A METHOD FOR GOLD COATING EXPERIMENTAL DETECTOR BEAMPIPES*

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Abstract

A thin metallic coating is required on the inside of central detector beryllium beampipes at high-current e^+e^- colliders in order to suppress detector backgrounds that arise from scattered synchrotron radiation. As part of two CESR/CLEO upgrades, three beryllium beampipes have been coated with gold using a magnetron sputtering technique. The apparatus will be described as well as the factors that influence the adhesion and uniformity of the resulting films. Finally, we discuss the characterization methods of the resulting films.

1 INTRODUCTION

High luminosity e^+e^- colliders require that unprecedented beam currents be brought into collision, while the high-energy experimental requirements demand that beam-induced detector backgrounds be minimized. Such beam-generated detector backgrounds arise from interaction of beam particles with residual gas in the vacuum chamber (beam-gas interactions) and from synchrotron radiation (SR) generated in nearby magnetic elements which scatters into the detector. Careful interaction region design [1] provides shielding of the detector for lost beam particles and shielding of the central detector beampipe from synchrotron radiation by careful placement of apertures. Even with apertures placed to eliminate direct SR that would otherwise strike the beampipe directly, the *scattered* radiation from these apertures is great enough that further suppression is required. A common method for further suppressing the scattered SR flux which is in use at the Cornell Electron Storage Ring (CESR), PEP-II, KEK-B and elsewhere is to apply a thin metallic coating to the inner surface of the collider detector beampipe (which is generally made of beryllium). Since the scattered SR flux strikes the beampipe at very shallow angles, very thin metallic layers provide adequate suppression of the scattered SR flux entering the detector.

As part of two recent upgrades to CESR and the CLEO detector [2, 3], we have developed a technique for coating the inside of small-radius ($r \simeq 2$ cm) beryllium beampipes with gold. For the CESR Phase II upgrade, a 10 μm gold coating was required, and for the upcoming CESR Phase III upgrade, a 5 μm layer is required. Both CLEO detector beampipes are double-walled, actively cooled Be beampipes manufactured by Brush Wellman-Electrofusion [4, 3]. The inner radius and length of the as-coated beampipe assemblies were 1.9 cm, 43 cm (Phase II) and 2.1 cm, 36.5 cm (Phase III), respectively. We describe the deposition technique, the coating "recipe" and the characterization of the resulting thin films.

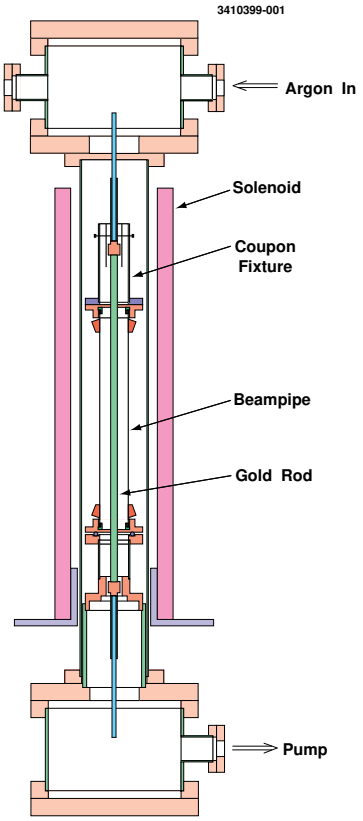

Figure 1: Beampipe coating apparatus

2 COATING METHOD AND APPARATUS

We use a cylindrical magnetron sputtering technique [5] for application of the gold coating. Due to the small radius of the beampipes , DC-diode sputtering without magnetic field was not practicable, since high sputtering gas pressures would be required (∼300 mTorr) to sustain a discharge. Sputtering at such high pressures results in very slow deposition rates and in films with undesirable surface structure. As a result, we sputtered in the presence of an axial magnetic field, which allows a discharge to be maintained at much smaller sputtering gas pressures; acceptable deposition rates result because of the enhanced ionization by secondary electrons as they travel in cycloidal, rather than straight-line, paths.

The coating apparatus which was recently used for the CESR Phase III/CLEO-III Be beampipe is shown in Figure 1. The Be beampipe is mounted to a stand which is elec-

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trically isolated from the chamber by ceramic standoffs. Atop the beampipe is mounted a small chamber to hold witness coupons which are coated along with the beampipe for quality control purposes. A water-cooled gold rod is mounted axially in the beampipe. This rod consists of a 1 mm thick layer of gold clad on 1/4 inch stainless steel tubing. Water cooling of the cathode is essential as very high power densities are reached at the surface due to ion-bombardment.

The beampipe and gold rod assembly sits inside an ultra-high vacuum system with large chambers on top and bottom for instrumentation, feedthroughs, and access. High-voltage water feedthroughs provide voltage and cooling water to the gold rod. The axial magnetic field is provided by a solenoid placed external to the vacuum system. The system is pumped with a 500 l/s turbo pump. Chamber pressure is monitored with a Granville-Phillips Stabil-Ion^{TM} hot filament gauge. Argon (UHP 99.999%) is introduced at the top of the chamber and is pumped at the bottom of the chamber, ensuring flow through the pipe. A commercial magnetron gun power supply is used for sputtering. An electrical connection to the beampipe is brought via a feedthrough outside the vacuum chamber. For back-sputtering of the beampipe (see below), high-voltage leads on the beampipe and gold rod are reversed. A thermocouple monitors the temperature of the witness coupon chamber during processing.

3 COATING RECIPE AND SPUTTERING PARAMETERS

The sputtering conditions and coating recipe were chosen to maximize the adhesion of the deposited film and to assure its longitudinal uniformity. Each will be discussed in turn.

3.1 Factors affecting adhesion

As is the case with any thin-film deposition, cleanliness of the substrate, cathode and vacuum system is the single most important factor in achieving an adherent film. Standard ultra-high vacuum handling techniques were followed for all components entering the vacuum chamber. All fixtures were acid etched prior to initial introduction into the vacuum system. Subsequent handling of fixtures was followed by scrubbing in soap and water, ultrasonic cleaning in Liquinox, and rinsing in isopropanol.

We found that cleanliness alone was not sufficient for acceptable adhesion of gold on beryllium or stainless steel. Three additional steps were required. First, prior to deposition, the Be beampipe was backsputtered. That is, the beampipe itself was sputtered in order to remove surface contaminants. In addition to cleaning the surface, back-sputtering may also help to remove the BeO layer. Secondly, we found that a thin layer of Cr ($\sim$150 nm) deposited on the Be substrate prior to gold deposition improved the adhesion. This technique of using a Cr interlayer is common in the semiconductor industry [6] and is thought to improve adhesion by bonding to the oxide layer [7]. Finally, after gold deposition the beampipe is vacuum baked at 300°C for 1 hour. This relatively low temperature bake is thought to promote diffusion at the Au-Be interface and thus improve adhesion [8, 9, 7].

In addition we found that proper Ar flow was essential for achieving adherent films. Argon was introduced at one end of the sytem and made to flow preferentially through the beampipe in order to supply fresh Ar to the discharge. Argon was pumped through the other end of the chamber always at the maximum possible throughput allowed by the turbo pumping system.

3.2 Factors affecting uniformity

We found three factors which strongly influenced the resulting gold thickness uniformity: 1) solenoid length, 2) magnetron operating point, and 3) cathode uniformity. The reduced magnetic field at the end of the solenoid produces a weaker discharge at the ends. We used a solenoid 66 cm in length whereas the beampipes were $\sim$40 cm in length. Care was taken to center the beampipe in the middle of the solenoid.

The operating region of the apparatus in magnetron mode is shown in Figure 2. For a given Argon gas pressure there is a minimum magnetic field required to sustain a plasma discharge. This minimum field is that which provides sufficient ionization by secondary electrons to just make up for losses, and is approximately given by the field for which secondary electron trajectories just miss the beampipe wall, thus making full cycloidal orbits in the system. In addition, there is a maximum magnetic field above which the discharge is extinguished. This is approximately the magnetic field for which the secondary electron path-length is shorter than the mean-free-path and hence secondary electrons are recaptured at the cathode surface. We found that the choice of operating point affects the resulting uniformity.

We chose to operate the magnetron at $P_{Ar} = 4$ mTorr and $B = 250$ G. This is sufficiently well removed from the extinguish lines of Figure 2 so that we acheive sputtering along the whole length of the rod despite the small drop in magnetic field at the ends due to finite solenoid length. For gold sputtering, we typically operated at 150 W (750 V, 0.2 A), which provided a deposition rate of $\sim$3 μm/hr.

Finally, we found that longitudinal nonuniformity of the cathode can deform the plasma discharge and produce longitudinally non-uniform coatings. We found that the plasma discharge was enhanced in regions where the cathode was of smaller radius. Nonuniformity in cathode radius of only $\sim$5% is significant and can produce non-uniform deposition profiles (see below).

4 COATING PROCEDURE

The step-by-step coating procedure is as follows. The magnetron supply power, magnetic field, and flowing Ar gas

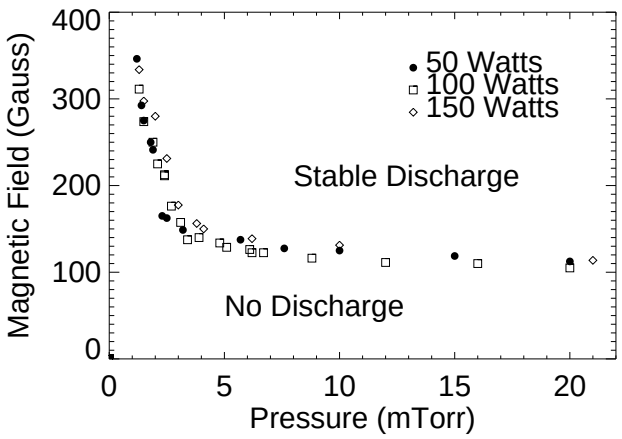

Figure 2: Magnetron operating region. Above the points a discharge is self-sustained. Below the points the discharge extinguishes.

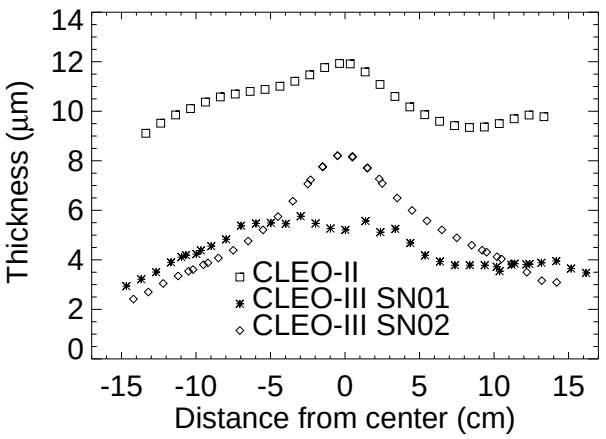

Figure 3: Gold thickness uniformity results for three Be beampipes measured by x-ray absorption.

pressure are noted.

1. Clean all fixture parts by scrubbing with abrasive pad and soap. Place in ultrasonic bath with Liquinox. Rinse in isopropanol and blow dry with N_2.
2. Assemble fixtures, Be beampipe and Cr rod. Place in vacuum system. Pump down.
3. Backsputter Be beampipe: 100 W (250 V) for 15 minutes, 275 mTorr Ar, $B = 0$.
4. Apply 150 nm Cr: 100 W (600 V) for 9 minutes, 4.0 mTorr Ar, $B = 250$ G.
5. Open vacuum system when cool, replace Cr with Au rod, reinstall in vacuum system and pump down.
6. Backsputter Be beampipe: 100 W (250 V) for 15 minutes, 275 mTorr Ar, $B = 0$.
7. Apply 5 μm Au: 150 W (750 V) for 90 minutes, 4.0 mTorr Ar, $B = 250$ G.
8. Remove assembly from vacuum system when cool.
9. Bake in vacuum furnace at 300°C for 1 hour.

5 RESULTS

Throughout the development of the coating procedure, coupons of Be and Stainless Steel were coated for various sputtering conditions. Two adhesion tests were found to be the most useful. The first is the simple "scotch-tape test" in which adhesive tape is attached to the film and pulled quickly in an attempt to remove the film. The second more demanding test requires scribing a grid of finely spaced cuts through the film down to the substrate (typically a 4x4 grid with cuts spaced $\sim$1 mm apart). This portion of the coupon was then subjected to the tape test. Generally, if a film passed this test, it could not be removed by any others means. The principal function of the witness coupons which were coated with the beampipe was to subject them to these adhesion tests. No tests were performed on the Be beampipe itself in order to maintain UHV cleanliness.

The various factors which affect thickness uniformity described above were discovered in the development stage through repeated test coupon runs. The thickness was determined by weighing coupons before and after coating.

The thickness uniformity of the coated Be beampipes was measured by a simple x-ray absorption method performed at the Cornell High-Energy Synchrotron Source (CHESS). The attenuation of an x-ray beam with energy just below the gold L_{III} edge was measured as a function of the longitudinal position on the beampipe. The thickness profiles for the three coated Be beampipes is shown in Figure 3. Uniformity is good for two pipes, but the third is thicker in the middle due to a non-uniform gold cathode, as described above. It should be mentioned that the detector tracking volume is within $\pm$6 cm, so it is this thickness which is most important.

6 REFERENCES

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