper chamber was again estimated based on a previously developed simulation. The evaluated δ_{max} values for these three surfaces were in the ranges of 0.8–1.0, 1.0–1.15, and 1.1–1.25, respectively. These values were consistent with the values obtained so far. As an application of the simulation, the effective η_e, η_{e-eff} (which included the geometrical effect of the antechamber) and δ_{max} values were also estimated for copper chambers with one or two antechambers. These chambers were installed in an arc section and a wiggler section, respectively. The evaluated η_{e-eff} and δ_{max} values were approximately 0.008 and 1.2, and 0.04 and 1.2, respectively, where $\eta_e = 0.28$ was assumed on the side wall. As expected, the η_{e-eff} values were considerably smaller than those obtained in the case of a simple circular chamber ($\eta_e = 0.28$–0.3). Further, the δ_{max} values were consistent with those obtained so far. With regard to the uncertainty in the simulation, the effect of the SEY spectrum on the estimation of δ_{max} values is briefly discussed. As the next step in our study, we plan to combine beam ducts with antechambers and TiN coatings; this combination is the most promising solution to ECI at present.

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Keywords: Electron-cloud instability; Secondary electron yield; Photoelectron yield; NEG coating; TiN coating; Antechamber

1. Introduction

One of the most critical problems in current and future high-luminosity colliders is the electron-cloud instability (ECI) in various positron and proton rings [1–11]. One promising method to suppress the ECI is to apply a surface coating with a low secondary electron yield (SEY) to the inner surface of the beam duct [9–31]. We have been focusing on a TiN coating and an NEG (Ti–Zr–V) coating and on investigating the effect of their SEYs on the electron cloud formation by using the KEK B-factory (KEKB) positron ring, that is, the low energy ring (LER) [32]. In the previous reports, the test chambers with these surfaces were installed at an arc section in the LER; around this section, the photons of the synchrotron radiation (SR) were directly irradiated with a line density of approximately 6.5×10^{14} photons $m^{-1} s^{-1} mA^{-1}$ [30,31]. The number of electrons around the beams was measured using an electron current monitor [30] and the measured values were

*Corresponding author. Tel.: +81 298 64 5227; fax: +81 298 64 3182.
E-mail address: yusuke.suetsugu@kek.jp (Y. Suetsugu).

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compared with each other. The measured electron currents of the NEG-coated chamber were almost the same as those of the uncoated copper chamber, except for a small difference in the high beam current region. On the other hand, the electron current of the TiN-coated chamber was clearly smaller than that of the NEG-coated and uncoated copper chambers by a factor of 2 for whole beam currents. Based on a simulation developed in this study, the photoelectron yield (PEY, η_e) and the maximum SEY (δ_{max}) of the TiN coating, NEG coating, and the copper were estimated. The δ_{max} values were found to be almost the same after sufficient electron bombardment [9–11]. It was also inferred that the SEY of the NEG coating was lower than that of copper; however, this benefit was lost due to the relatively high PEY of the NEG coating, which was comparable to that of the copper.

As a continuation to the previous studies, the SEY and the PEY of a TiN coating and an NEG coating were recently investigated in the same manner at a straight section of the LER, where considerably less direct photons (approximately 3.3×10^{12} photons $m^{-1}\,s^{-1}\,mA^{-1}$) were irradiated. It was expected that the effect of SEY would become evident by reducing the effect of the photoelectrons, and in fact a clear difference was observed between the NEG-coated and the copper chambers. Further, the TiN-coated chamber produced the smallest electron current. The evaluations of the δ_{max} and η_e of these surfaces were also attempted on the basis of the simulation mentioned previously, and the estimated δ_{max} and η_e were found to be almost consistent with those obtained in the experiment at the arc section.

The simulation was applied to estimate η_e and δ_{max} for copper beam chambers with one or two antechambers [33–36]. The antechamber scheme is said to be effective in reducing the effect of photoelectrons. Antechambers were installed into an arc section and a wiggler section of the LER, where 8×10^{15} and 8×10^{14} photons $m^{-1}\,s^{-1}\,mA^{-1}$ were irradiated, respectively. The measured electron currents were well reproduced with a much lower η_{e-eff} (less than approximately 1/10) as compared to those obtained in a circular chamber; η_{e-eff} is the PEY (η_e) that includes the geometrical effect of the antechamber. The estimated δ_{max} values were almost the same as those obtained so far for copper. With regard to the uncertainty in the simulation, the effect of the energy spectrum of the SEY on the estimated δ_{max} was briefly considered. The results obtained so far will provide valuable data in designing vacuum chambers for future accelerators such as the Super B factories [37] and the damping ring (DR) of the International Linear Collider (ILC) [38].

2. Experiments at straight section

2.1. Test chambers

The test chambers had a length of 1.35 m and a diameter of 94 mm, which are the standard dimensions for the KEKB LER [39–41]. The material of the chamber was oxygen-free copper (OFC) with a grade equivalent to C1011. The chamber was cold-drawn, and the roughness in the axial direction was very small (R_a~0.02). The copper chamber, or the uncoated chamber, was cleaned with an acid, which is the standard procedure for the KEKB beam ducts.

The coating of TiN 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 in a previous experiment [31,42]. Titanium was sputtered onto the inner surface of the test chamber by a glow discharge in an $Ar+N_2$ atmosphere of 0.6 Pa. The atomic ratio of Ti:N of the coating was 55:45, and the thickness was in the range of 0.3–0.4 μm. Prior to the coating, the chamber was baked at 220 °C for 72 h, and subsequently the inner surface was subject to argon discharge-cleaning with a ion dose of approximately 1×10^{18} ions cm^{-2}; a thin, pure Ti underlayer was then deposited to promote adhesion. The applied voltage was 380 V and the discharge current was approximately 1.72 A. The maximum SEY (δ_{max}) was measured using a stainless steel sample; it was approximately 1.76 at an electron energy of 375 eV [10] (as-received).

On the other hand, the NEG coating onto the test chamber was performed by SAES Getters SpA., Italy. Before the coating, the chamber substrate was cleaned according to the CERN standard procedure, and it was then evacuated and baked at approximately 150 °C for 24 h [43]. The NEG materials—Ti, Zr, and V—were sputtered onto the inner surface in the under Kr atmosphere and a pressure of 1.5 Pa. The discharge voltage was 260 V, while the substrate temperature was maintained at 100 °C. The compositions were determined as Ti = 28%, Zr = 28%, and V = 44% and the thickness was approximately 1.1 μm. The δ_{max} value of the coating on a stainless steel sample was approximately 1.9 for electrons with an energy of 250 eV [10] (as-received).

Before the installation into the LER, all the test chambers were baked at 150 °C for 24 h. However, the NEG-coated chamber was additionally baked at 200 °C for 2 h in order to activate the coated NEG in the final stage of baking [15].

2.2. Setup in the ring

The test chambers were installed in order into a straight section of the KEKB LER in the spring of 2006. They 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 maximum stored beam current was approximately 1700 mA (1389 bunches) [32]. 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 some of the direct