

MEASUREMENTS OF SECONDARY ELECTRON YIELD OF METAL SURFACES AND FILMS WITH EXPOSURE TO A REALISTIC ACCELERATOR ENVIRONMENT*

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Abstract

One of the central goals of the CESR Test Accelerator program is to understand electron cloud (EC) effects in lepton rings and how to mitigate them. To this end, measurements of the secondary electron yield (SEY) of technical surfaces are being done in CESR. The CESR in-situ system, operating since 2010, allows for SEY measurements as a function of incident electron energy and angle on samples that are exposed to a realistic accelerator environment, typically 5.3 GeV counter-rotating beams of electrons and positrons with 150 to 200 mA of current per beam. The system was designed for periodic measurements to observe beam conditioning of the SEY and discrimination between exposure to direct photons from synchrotron radiation versus scattered photons and cloud electrons. Measurements so far have been made on bare metal surfaces (aluminum, copper, stainless steel) and EC-mitigatory coatings (titanium nitride, amorphous carbon, diamond-like carbon). The SEY results are being used to improve predictive models for EC build-up and EC-induced beam effects.

INTRODUCTION

The goals of the CESR Test Accelerator (CESRTA) program include gaining a better understanding of electron cloud effects and their mitigation, low emittance operation, and related problems likely to be encountered in future lepton rings [1]. In-situ measurements of the secondary electron yield of surfaces are one of the elements of the EC studies program. The goals of the in-situ SEY studies include (i) measuring the SEY of surfaces that are used for beam chambers; (ii) measuring the effect of beam conditioning; and (iii) comparing different materials and mitigation coatings. The SEY apparatus is based on technology developed at SLAC for measurements in PEP-II [2]; systems similar to the CESRTA stations were recently sent to Fermilab for EC studies in the Main Injector [3].

One the unique aspects of the CESRTA SEY studies is that they allow for frequent measurements, so that we can observe beam conditioning as a function of time. This is in contrast to other studies, in which the samples are measured, exposed to the beam environment for several months, removed, and then remeasured. The CESRTA in-situ samples are typically measured weekly during a regularly-scheduled 6-hour tunnel access. The SEY chamber design allows for samples to be exchanged rapidly; this can be done during a 6-hour access if needed. A second

unique aspect is to measure 2 samples at different angles (one in the horizontal plane, the other 45° below the horizontal plane) simultaneously, which allows us to compare conditioning by bombardment from direct synchrotron radiation (SR) photons in the middle of the horizontal sample versus bombardment by scattered photons and electrons from the cloud for the 45° sample and the top and bottom of the horizontal sample. A third unique aspect is that we can keep some samples in ultra-high vacuum after beam conditioning and observe the changes in SEY over several weeks, without exposure to nitrogen gas or air.

Results from CESRTA in-situ SEY measurements on Al, TiN, and amorphous carbon (aC) have been reported previously [1, 4, 5]. Measurements on additional Al and TiN samples are reported in this paper, along with measurements on Cu, stainless steel, and diamond-like carbon (DLC). The TiN, aC, and DLC films were coated by SLAC, CERN, and KEK, respectively. In parallel with the in-situ measurements, improvements have been made to the measurement systems and techniques, which will be summarized herein as well. One major reason for improvements in the techniques was the observation that samples with DLC coatings could experience charging with traditional SEY measurement methods [1].

APPARATUS AND METHODS

The SEY stations are shown in Figure 1. An actuator is used to move the sample from the SEY measurement chamber to the beam pipe while it remains under vacuum. The SEY is measured with a DC electron gun and a picoammeter. Because the SEY depends on the energy and angle of the incident electron, the energy and deflection of the electron gun are varied.

The techniques used for the initial SEY measurements have been reported elsewhere [1, 4, 5]. Recent improvements include (i) reducing the gun current from 2 nA to about 200 pA to reduce charging and unintended conditioning; (ii) installation of a nitrogen gas “blanket” around the ceramic to reduce the leakage current that flows when the sample is biased; (iii) measurement of the leakage current so that it can be subtracted when calculating the SEY; (iv) redesign of the system to ensure that the horizontal sample receives direct SR; and (v) scanning the sample surface with more range and resolution.

SEY MEASUREMENTS

In most cases, one pair of samples of each type was measured; for TiN, a second pair was measured, exposed to air, and then remeasured; for Al, five samples were measured,

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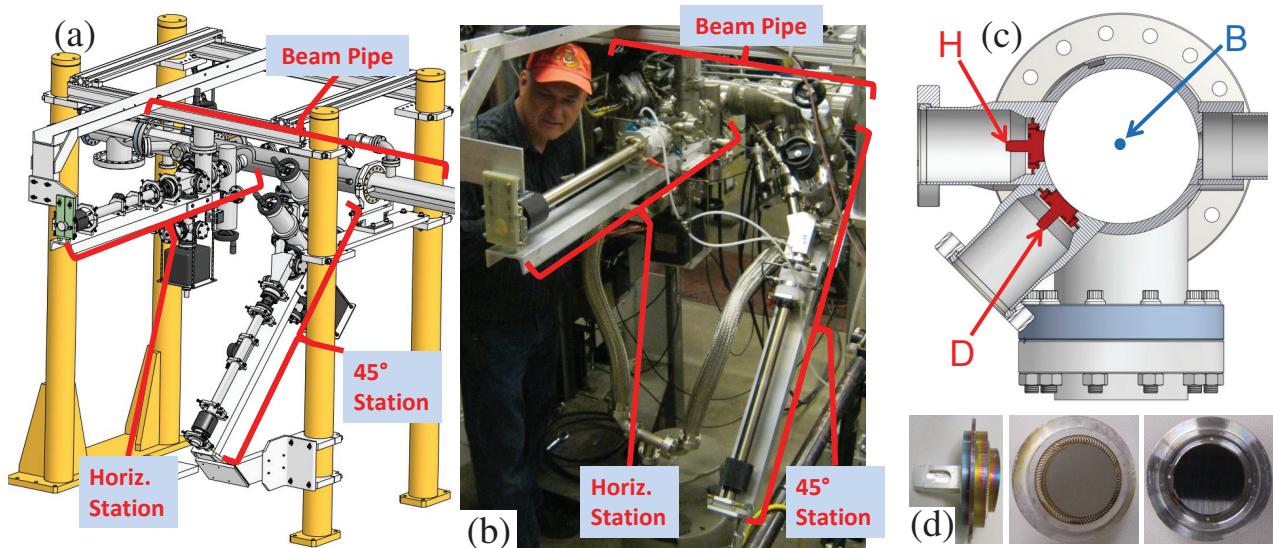


Figure 1: (a) Drawing and (b) photograph of the SEY stations. (c) “Beam’s eye” view of the SEY stations showing the beam (B), horizontal sample (H), and 45° sample (D). (d) Photographs of TiN (left, middle) and DLC (right) samples.

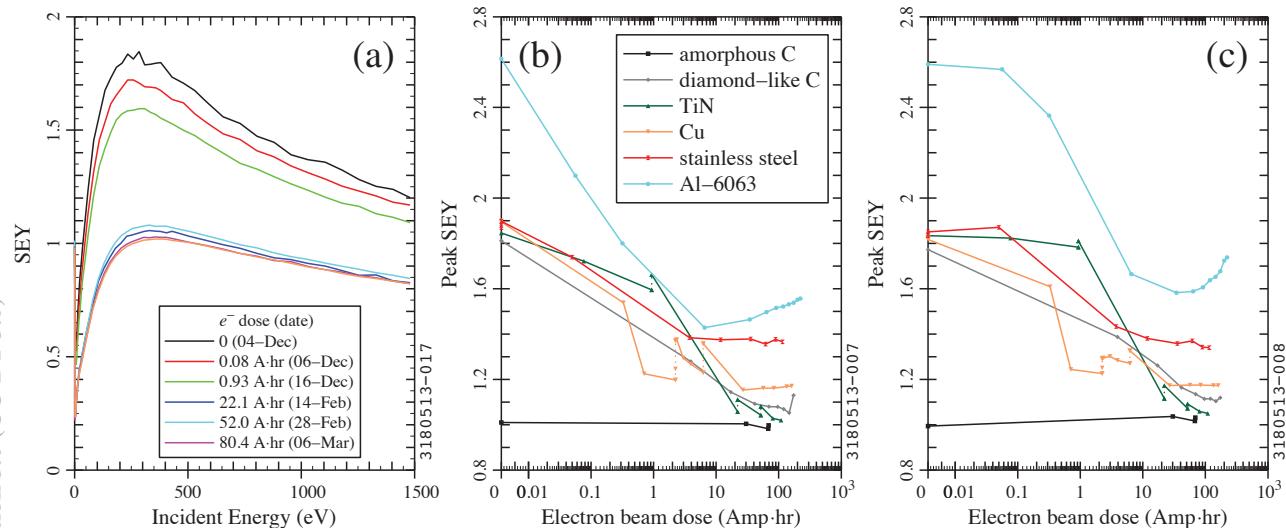


Figure 2: (a) SEY as a function of incident energy for the second horizontal TiN sample (December 2011 to March 2012). Peak SEY as a function of dose for (b) horizontal and (c) 45° samples of various materials.

three made from 6061 alloy and two made from 6063 alloy. The measurements reported in this section were done at an incident angle of 25°, with the electron beam spot at the middle of the sample except when indicated otherwise.

Beam Conditioning

Figure 2a shows an example of the measured SEY as a function of energy and beam dose. Figures 2b and 2c show the most recent measurements of the peak SEY as a function of beam dose for each of the materials. Generally, the beam conditioning happens rapidly at low beam doses, and slows down as the beam dose increases. Direct SR (Figure 2b) produces more rapid conditioning at low beam doses; the results are similar for high beam doses. The initial and final peak SEY values for Cu, DLC, and TiN are similar, although TiN conditions to a slightly smaller value and Cu conditions to a slightly larger value. The initial

peak SEY of stainless steel is similar to that of Cu, DLC, and TiN, but stainless steel has higher peak SEY after conditioning. The SEY of Al is significantly higher than that of other materials. After initial conditioning, the peak SEY of Al appears to increase slowly with time; it is possible that a similar, but less pronounced, effect happens with Cu. The peak SEY of aC remains near 1, with little dependence on beam dose.

Conditioning of Al was measured previously at SLAC via bombardment by a DC electron gun. They also observed a rapid decrease in the peak SEY for Al, followed by a slow increase, though the overall SEY values were higher than what we measured [6].

Azimuthal Dependence

Figure 3 shows the measured SEY as a function of azimuthal angle along the beam pipe for Al and TiN. Direct Accelerator Technology and Main Systems

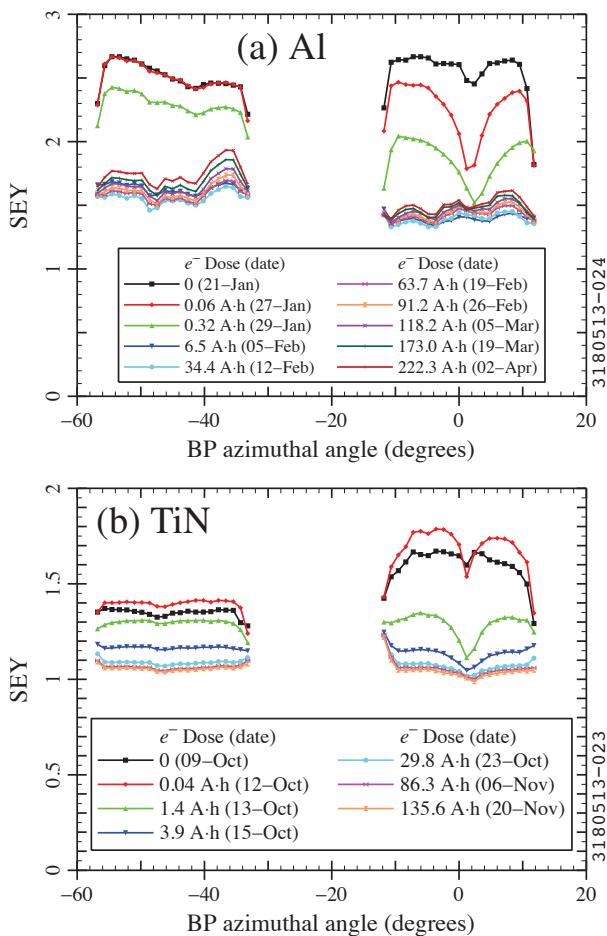


Figure 3: SEY as a function of azimuthal angle along the beam pipe for (a) Al-6063 samples and (b) TiN samples after air exposure. The incident energy is 405 eV.

SR bombardment should in principle happen at zero angle. There is a significant dip in the SEY near zero for low beam doses, consistent with more rapid conditioning by direct SR, as discussed above. The Al-6063 samples (Figure 3a) show more variation in SEY as a function of position than the TiN samples (Figure 3b) or stainless steel samples (not shown). The Al-6061 samples also showed more sample-to-sample variation than other materials [1, 4].

Deconditioning in Vacuum

Figure 4 shows the beam dose and peak SEY of horizontal samples as a function of time for 3 different materials which were first conditioned with beam (yellow background) and then kept in vacuum for several weeks without exposure to air (blue background). In vacuum, the peak SEY of Cu increases the most rapidly, while the peak SEY of TiN increases the most slowly. The trends were similar for the 45° samples (not shown).

CONCLUSION

We have used in-situ secondary electron yield stations to measure conditioning of metal and coated samples by CESR beams. Improvements in the measurement techniques have been implemented along the way. We

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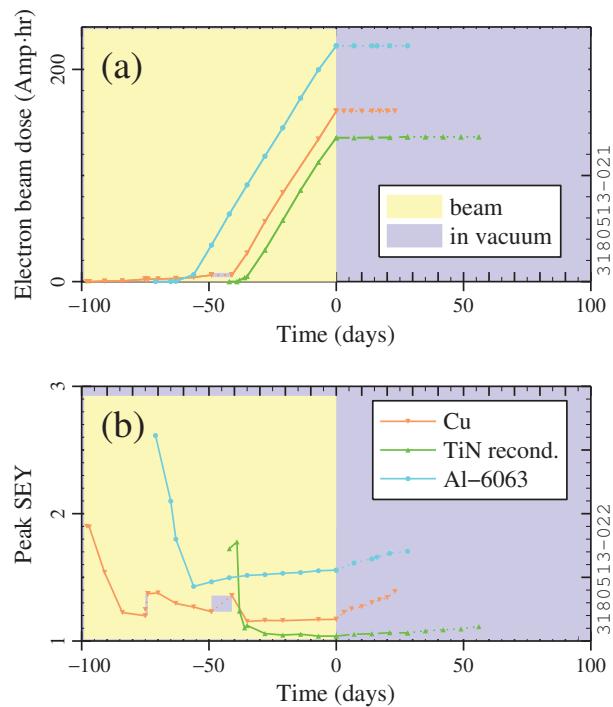


Figure 4: (a) Beam dose and (b) peak SEY as a function of time for selected horizontal samples. A yellow background indicates that the samples were in the beam pipe and exposed to the CESR beams; a blue background indicates that the samples were in the SEY chambers under vacuum.

have observed differences between conditioning by direct synchrotron-radiated photons versus scattered photons and electrons at low beam doses; for high beam doses, the net conditioning appears to be similar for the different bombardment mechanisms.

We plan to gather more statistics and further refine our SEY measurement and analysis techniques. Our ultimate goal is to use the SEY measurements under realistic conditions to constrain SEY model parameters as much as possible; this will help improve the predictive ability of models for the build-up of the electron cloud in accelerators, allowing for the design of future accelerators with higher performance and higher reliability.

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