IN SITU SECONDARY ELECTRON YIELD MEASUREMENT SYSTEM AT CesrTA*

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Abstract

Measuring the secondary electron yield (SEY) on technical surfaces in accelerator vacuum systems provides essential information for the study of electron cloud growth and suppression, with application to many accelerator R&D projects. As a part of the CesrTA research program, we developed and deployed an in-situ SEY measurement system. A two-sample SEY system was installed in the CesrTA vacuum system with one sample exposed to direct synchrotron radiation (SR) and the other sample exposed to scattered SR. The SEYs of both samples were measured as a function of the SR dosages. In this paper, we describe the in-situ SEY measurement systems and the initial results on bare aluminum (6061-T6), TiN-coated aluminum, amorphous carbon-coated aluminum, and amorphous carbon-coated copper samples.

INTRODUCTION

In electron and positron storage rings, an electron cloud inside the vacuum chamber can disrupt the stored beam and degrade the ring performance [1]. Hence electron cloud considerations are important to the design of the damping rings for the International Linear Collider. Emission of secondary electrons from the vacuum chamber surface is one source of electrons for the cloud. There are several methods to lower a material's SEY. These include coatings [2], grooving the surface [1], and processing the surface with electron or photon bombardment [3].

SEY studies have been previously done on samples exposed to an accelerator environment [2]. However, the time between measurements has often been several months, because the sample must be physically removed from the accelerator vacuum chamber for SEY analysis, which can be done only infrequently. Hence, the SEY as a function of SR dose is difficult to determine with good resolution.

In our studies, we used the stored beam at the Cornell Electron Storage Ring (CESR) to measure the effects of direct and scattered SR from a bending magnet on samples, using an in-situ SEY station to take measurements on samples roughly once a week. Measurements are taken at 9 points of a 3×3 grid (6.4 mm $\times$ 6.4 mm) on each sample. Measurements were done on samples coated with SEY-reducing films and bare metal samples.

The in-situ SEY station allows SEY measurements without removal of the sample from the vacuum system. Measurements can be taken in approximately 1.5 hours. This allows us to use the (approximately) weekly tunnel access for SEY measurements to study the SEY as a function of SR dose. More information on the apparatus, techniques, and initial results is available elsewhere [4].

IN-SITU MEASUREMENT STATION

Our in-situ measurement station consists of a sample mounted on an electrically isolated linear magnetic manipulator and a Kimball Physics ELG-2 electron gun, positioned at 25° to the manipulator axis. Two samples can be installed, one mounted at the horizontal radiation stripe and one mounted at 45° below it (see Figure 1).

During accelerator operation, the sample is inserted flush with the beam pipe and is exposed to SR. During access periods, the sample is retracted such that the center of the sample is aligned with the center line of the electron gun. The electron gun is positioned 32 mm from the center of the sample for the measurements. A Keithley 6487 picoammeter is attached electrically to the sample to provide a biasing voltage on the sample and to measure the current, as done in previous studies [5].

SECONDARY ELECTRON YIELD

The SEY is the ratio of the current of secondary electrons (I_{SEY}) from the sample to the current of primary electrons incident on the sample (I_p). Because our vacuum chamber is connected to our grounded beam pipe, we can only measure I_{SEY} indirectly. First, the primary electron current I_p is measured by biasing the sample at a high positive voltage of ~150 V to recapture secondaries. Second, the total

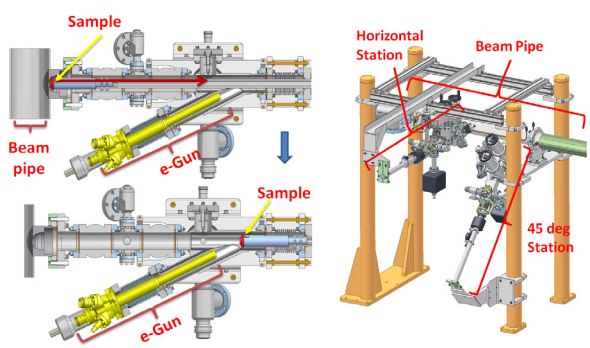

Figure 1: Left: Cross-sectional view of in-situ measurement station with sample inserted in beam pipe (top left) and sample retracted for measurement (bottom left). Right: external view of horizontal and 45° stations.

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current I_t is measured by biasing the sample with low negative voltage (~ -20 V) to repel secondaries produced by the electron beam, and also to repel secondaries from "adjacent parts of the system that are excited by the elastically reflected primary beam" [6]. Since I_t is effectively the sum of I_p and I_{SEY} (note that sign of I_{SEY} is opposite that of I_p), we calculate the SEY as $SEY = (I_t - I_p)/I_p$.

DATA ACQUISITION SYSTEM

An electrical schematic of the system is shown in Figure 2. The current on the sample is measured during three separate electron beam energy scans. Each scan automatically steps the electron gun energy from 20 eV to 1500 eV in increments of 10 eV. This process is controlled by a LabVIEW interface we developed [4] using existing software from Kimball Physics and Keithley. The first scan is done with a 150 V biasing voltage on the sample to measure I_p. This measurement is taken between grid points 5 and 9 to avoid processing the measurement points with the electron beam during the I_p measurement.

The second scan steps through the same gun energies with a bias voltage of -20 V on the sample to measure I_t. At each gun energy, the beam is rastered across all 9 grid points while the program records the current for each point.

To minimize error due to drift in the gun output current, we take a second I_p scan after the I_t scan. After the scan, the two I_p sets are averaged and the SEY is calculated at each energy. Identical measurements are performed on the 45° system and the horizontal system.

RESULTS

The SEY generally increases as a function of incident electron energy and then decreases (see Figure 6 below). In tracking the SEY, useful metrics are the peak SEY and the energy E_{max} at which the peak occurs.

TiN-Al samples from SLAC were installed in CESR in both the horizontal and 45° stations from January to August 2010 and their SEYs were measured roughly once a week. The progression of the peak SEY and E_{max} for the center grid point is shown in Figure 3. The sample in the horizontal setup began with a peak SEY of almost 1.8 and reached a minimum SEY peak of just under 1. The sample in the 45° station started with a peak SEY of just above 1.7 and reached a minimum SEY peak of around 1.2.

In August 2010, the samples were replaced with Al6061-T6 samples and their SEYs were measured after weekly SR dosages. These results are shown in Figure 4. The sample in the horizontal setup began with a peak SEY of 2.5 for the center grid point, and reached a minimum SEY peak of around 1.5. The sample in the 45° station began with a peak SEY of 2.25 for the center grid point and ended with a minimum SEY peak of 1.6.

In November 2010, the samples were replaced with amorphous carbon-coated samples from CERN. The peak SEY of the samples as a function of dose in CESR is shown in Figure 5. As can be seen, the peak SEY of both samples is hardly affected by the SR.

Our results shows a steady decrease in SEY peak with increasing beam dosage, D, proportional to $D^{-0.030}$ for both the bare aluminum and the TiN coated aluminum samples. In each case, the 45° system has a consistently higher SEY than the horizontal system. In Al6061 samples, we observed a lower peak SEY than previously measured

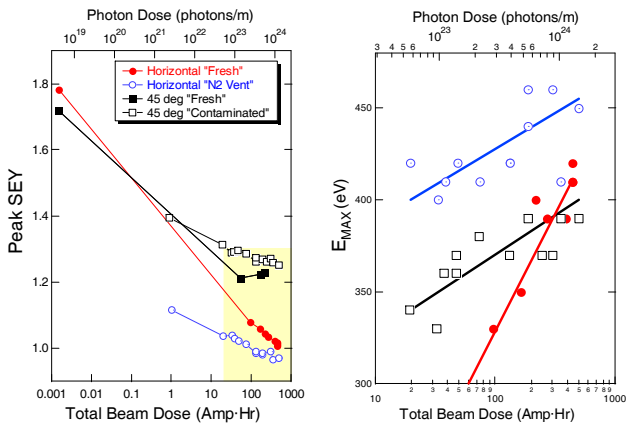

Figure 3: Dependence of SEY peak and E_{max} on dose for TiN-Al samples in the horizontal and 45° stations.

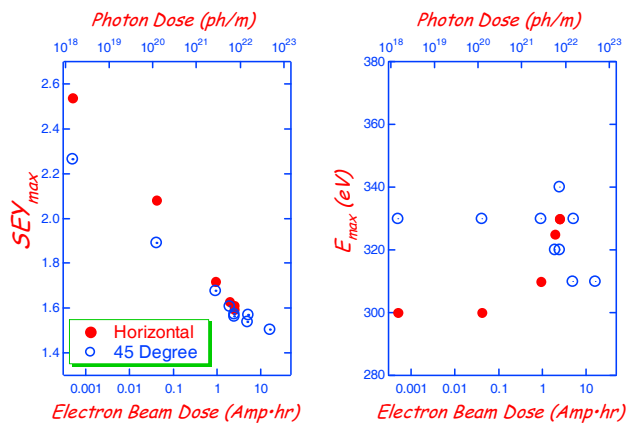

Figure 4: Dependence of SEY peak and E_{max} on dose for Al6061-T6 samples in the horizontal and 45° stations.

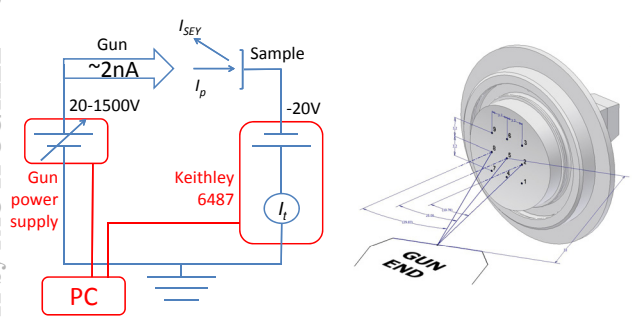

Figure 2: Left: Data acquisition schematic. Right: 9 grid points where the SEY is measured.

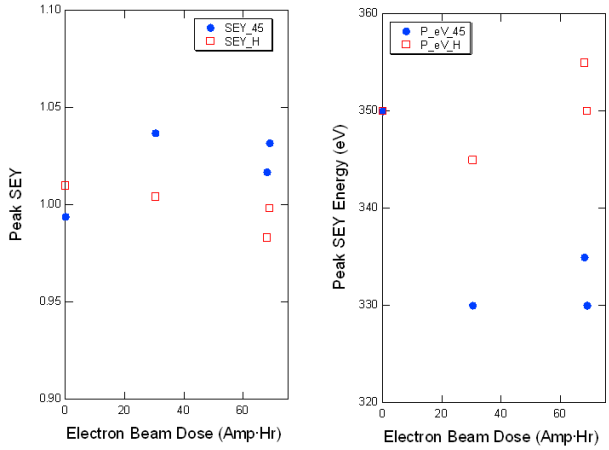

Figure 5: Dependence of SEY peak and E_{max} on dose for amorphous carbon-coated samples in the horizontal and 45° stations.

in other aluminum samples [3]. The amorphous carbon-coated samples show almost no change in the peak SEY.

We observed small, consistent differences in the peak SEY corresponding to the angle θ between the incident electron gun beam and the normal to the sample surface. We have $\theta = 20°$ for points 1, 2, and 3; $\theta = 25°$ for points 4, 5, and 6; and $\theta = 30°$ for points 7, 8, and 9. Higher SEYs were observed at points with larger θ. An example is shown in Figure 6. At $E_{max} = 300$ eV, the SEY dependence on incident angle θ is $\exp[1 - 0.45\cos(\theta)]$.

CONCLUSION AND FUTURE WORK

The main processing of the Al6061 and the TiN-Al samples occurred within the first two weeks, with a total photon dose of 10^{22} photons/m; after that, the SEY decrease was about 1% per week. The SEY of amorphous carbon-coated samples shows only a slight change. For the Al6061 alloy, we observed that the SEYs after processing are lower than the reported minimum SEY value of 1.8 of Al6063 from SLAC [3], decreasing at a rate of $D^{-0.030}$.

Stray magnetic fields were a major source of uncertainty, causing a distortion in the position and size of the electron beam, especially at low beam energy. Stray fields were minimized by using mu metal shielding inside the SEY system, reducing the magnetic field to a few milligauss.

We are working on mitigating the effects of the current drift of the electron gun. The drift causes a systematic error of around 2 to 4% in the calculated SEY. One method we are investigating is to measure I_p for a given gun energy, and then change the bias voltage to measure I_t at the same energy, before stepping to the next energy and repeating the process. However, we must account for the discharging time of the capacitance of the SEY system and cables when we switch the biasing voltage from 150 V to −20 V, which can dramatically distort our current readings. The discharging of the system can be on the order of minutes. In our present method, the biasing voltage is only switched twice, adding just a few minutes to the measurement time. However, the method we are investigating switches the bias voltage at every energy—with 150 gun energy changes per scan, the measurement time may be prohibitively long. We are investigating modifications to minimize the stray capacitance or take fewer energy points.

We plan to compare Al6063 and Al6061 alloys to resolve the cause of the discrepancy in peak SEY. Other future work will include the study of other material samples, including samples cut from an extruded, aged (30+ years) 6063 aluminum CESR chamber. In addition, we plan to measure the SEYs of materials coated in non-evaporable getter (NEG) thin film, and continue to study amorphous/diamond-like carbon samples.

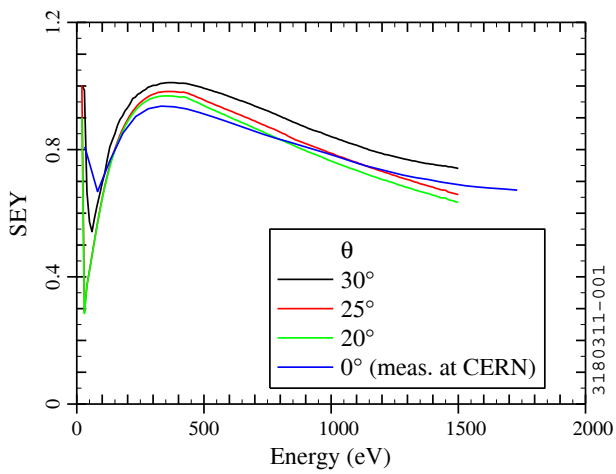

Figure 6: Angular dependence of SEY as a function of incident electron energy for amorphous carbon-coated stainless steel sample.

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