TiN COATING OF ACCELERATOR BEAMLINE CHAMBERS*

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Abstract

A titanium nitride (TiN) coating can reduce multipactoring problems in vacuum cavities and also reduce photoemission electrons from beam-pipe surfaces. A new technique is being explored at LBNL that will allow an efficient way to coat differently-shaped surfaces with TiN. In this technique, an rf-induction discharge with an exposed Ti induction antenna is employed. Tests are being performed using argon, nitrogen, and a mixture of argon and nitrogen gases. It is found that the characteristics of the TiN coating depends on the processing time and the gas that forms the discharge plasma.

I INTRODUCTION

One of the problems encountered in many high-power rf systems is multipactoring inside vacuum rf cavities. The potential for multipactoring occurs whenever the secondary electron emission coefficient of the surface exceeds unity. Under this condition, electrons can be accelerated by the rf fields onto the surface, causing more electrons to be emitted than the number impinging upon them. The electron current becomes amplified within a few rf cycles, not only absorbing a large percentage of the rf power, but depositing that power as heat in a very localized area. Multipactoring can be a serious problem in high-power rf cavities, often preventing not only sustained operation, but in many cases, preventing satisfactory operation altogether.

The secondary electron emission coefficient of titanium Ti is always less than unity. [1] A thin layer of Ti on the rf component surfaces should eliminate the potential for multipactoring. However, pure Ti is very reactive and it forms an oxide when exposed to air or water vapor. The titanium-oxide layer is not durable and has a higher secondary electron emission coefficient than pure Ti. On the other hand, a titanium-nitride layer is very stable and it has a secondary electron emission coefficient similar to pure Ti.

II TIN COATING METHODS

Several methods have been tested for TiN coating of vacuum chambers. In one approach, Ti is first evaporated from a hot Ti filament and the Ti neutrals are deposited on the substrate surfaces. Ammonia gas NH_3 is then introduced into the system and the gas molecules interact with the Ti to form TiN. [2] The drawback for this technique is that the Ti vapor lands on the substrate surfaces softly with very low energy. As a result, the TiN coating is not strongly bonded to the surface and the coating comes off quite easily. Second, the thickness and stoichiometry of the coating (i.e. ratio of Ti:N) cannot be controlled accurately. In the plasma discharge technique, a Ti electrode is used as the cathode while the metal chamber wall acts as the anode. A plasma is formed when a high voltage is applied between the anode and the cathode. The filling gas is normally a mixture of argon and nitrogen. This technique enables one to deposit both Ti and N on the substrate surfaces in the form of positive ions. Not only the deposition rate is higher, but the ions acquire some energy (several or tens of eV) as they cross the anode sheath. For this reason, stronger bonding between the TiN coating and the substrate can be achieved.

The new TiN coating technique described in the following section employs rf induction discharge instead of dc discharge. The Ti neutrals are sputtered from a bare Ti antenna coil and the plasma (Ar or a mixture of Ar and N_2) is generated by rf discharge. The experimental setup is simple and easy to operate. As the implant ion dose rate is high, the processing time is much faster than the dc discharge or the evaporation method. In addition, this technique allows an efficient way to coat differently shaped surfaces.

III EXPERIMENTAL SETUP

Figure 1 is a schematic of the experimental setup. The test chamber is a section of the B-factory low-energy booster-ring beamline chamber. It is made of aluminum and has water cooling channels built into it. The rf antenna is water-cooled and is fabricated from 2-mm-OD titanium tubing. The tubing is wound to match the oval shape of the chamber (Fig. 2). Two water-cooled copper plates are installed on top and bottom of the antenna so as to limit the volume of the discharge plasma. The entire antenna unit can be moved in and out with an electric motor attached on top of the setup. Both the water and gas inlets and the pumping port are located at the top flange.

The rf supply is a 13.56 MHz generator with a maximum output power of 2.5 kW. The rf power is coupled into the plasma through a matching network which is connected to the leads of the rf antenna. In normal discharge operation, the capacitor in the matching circuit is adjusted to minimize the reflected rf power. Although the rf supply is capable of delivering 2.5 kW

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output power, only 1 kW of output power is used for this test.

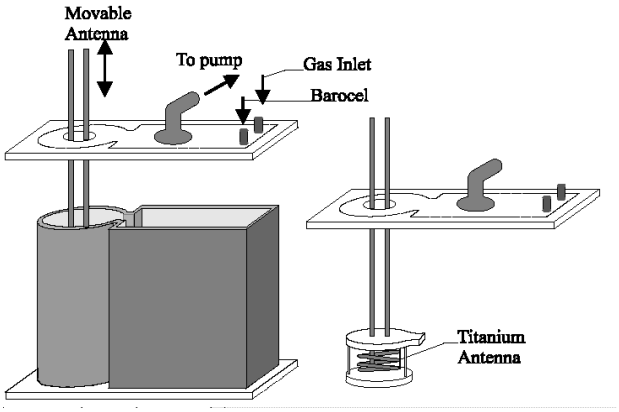

Fig. 1 Experimental setup for TiN coating of a B-factory beamline chamber

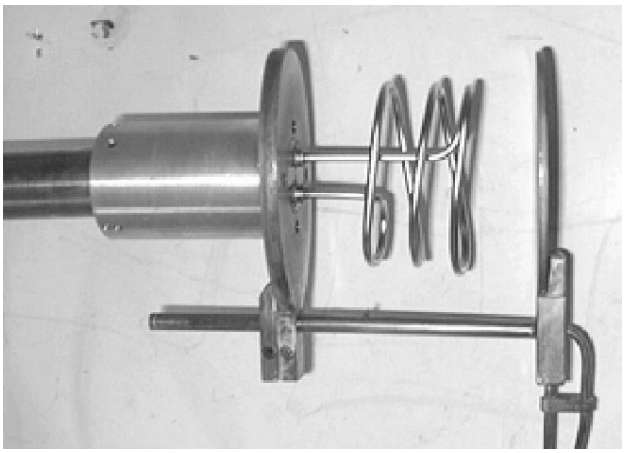

Fig. 2 A picture showing the water-cooled titanium rf induction antenna.

IV EXPERIMENTAL RESULTS

In order to investigate the characteristics of the TiN coating, three aluminum disk samples are installed on the chamber as illustrated in Fig. 3. The inner surface of the chamber as well as the sample disks are chemically cleaned to remove the oxide layer. The chamber is initially evacuated to a base pressure of about 2×10^{-6} Torr. Argon, nitrogen or a mixture of argon and nitrogen gas is then introduced into the chamber until the pressure reaches ~20 mTorr. The output power of the rf supply is gradually increased until a plasma is formed. The rf reflected power is minimized by adjusting the capacitor of the matching network.

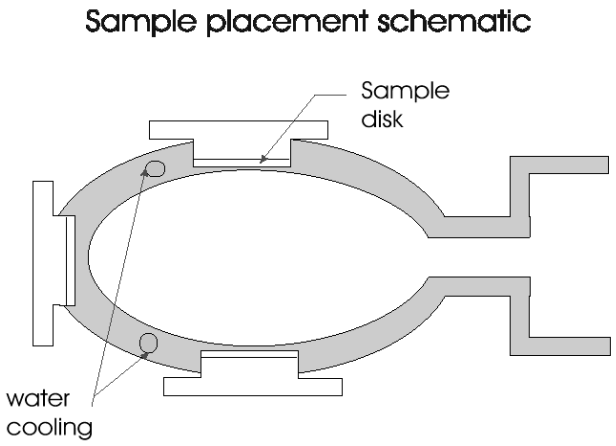

Fig. 3 A schematic diagram showing the locations of the three sample disks when they are mounted in the beamline chamber.

Disk samples and the beam pipe have been TiN coated with several different operating conditions. In general, a reasonably thick TiN coating can be achieved if the system is first operated with a pure argon plasma. The argon ions can sputtered the Ti from the antenna due to the high negative potential. Some of the Ti atoms are ionized and they are implanted into the chamber surface with energies in the order of tens of eV (due to the high plasma potential of rf discharge). After about 20 minutes, the argon plasma is turned off and is replaced with a nitrogen plasma. The N^+ and N_2^+ ions as well as the neutrals then react with the Ti on the walls to form TiN.

Table I shows the analyzed results for three sample disks under different processing conditions. It is found that the color of the TiN coating varies from blue to gold, depending on the thickness as well as the stoichiometry of the film. By first operating the system with argon for 15 min followed with a mixture of Ar/N_2 (30% N_2) for another 15 min, the stoichiometry (Ti/N) ratio is unity and the thickness of the coating exceeds 500 nm.

Table I.

Discharge gas (nm)	Ti/N Stoichiometry	Thickness
Ar/N_2 (15% N_2) (48 min)	1.08	12.6
Ar (32 min) N_2 (16 min)	0.74	779
Ar (15 min) Ar/N_2 (30% N_2) (15 min)	1.02	555

In this experiment, movement of the antenna is limited to the length of the beamline chamber which in this case is ~30 cm. It has been demonstrated that a dense plasma can be generated even when the coaxial cable between the matching network and the antenna is 6 meters long. Thus, this TiN coating technique can easily be applied to long beamline chambers typically found in synchrotrons and storage or accumulator rings.

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