

DEVELOPMENT OF TiN COATING SYSTEM FOR BEAM DUCTS OF KEK B-FACTORY

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Abstract

A titanium nitride (TiN) coating system for copper beam ducts of KEK B-factory (KEKB) was developed to reduce the secondary electron yield (SEY) of the inner surface, which would mitigate the electron cloud instability. The coating was done by DC magnetron sputtering of titanium in argon and nitrogen atmospheres. The duct was set vertically, and a titanium cathode rod was hung from the top on the center axis of the duct. A magnetic field was supplied by a movable solenoid coil placed outside of the duct. Preliminary experiments using small copper samples showed that a 200-nanometer-thick TiN film coated at 150 °C is the best from the viewpoints of the SEY and adhesion strength. The SEY of the coated sample decreased to 60% of that of non-coated copper after an electron dose of 0.01 C/mm², and the maximum SEY was 0.84. Using the coating system, several ducts with a length of up to 3.6 m was successfully coated. Some of them were installed into the KEKB positron ring last summer, and no problem was found in the following beam operation with a beam current of up to 1.6 A. One coated duct with an electron monitor was installed this winter, and the reduction of the electrons in it was confirmed.

INTRODUCTION

For positron rings of future high luminosity colliders like Super KEKB, it is an important issue to mitigate the electron cloud instability [1]. To reduce the electron cloud, it is necessary to decrease the SEY of the inner surface of the duct such as TiN and NEG is effective in that [2-4]. So far, some beam ducts coated with TiN and NEG has been installed into KEKB positron ring (low energy ring, LER), and the electron cloud density in the beam ducts has been measured to study the effect of the coatings [5, 6].

On the other hand, it is also effective to reduce the number of the photoelectrons in the beam channel which act as the source of the electron cloud. In a beam duct with antechambers, the number of the photoelectrons in beam channel is much less than that in a duct without antechambers, since the photoelectrons emitted from a side wall of the antechamber far from a beam channel can't come into the beam channel easily. To confirm the effectiveness of the antechamber, we have installed some beam ducts with antechambers in LER and it was found that the electron cloud reduced in them [5, 6].

The results of above measurements at LER showed that the TiN coated beam ducts with antechambers is one of the candidates for the beam duct of Super KEKB. Therefore, we started to develop a TiN coating system for long beam ducts of accelerators.

PRELIMINARY EXPERIMENT

Experimental Setup

The setup of the preliminary experiment is shown in Fig. 1. The length and inner diameter of the test chamber was 404 mm and 96 mm, respectively. The coating was done by DC magnetron sputtering of titanium in argon (2 Pa) and nitrogen (0.5 Pa) atmospheres. The test chamber was set vertically, and a titanium cathode rod ($\phi 21.7$ mm) was hung from the top on the center axis of the test chamber. The titanium rod was pocked with circular holes ($\phi 0.5$ mm) spirally and a distance between holes was 50 mm. The gases were supplied into the test chamber uniformly via this titanium rod. The applied voltage was -400 V. Anode was the test chamber which was electrically-grounded. The magnetic field (16 mT) was supplied by a solenoid coils placed outside of the test chamber. The test chamber had three ports for sample holders, windows and film thickness meters with a distance of 130 mm between them. The sample holder had a heater in it and the temperature of the sample during the coating process could be controlled.

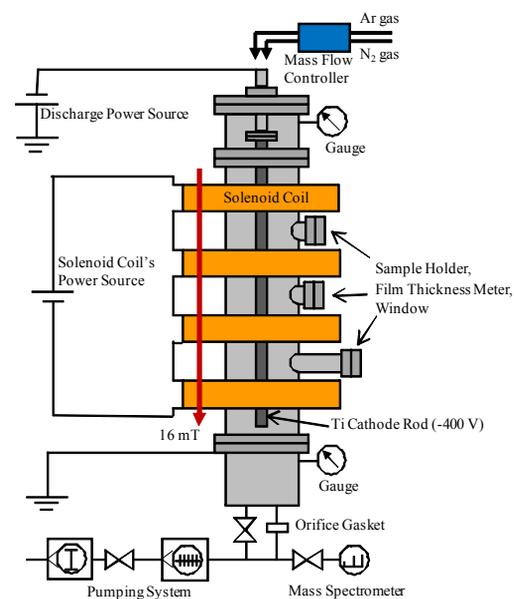


Figure 1: Schematic view of the test stand.

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Table 1: Thickness of TiN film and temperature during the coating process of the samples.

ID number of samples	Thickness of TiN film [nm]	Temperature [degree C]
#1	100	25
#2	100	150
#3	100	250
#4	200	25
#5	200	150
#6	200	250

Copper samples with a diameter of 15 mm and a thickness of 1.5 mm were set on the sample holder and the adhesion strength and the SEY was measured. We use copper as the substrate because the beam duct of KEKB was made of copper. We made six samples varying the thickness of TiN film (100, 200 nm) and the temperature of samples during the coating process (25, 100, 150 °C) to compare the difference between them. The ID number of the samples and their parameters are summarized at Table 1.

Results of Preliminary Experiment

The adhesion strength was estimated by the nano-scratch test. The loads on the diamond indenter at which the delamination of the coating were occurred were taken as an indication of the adhesion strength. The result is shown in Fig. 2. The adhesion strength of the sample #5 (150 °C-200 nm) was the largest of all.

The result of the SEY measurements of the TiN coatings is shown in Fig. 3. The history of the SEY versus electron dose is shown in Fig. 3 (a). The incident energy of the electrons was 250 eV, and the irradiated area was 20 mm². The SEY of the TiN films were smaller than that of the copper sample. Especially, the reduction of the SEY of the sample #5 was outstanding and it decreased to about 60 % of copper when the electron dose was 0.01 C/mm².

The energy spectrums of the SEY of the sample #5 are shown in Fig. 3 (b). The SEY reached its maximum value when the incident energy was around 400 eV. For electron

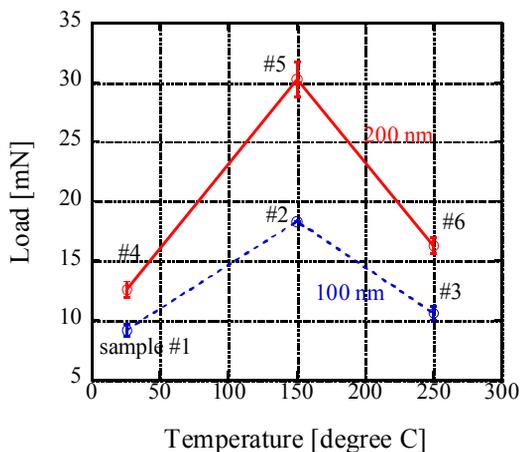


Figure 2: Adhesion strength of TiN films estimated by the nano-scratch test.

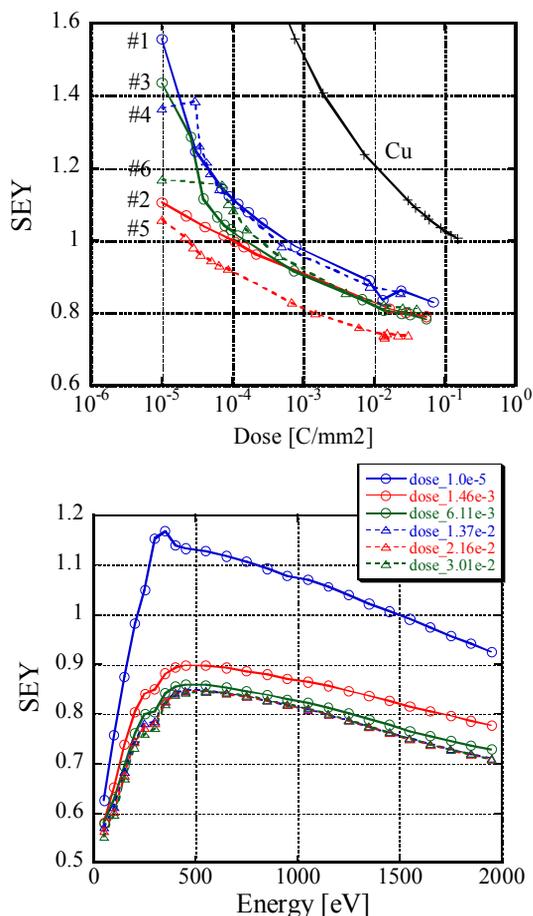


Figure 3: (a) SEY of TiN films as a function of electron dose. (b) SEY spectrums of the sample # 5 for various electron dose.

dose about 0.001 C/mm², the maximum value of the SEY was about 0.84.

From the results of the preliminary experiments, it was found that the sample #5 was most suitable to the beam duct of KEKB and therefore its parameters were set as our goal.

COATING SYSTEM

Setup

The schematic configuration and actual setup of the TiN coating system for long beam ducts are shown in Fig. 4. The beam duct with antechambers with a length of 3.6 m was set vertically. The basic design was almost the same as that of the preliminary experiment, except for the solenoid coil. In this system, the movable solenoid coil with a length of 800 mm was adopted and whole duct was coated by moving the position of the solenoid coil every several hours. The length of the coil was limited by the ability of a power supply and cooling system. Some heaters were put on the duct and the temperature of the duct during the coating process was controlled. The length of the titanium rod was 4.2 m.

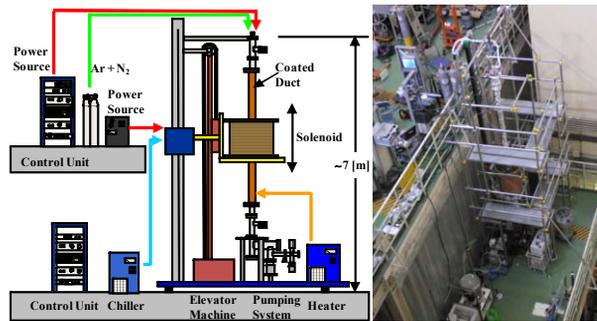


Figure 4: Schematic configuration and actual setup of the TiN coating system for long beam ducts.

Coating Test

Since the beam ducts don't have ports for the thickness meter, it is impossible to monitor the thickness of the TiN films during the sputtering. To determine how to move the solenoid coil to make a TiN film with a thickness of 200 nm all over the duct, the growth rate of the TiN film was measured by using a test duct with ports for the thickness meter before we coated real beam ducts.

According to the results of the preliminary test, the temperature of the duct was raised up to 150 °C. However, it was found that the titanium rod was away from the center axis of the duct due to the thermal deformation. To suppress this thermal deformation, the temperature was reduced from 150 °C to 130 °C when the real beam duct was coated.

Results and Discussions

On the bases of above results, several beam ducts with antechambers of KEKB, which length were up to 3.6 m, were coated with TiN. The thickness of TiN film was 200 nm and the temperature during the coating was 130 °C. The pictures of the inner surfaces of the beam ducts after the coating are shown in Fig. 5. It was confirmed that the inner surface of the coated duct was uniformly colored and there was no flake of TiN film in it.

Several coated ducts were installed into LER last summer, and no problem was found in the following beam operation with a beam current of up to 1.6 A.

One coated duct with an electron monitor [5, 6] was

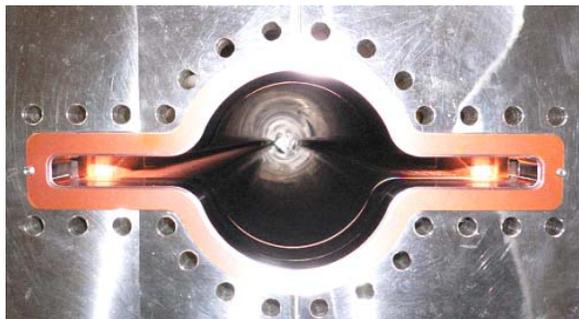


Figure 5: Inner surfaces of the beam duct after the TiN coating.

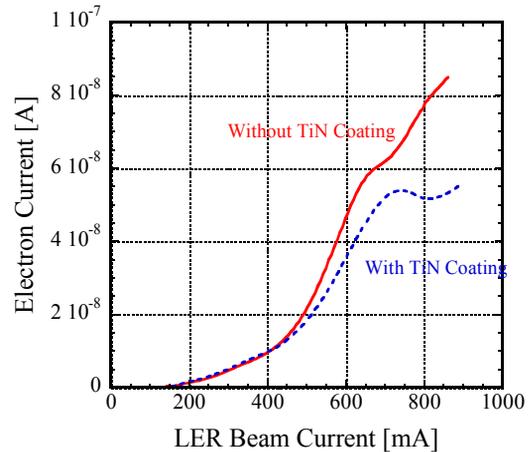


Figure 6: Measured electron currents for the uncoated (solid line) and TiN coated (dashed line) copper duct.

installed this winter, and the effect of the coating was investigated. The result is shown in Fig. 6. Bunch filling pattern was 3 bucket spacing, 200 bunches and 4 trains. The retarding voltage of the electron monitor was 1 kV [5, 6]. When the beam current was low, where the photoelectrons due to the synchrotron radiation were dominant [5], there was not much difference between coated and uncoated duct. However, when high current was stored, where the secondary electrons emitted from the beam duct were dominant [5], the electron density in the coated duct was much less than that in the uncoated duct. It was found that the electron density in the coated duct reduced to about 67 % of that in the uncoated duct when the beam current was 800 mA. This result indicated that the TiN film coated by this system was effective to reduce the electron cloud.

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