VERSATILE DEVICE FOR IN-SITU DISCHARGE CLEANING AND MULTIPLE COATINGS OF LONG, SMALL DIAMETER TUBES*

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Abstract

Electron clouds, which can limit machine performance, have been observed in many accelerators including RHIC at BNL. Additional concern for the RHIC machine, whose vacuum chamber is made from relatively high resistivity 316LN stainless steel, is high wall resistivity that can result in unacceptably high ohmic heating for superconducting magnets. The high resistivity can be addressed with a copper (Cu) coating; a reduction in the secondary electron yield can be achieved with a TiN or amorphous carbon (a-C) coating. Applying such coatings in an already constructed machine is rather challenging. We have been developing a robotic plasma deposition technique for *in-situ* coating of long, small diameter tubes. The technique entails fabricating a device comprising of staged magnetrons mounted on a mobile mole for deposition of about 5 μm of Cu followed by about 0.1 μm of a-C. As a first step, a 15-cm Cu cathode magnetron was designed, fabricated, and 30-cm long samples of the RHIC pipe have been coated with 2 μm to 5.6 μm of copper. Deposition rates of up to 92 Å/sec with an average coating rate of 30 Å/sec were measured. Effects on RF resistivity is also to be measured.

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, which can cause emission of secondary electrons resulting in electron multipacting effect. 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 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.

DEPOSITION PROCESSES AND OPTIONS

Coating methods can be divided into two major categories: chemical vapor deposition (CVD) and physical vapor deposition (PVD). Reference [11] contains a comprehensive description of the various deposition processes; unless otherwise noted, information contained in the next two sections is referenced in [11].

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 for the same reasons. Therefore, evaporation must be accomplished locally. One option is a plasma device on a mole that generates and deposits the vapor locally.

Presently, there are a variety of PVD methods used to deposit coatings on various substrates[11]. By definition, physical vapor deposition entails purely physical processes of evaporating materials. The vapor then condenses on the desired substrate. There is a wide variety of vapor generation techniques ranging from high temperature evaporation to sputter bombardment by electron beams, ion beams and plasma. The latter involves a discharge like RF, glow, or an arc. The long distance between access points and the need to have a mole like deposition device precludes the use of RF plasmas.

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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. In magnetrons, magnetic fields are utilized to confine electrons that generate high density plasma (usually argon or xenon) near the surface of the material that is being sputtered. 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 [12] 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 50 W/inch^2 on the magnetron cathode, though with intense cooling cathode power of 100 W/inch^2 is achievable.

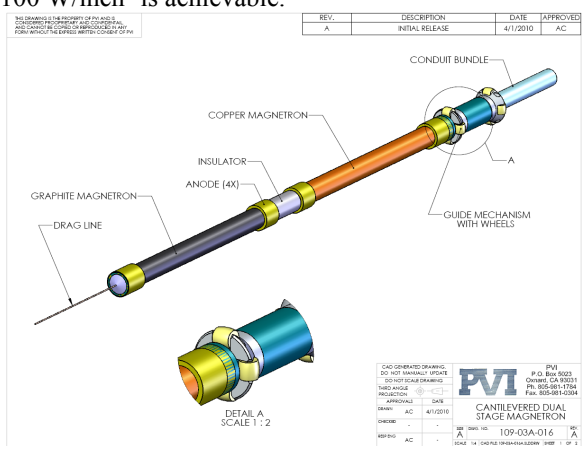

Figure 1 diagram of the deposition device based on dual stage magnetrons.

PLANNED DEPOSITION TECHNIQUE

The ultimate objective is to develop a plasma deposition device for *in-situ* coating of long, small diameter tubes with about 5 µm of Cu following by a coating of about 0.1 µm of a-C. Figure 1 is a scheme of a plasma deposition technique based on staged magnetrons. Plasma deposition sections consist of two, connected through an insulator, cylindrical magnetron devices. The first magnetron stage has oxygen free high conductivity copper cathode, while the second stage has a graphite cathode. Internal ring permanent magnets form the magnetic field. Magnetron assembly is to be mounted on a carriage (***mole***), which is to be pulled by a cable assembly driven by an external motor. To accommodate for any diameter variances, including bellow crossing, the carriage will have a spring-loaded guide wheel assembly. Spool drive mechanism is shown in figure 2. A dragline, which is attached to end (opposite to the carriage) of the graphite cathode, is used to initially pull the magnetron assembly and cable bundle to the end, where coating begins. The dragline, which is also motor driven, is a strong thin cable made of either high-tensile fishing line, or Teflon sleeved (Teflon coated) Inconel or equivalent. Should there be evidence that either the Teflon or the fishing line live any residue, a pure metal line is to be used. During coating, the magnetron assembly and cable bundle are pulling the dragline (in a direction opposite to, which the dragline pulled on the magnetron assembly and cable bundle).

If needed, a brushless DC servo-motor driving 4 rows of internal wheels moves the carriage, which has position feedback, assists carriage motion.

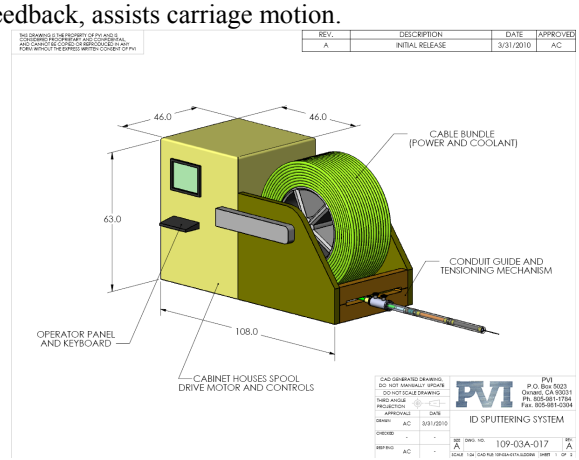

Figure 2 perspective view of spool drive mechanism.

Based on the fact that magnetrons with 2.1 meter long cylindrical cathodes exist in commercial systems[13], in a previous paper[14], it was assumed the copper magnetron section can be 2 m long. And at a Cu coating rate of 5 Å/sec, 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. And 2 m Cu cathode would not need reloading.

But curvature in the RHIC dipoles would limit single deposition device length to 59 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, as shown in figure 3, or magnetrons with reloading provisions, which would require access bellows.

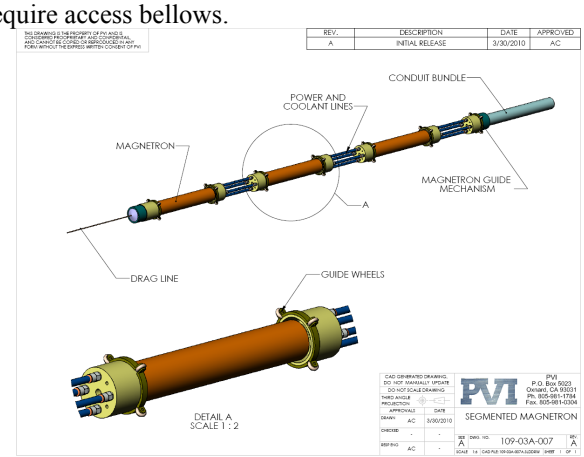

Figure 3 sketch of multiple magnetrons.

If support wheels can be can be utilized, multiple magnetrons in a train like assembly would work.

EXPERIMENTAL RESULTS

A mobile magnetron, shown in figure 4, with a 15 cm long cathode was designed, fabricated, and tested to coat 30 cm long samples of RHIC cold bore tubes with up to 6.1 μm with OFHC at an average coating rate of 30 Å/sec. Copper deposition rates were measured with a 6 MHz crystal rate monitor. A coated sample is shown in Fig. 5.

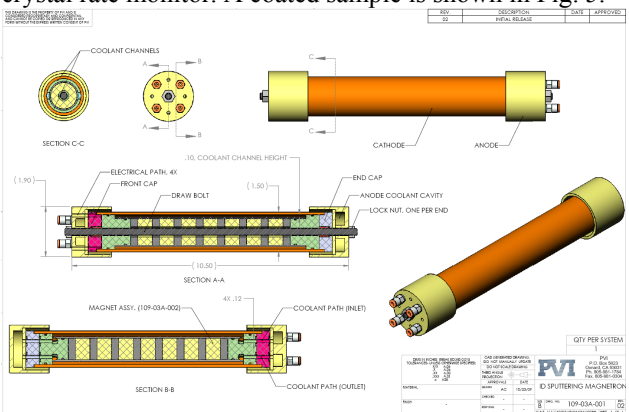

Figure 4 complete drawing of the experimental magnetron

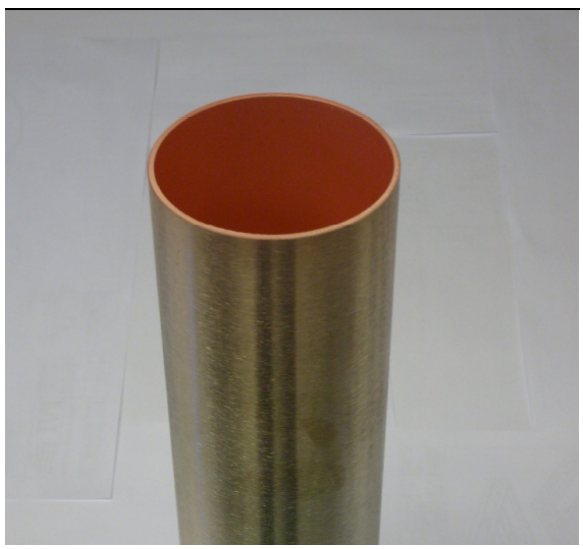

Figure 5 copper coated RHIC tube sample

Next step is to measure resistivity of coated samples with various thicknesses in the range of 2.5 μm - 6.1 μm to determine minimal copper thickness needed.

DISCUSSION

A year ago the coating technique seemed feasible, but a number of challenging hurdles were anticipated[14]. Since then experimental copper coating rate was found to be a factor 6 faster! And, solutions were found for engineering issues like cabling and bellow crossing, but other obstacles like limit on device length and possible cathode reloading need appeared. None of the obstacles appear insurmountable, since in worst case scenario, some of RHIC bellows can be replaced with access bellows, as shown in figure 6, to enable cathode reloading.

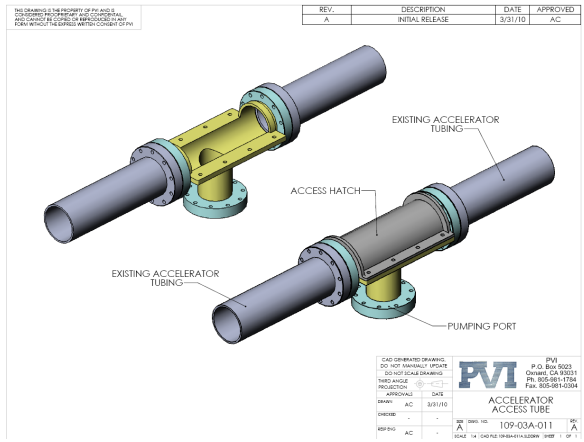

Figure 6 drawing of access bellows

ACKNOWLEDGEMENT

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