BNL-98853-2013-CP

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Presented at the 4th International Particle Accelerator Conference (IPAC 13)
Shanghai, China
May 12-17, 2013

Collider-Accelerator Department
Brookhaven National Laboratory

U.S. Department of Energy
DOE Office of Science

DISCLAIMER

DEVICE AND TECHNIQUE FOR IN-SITU COATING OF THE RHIC COLD BORE VACUUM TUBES WITH THICK OFHC*

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Abstract

To rectify the problems of electron clouds observed in RHIC and unacceptable ohmic heating for superconducting magnets that can limit future machine upgrades, we started developing a robotic plasma deposition technique for *in-situ* coating of the RHIC 316LN stainless steel cold bore tubes based on staged magnetrons mounted on a mobile mole for deposition of Cu followed by amorphous carbon (a-C) coating. The Cu coating reduces wall resistivity, while a-C has low SEY that suppresses electron cloud formation. Recent RF resistivity computations indicate that 10 μm of Cu coating thickness is needed. But, Cu coatings thicker than 2 μm can have grain structures that might have lower SEY like gold black. A 15-cm Cu cathode magnetron was designed and fabricated, after which, 30 cm long samples of RHIC cold bore tubes were coated with various OFHC copper thicknesses; room temperature RF resistivity measured. Rectangular stainless steel and SS discs were Cu coated. SEY of rectangular samples were measured at room; and, SEY of a disc sample was measured at cryogenic temperatures.

INTRODUCTION

Electron clouds, which have been observed in many accelerators, including the Relativistic Heavy Ion Collider at the Brookhaven National Laboratory [1-3], can act to limit machine performance through dynamical beam instabilities and/or associated vacuum pressure degredation. Formation of electron clouds is a result of electrons bouncing back and forth between surfaces, with acceleration through the beam, which can cause emission of secondary electrons resulting in electron multipacting. One method to mitigate these effects would be to provide a low secondary electron yield surface within the accelerator vacuum chamber.

At the same time, high wall resistivity in accelerators can result in unacceptable levels of ohmic heating or to resistive wall induced beam instabilities [4]. This is a concern for the RHIC machine, as its vacuum chamber in the cold arcs is made from relatively high resistivity 316LN stainless steel. This effect can be greatly reduced by coating the accelerator vacuum chamber with oxygen-free high conductivity copper (OFHC), which has conductivity that is three orders [5,6] of magnitude larger than 316LN stainless steel at 4 K. And, walls coated with titanium nitride (TiN) or amorphous carbon (a-C) have shown to have a small secondary electron yields (SEY)[7,8]. But, recent results [9] strongly suggest that a-C has lower SEY than TiN in coated accelerator tubing. Applying such coatings to an already constructed machine like RHIC without dismantling it is rather challenging due to the small diameter bore with access points that are about 500 meters apart. Although R&D has yielded some results, it is still work in progress.

DEPOSITION PROCESSES AND OPTIONS

Coating methods can be divided into two major categories: chemical vapor deposition (CVD) and physical vapor deposition (PVD). Reference [10] contains a comprehensive description of the various deposition processes; unless otherwise noted, information contained in the next two sections is referenced in [10].

Due to the nature of the RHIC configuration, only PVD is viable for in-situ coating of the RHIC vacuum pipes. First, the temperature under which coating can be made cannot be high (400°C is required for some conventional CVD), since the RHIC vacuum tubes are in contact with superconducting magnets, which would be damaged at these temperatures. A second very severe constraint is the long distance between access points. Introduction of vapor from access points that are 500 meters apart into tubes with 7.1 centimeters ID would likely not propagate far and result in extremely non-uniform coating.

But these constraints also severely restrict PVD options. Obviously evaporation techniques (ovens, e-beams) cannot be used in 7.1 centimeters ID, 500-meter long tubes. Therefore, evaporation must be accomplished locally. Presently, there are a variety of PVD methods used to deposit coatings on various substrates [10]. There is a wide variety of vapor generation techniques ranging from high temperature evaporation to sputter bombardment by electron beams, ion beams and plasma, which are precluded by the geometry.

*Work supported by Work supported under Contract No. DE-AC02-98CH1-886 with the US Department of Energy.

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MAGNETRON DEPOSITION STATE-OF-THE-ART

Of the plasma deposition devices like magnetrons, diodes, triodes, cathodic arcs, etc., magnetrons are the most commonly used plasma deposition devices. Major advantages of magnetron sputtering sources are that they are versatile, long-lived, high-rate, large-area, low-temperature vaporization sources that operate at relatively low gas pressure and offer reasonably high sputtering rates as compared to most other sputtering sources. Because of these superior characteristics magnetron sputtering is the most widely used PVD coating technique. Although arc discharges operate with higher intensity, they require the use of special filters [11] to eliminate macroparticles that reduce the net deposition rate to those of magnetrons.

Typical coating rates by magnetrons (w/argon gas) are 5 Å/sec for a power of 10 W/cm^2 on the magnetron cathode, though with intense cooling cathode power of 20 W/cm^2 is achievable.

THE DEPOSITION TECHNIQUE

Originally the objective was to develop a plasma deposition device for *in-situ* coating of long, small diameter tubes with about 5 - 10 μm of Cu following by a coating of about 0.1 μm of a-C. But, recent results [12] indicated that clean, conditioned copper coating had sufficiently low SEY, i.e., no a-C coating is needed. The magnetron design underwent a number of iterations A mobile magnetron, shown in figure 1, with a 15 cm long cathode was designed, fabricated, and tested to coat various samples of RHIC cold bore tubes with up to 10 μm with OFHC at an average coating rate of 30 Å/sec. Internal ring permanent magnets form the magnetic field. Magnetron assembly was mounted on a carriage (***mole***) pulled by a cable assembly driven by an external motor. The cable bundle, which is enclosed in 6 mm diameter stranded SS (or braided copper), contains electric power and water cooling feeds, as well as some instrumentation wires. Umbilical spool chamber and the cable assembly are under vacuum. Other aspects including the dragline have been described elsewhere [13].

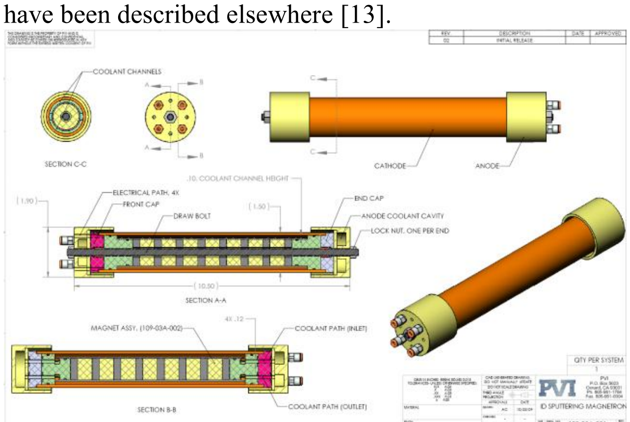

Figure 1: Complete drawing of the 1st magnetron.

A magnetron, shown in figure 2, with a 50 cm long copper cathode was designed fabricated (cooling and weight limits the length), and successfully operated. To increase cathode lifetime, thicker cathode (x2), stronger magnets, and movable magnet package are used. If needed Tesla coil or a beta emitter (Ni-63) is to be utilized to initiate/maintain discharge. The magnetron is mounted on a carriage with spring loaded wheels that successfully crossed bellows and adjusted for variations in vacuum tube diameter, while keeping the magnetron centered. Some deposition experiments were performed with spring loaded wheels on both sides of the magnetron, such that a set of wheels rolls over coated areas. No indentation in or damage to coating was observed, i.e. train like assembly option is viable.

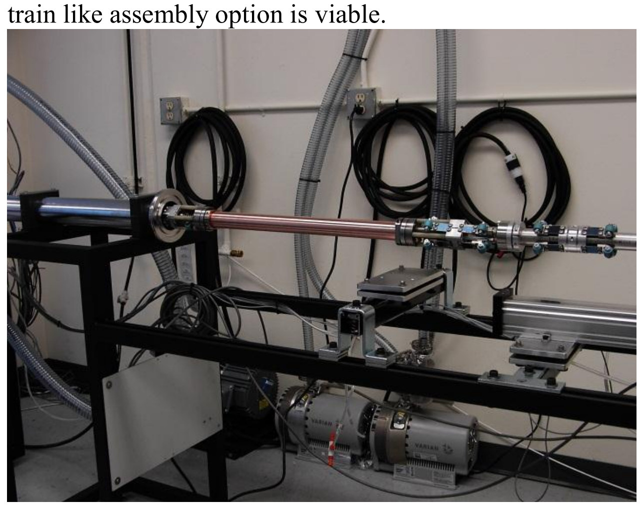
Figure 2: Photo of the magnetron assembly.

Initially with 2 m long cylindrical cathodes were previously considered [13], based on which with Cu coating rate of 5 Å/sec (though much higher rates were achieved), it would take 2.78 hours to deposit 5 μm of Cu, i.e., close to 3 hours to move one cathode length. With a 2 meter long cathode it would take 695 hours (or 29 days; a fraction of a typical RHIC shutdown period) to coat 500 m. But magnetron weight limits single deposition device length to about 50 cm. Consequently, the technique is to involve one of two options: multiple magnetrons in a train like assembly, having a total exposed cathode length of 2+ meters, or magnetrons with reloading provisions, which would require access bellows.

RF RESISTIVITY & SEY MEASUREMENTS

Room and cryogenic temperature SEY measurements were performed at CERN on small OFHC copper coated stainless steel samples, with Cu coating thicknesses of 2 μm, 5 μm, and 10 μm [12]. Obtained results coupled with those of literature [14,15] indicate that baked & scrubbed Cu coating can achieve SEY of 1.

RF resistivity measurements on 32 cm long RHIC stainless steel tubes coated with 2 μm, 5 μm, and 10 μm, thick OFHC indicated that for the later 2 coatings conductivity was about 84% of pure copper. Since joints and connectors reduce experimentally measured Q, conductivity value of coatings may be even closer to pure solid copper.

Although resistivity at cryogenic temperature might be different (it must be measure in a system that's being designed), Computations indicate [16] that 10 µm of copper should be acceptable for even the most extreme future scenarios.

COATING ADHESION STRENGTH

Consistent coatings with good adhesion are achieved routinely with discharge cleaning. Although discharge cleaning for surface preparation has been known for a while [17], ours was optimized with a first (proprietary) step that may not be needed in RHIC. Next a positive voltage (of about 1 kV) is applied to the magnetron or a separate cleaning anode and to move the discharge down the tube at a pressure of over 2 Torr. The optimized results yielded **adhesion strength** of **over 12 kg**.

(a) (b)

Figure 3: Pull test fixture and sample.

First a full size stainless steel RHIC tubing was coated, after which a section was cut out, to which a piece of copper was soldered. That sample was tested for pull strength in the pull test fixture shown in figure 3a. Figure 3b is an expanded photo of the sample in the test device. Maximum pull of that fixture is 12 kg; Optimized coatings required more than 12 kg to be peeled off. A fact bodes well for magnetic quench survival

DISCUSSION

Basically, the only remaining issue to resolve is determination and optimization of RF conductivity at cryogenic temperatures and performing magnet quench tests on copper coated RHIC cold bore tubing. Otherwise Lowering RHIC cold bore resistivity and SEY with in-situ copper coating seems feasible!

ACKNOWLEDGEMENT

Notice: This manuscript has been authored by Brookhaven Science Associates, LLC under Contract No. DE-AC02-98CH1-886 with the US Department of Energy.

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