

IN SITU SEY MEASUREMENTS AT CEsrTA*

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Abstract

Two in-situ secondary electron yield (SEY) measurement stations were developed at Wilson Laboratory and installed in the L3 section of the Cornell Electron Storage Ring (CESR) in order to track the evolution over time of the SEY peaks of technical surfaces in an accelerator environment, with exposure to direct and scattered synchrotron radiation (SR). Samples were positioned flush with the inner diameter of the beam pipe with one positioned horizontally in the radiation stripe, exposing the sample to direct and scattered radiation, and one at 45° beneath the radiation stripe, exposing the sample to only scattered radiation. Additionally, both samples are exposed to bombardment by electrons from the “electron cloud” in the stainless steel beam pipe. In this paper, we describe the in-situ SEY measurement systems and the initial results on bare aluminum (6061-T6) and TiN-coated aluminum samples.

INTRODUCTION

One mechanism that can limit the performance of a particle accelerator is associated with the formation of an electron cloud inside the vacuum chamber. The electron cloud can disrupt the beam, limit the current, or degrade the beam quality. Electron cloud issues are particularly important for rings, because the impact of small perturbations from the cloud can have a large effect on the stored beam over many turns around the ring. Consequently, control and mitigation of electron cloud effects are an important part of the design effort for the damping rings for the International Linear Collider (ILC) [1] and other future accelerators.

Emission of secondary electrons from the inside surface of the accelerator vacuum chamber is one source of electrons for the cloud. A key quantity is the secondary electron yield (SEY), the ratio of emitted secondary electrons to incident “primary” electrons striking the surface. The SEY depends on the kinetic energy and incident angle of the primary electrons. Because the secondary electrons must leave the surface, the surface characteristics, including surface contaminants, influence the SEY. In order to make accurate predictions about electron cloud effects, it is important to know the SEY under realistic surface conditions.

Because secondary emission happens at the surface, it is possible to change the SEY of a material. Methods to reduce the SEY include coatings [2], grooving the surface [3], and processing the surface with electron bombardment

[4]. Lowering the SEY can reduce the number of secondaries contributing to the electron cloud, thereby lessening the adverse impact on the beam.

A research program with the Cornell Electron Storage Ring (CESR) was established to study effects that will impact future rings such as the ILC damping rings. Electron cloud studies are a major part of this CESR Test Accelerator (CesrTA) program [5]. One aspect of the CesrTA program is the study of the SEY of technical surfaces in a realistic accelerator environment.

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, an operation which can be done only infrequently. Hence, the SEY as a function of SR dose is difficult to determine with good resolution. One goal of the CesrTA program was to study surface conditioning with improved time resolution.

In our studies, we measure the SEY on samples as a function of the SR dose from a bending magnet, using an in-situ SEY station to take measurements roughly once a week. The typical CESR energy is 5.3 GeV and typical beam currents are 200 mA for electrons and 180 mA for positrons. The SEY station is located in CESR L3 East, so the SEY samples are exposed predominantly to SR from the electron beam. As shown in Figure 1, measurements are taken at 9 points of a 3 × 3 grid (6.4 mm × 6.4 mm) on

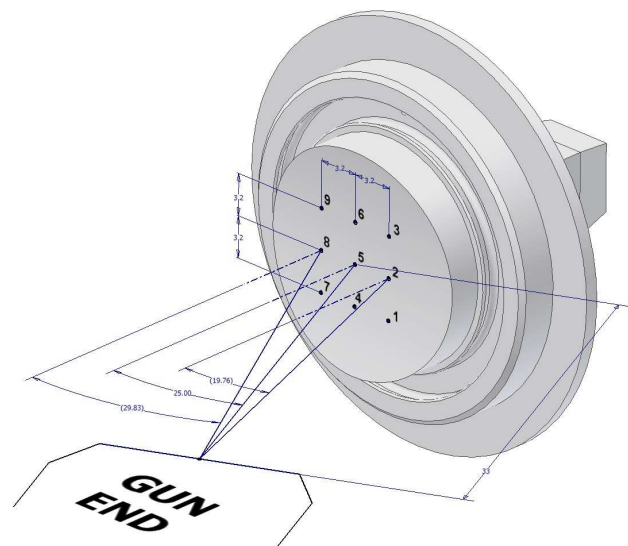


Figure 1: Isometric view of a sample showing the 9 grid points where the SEY is measured.

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each sample. Measurements have been 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 CESR maintenance access to measure the SEY as a function of SR dose. In this paper, we will discuss the in-situ measurement apparatus, techniques, and initial results.

IN-SITU MEASUREMENT STATION

Our in-situ measurement station, shown in Figure 2, consists of a sample mounted on an electrically isolated magnetic manipulator and a dc electron gun¹ positioned at 25° to the manipulator. Two of these setups were installed in the CESR beam pipe, one mounted at the horizontal radiation stripe and one mounted at 45° from the horizontal plane, below the radiation stripe.

During accelerator operation, the sample is inserted flush with the inside of the beam pipe and is exposed to SR (Figure 2, upper left). During access periods, the sample is retracted from the beam pipe such that the center of the sample is aligned with the center line of the electron gun (Figure 2, lower left). The electron gun is positioned 32 mm from the center of the sample for the measurements. The SEY measurement circuit is the same as that used in pre-

vious studies [6]. A picoammeter² is used to measure the current from the sample; the sample dc bias is provided by a power supply internal to the picoammeter. During the SEY measurements, the two gate valves are closed to isolate the CESR vacuum system from the SEY system. The SEY station's vacuum system was designed to allow us to replace samples with minimal tunnel access time.

The SEY stations were assembled and tested prior to installation into CESR. Stray magnetic fields were found to be 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 adding mu metal shielding inside the SEY vacuum chamber, which reduced the stray magnetic field to a few milligauss.

SECONDARY ELECTRON YIELD

The SEY is defined as

$$SEY = I_{SEY} / I_p, \tag{1}$$

where I_p is the current of the primary electrons incident on the sample and I_{SEY} is the current of the secondary electrons expelled by the bombardment of primary electrons. The SEY depends on the energy and angle of incidence of the primary electron beam. The primary current I_p is measured by firing electrons at the sample with the electron gun and measuring the current from the sample with a positive

¹Model ELG-2, Kimball Physics, Inc., Wilton, NH.

²Model 6487, Keithley Instruments, Inc., Cleveland, OH.

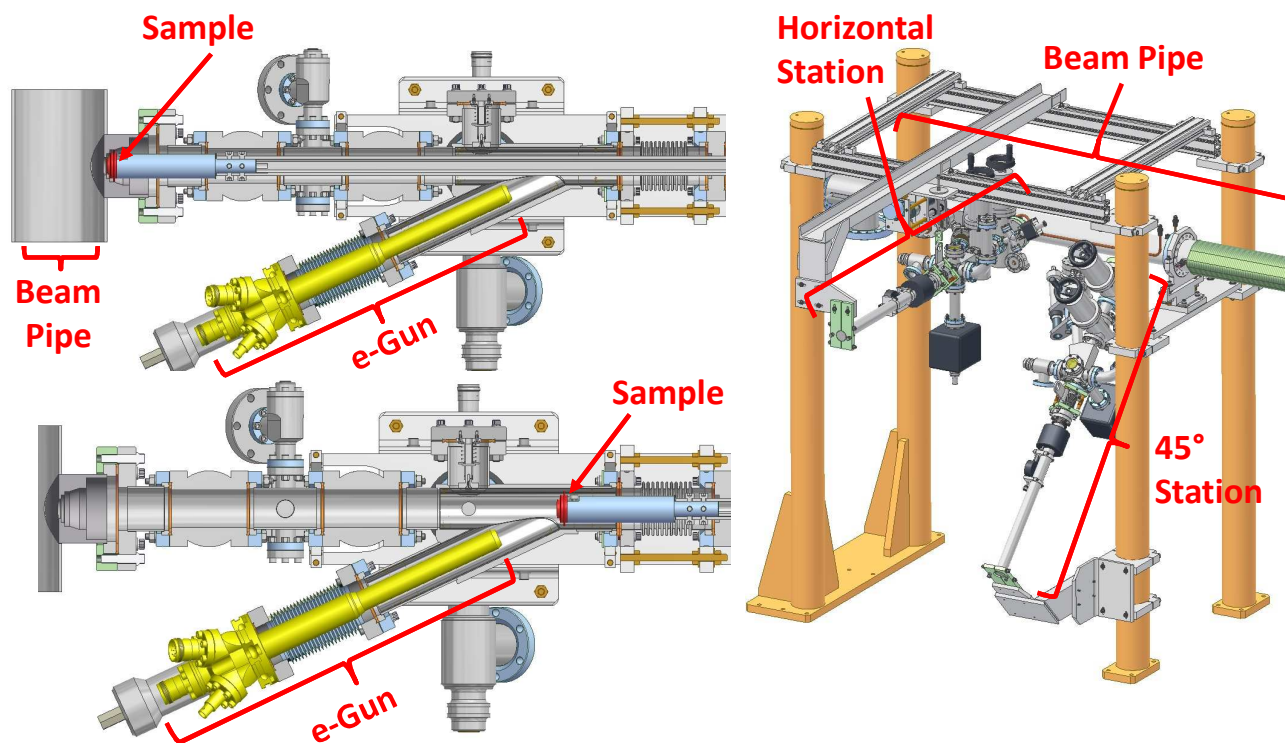


Figure 2: Left: Cross-sectional view of in-situ measurement station with the sample inserted into the beam pipe (top left) and with the sample retracted for SEY measurements (bottom left). Right: external view of horizontal and 45° stations.

bias voltage. A high positive biasing voltage of ~ 150 V is used to recapture secondaries produced by the primary beam, so that the net current due to secondaries is zero.

The current I_{SEY} due to secondary electrons is measured indirectly. The total current I_t is measured by again firing electrons at the sample, but with a low negative bias (~ -20 V) on the sample to repel secondaries produced by the primary electron beam, and also to repel secondaries from “adjacent parts of the system that are excited by the elastically reflected primary beam” [7]. Since I_t is effectively the sum of I_p and I_{SEY} ($I_t = I_p + I_{SEY}$, with I_{SEY} and I_p having opposite signs), we calculate SEY as

$$SEY = (I_t - I_p) / I_p. \quad (2)$$

Some SEY systems include a third electrode for a more direct measurement of I_{SEY} , for example the system at KEK [3]. Our in-situ setup cannot accommodate the extra electrode, so we cannot use the more direct method; we must use the indirect method described above.

DATA ACQUISITION SYSTEM

Figure 3 shows an electrical schematic of the system. With the sample retracted from the beam pipe, the current from the sample is measured during three separate electron beam energy scans with the electron gun. Each scan automatically steps the gun energy from 20 eV to 1500 eV in increments of 10 eV. This process is controlled by a data acquisition program we developed in LabVIEW (see Figure 4), using LabVIEW driver programs from Kimball Physics and Keithley. The first scan is done with a 150 V biasing voltage on the sample to measure I_p , with gun settings for $I_p \approx 2$ nA. This measurement is taken between

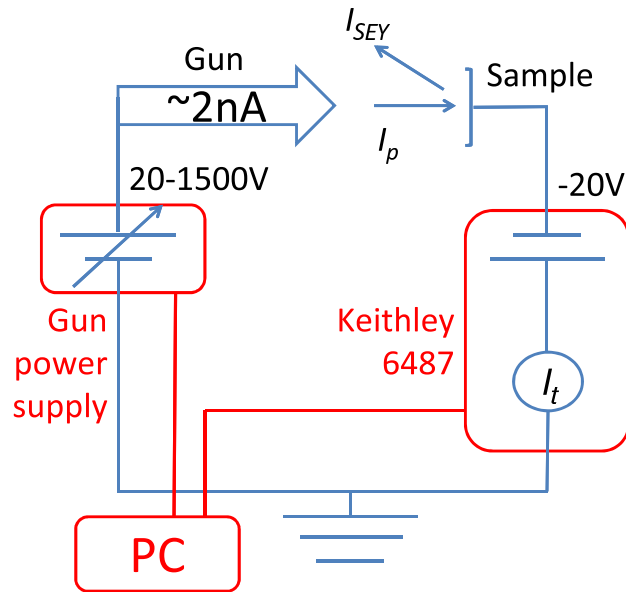
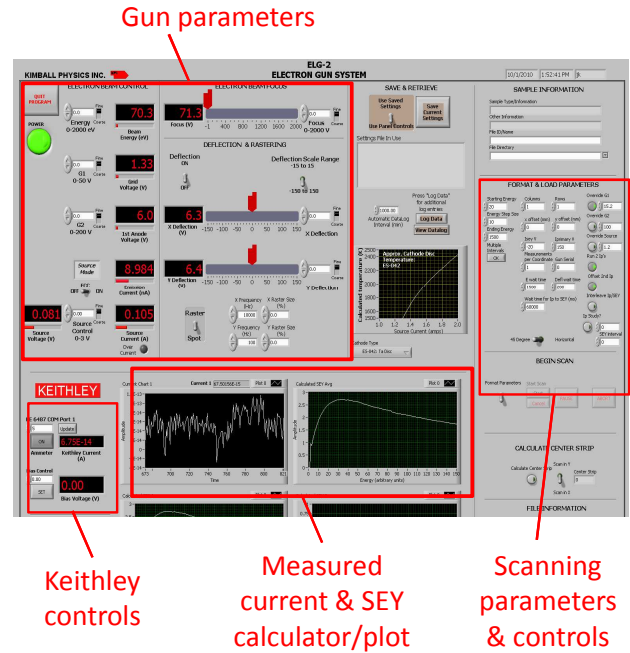
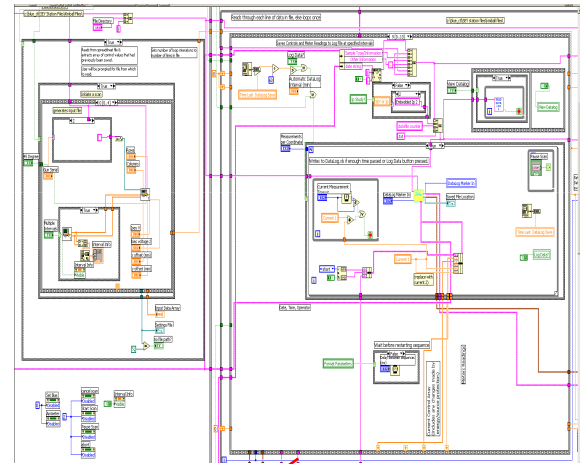


Figure 3: Schematic of electrical system for SEY measurements.



Gun parameters
Keithley controls
Measured current & SEY calculator/plot
Scanning parameters & controls



LabVIEW block diagram

Figure 4: LabVIEW interface and user controls for SEY measurements.

grid points 5 and 9 (see Figure 1) 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 data acquisition system records the current for each point.

The gun has a current drift of $\sim 10\%$ per hour. There is an “emission control” mode for the gun with a 0.1% beam stability, but this mode of operation is not compatible with a continuously changing beam energy, as is the case for our measurements. Because of the current drift, the I_p measured in the first energy scan is not exactly the same as the I_p in the second energy scan in which we measure I_t . Be-

cause of the current drift, we repeat the I_p measurement after measuring I_t and average the I_p values for each gun energy when calculating SEY for each energy.

Our LabVIEW software performs all of the measurements, calculates the SEY at each energy from I_t and the average I_p using Equation (2), displays the SEY as a function of energy, and saves the data. Identical measurements are performed on the horizontal system and the 45° system.

INITIAL RESULTS

Aluminum Samples with TiN Coatings

Aluminum samples with titanium nitride coatings provided by M. Pivi (SLAC National Accelerator Laboratory) 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. These results are summarized in Figure 5. There is a peak in the SEY for an incident electron energy near 400 eV. A significant decrease in the SEY is evident between the first round of measurements and subsequent measurements. As the SEY decreases, there is a slight upward shift in the energy at which the peak in the SEY occurs, as indicated by the dotted lines in Figure 5.

The value of the SEY peak and the energy E_{max} at which the peak occurs are useful metrics for tracking the SEY behavior as a function of exposure. The beam conditioning behavior of the samples is illustrated in Figure 6, which shows the peak SEY and E_{max} for the center grid point as a function of accumulated dose. The bottom axis indicates the electron beam current integral in ampere-hours; the top axis indicates the calculated SR dose to the vacuum chamber wall in photons per meter. Neither of these values includes a contribution from the positron beam, because the dominant source of SR for the SEY stations is the electron beam. The SR photon dose in Figure 6 accounts for direct SR from the beam onto the chamber wall at the location of the SEY stations: it represents the “source term” and does not attempt to include the effects of scattering of photons (or production of photo-electrons). The dose calculation does not differentiate between the horizontal and 45° stations, even though the 45° station does not receive direct SR and the stations’ distance from the bending magnet is not exactly the same.

As can be seen in Figure 6, the sample in the horizontal station 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. As indicated above, E_{max} increased slightly as the peak SEY decreased.

Aluminum Alloy Samples

In August 2010, aluminum alloy samples (Al6061-T6) were installed in the in-situ systems. The results are shown in Figures 7 and 8. The sample in the horizontal setup began with a peak SEY of 2.5 for the center grid point, and

reached an SEY peak of 1.6 after 3 ampere-hours of exposure. The sample in the 45° station began with a peak SEY of 2.25 in the center and reached a peak SEY of 1.6 after the same exposure, arriving at a peak SEY of 1.5 after 20 ampere-hours of exposure. The difference in the initial SEY between the two samples is presumably due to differences in the initial surface condition. We did not observe very significant changes in the E_{max} values.

Discussion

Our measurements at the center of the sample demonstrate a steady decrease in SEY peak with increasing beam dosage, D . As an example, for a “fresh” TiN-Al sample in the horizontal system, the measured peak SEY is proportional to $D^{-0.034}$. In each case, the 45° system has a consistently higher SEY than the horizontal system. For Al6061 samples, we observed a lower peak SEY than previously measured in other aluminum samples [4].

We observed small, consistent differences between the peak SEYs for different grid points, correlated with the incident angle of the beam from the electron gun. The incident angle (measured relative to the normal to the sample surface) is 20° for Points 1, 2, and 3; 25° for Points 4, 5, and 6; and 30° for Points 7, 8, and 9 (Figure 1). Higher SEYs were observed at points with larger incidence angles for the electron gun beam, as can be seen in Figure 9, which shows repeated measurements of the peak SEY for all grid points over several weeks. There is reasonably good consistency between different grid points, with a small but systematic increase in the peak SEY between the first three points, middle three points, and last three points.

Our observation that the SEY depends on angle of incidence is qualitatively consistent with the observations that, as the primary electron angle goes from normal incidence toward grazing incidence, the SEY increases; this has been reported in recent secondary emission studies [7] as well as early experiments [8].

It should be pointed out that the initial peak SEY for this sample was about 1.8; the initial measurements are not included in Figure 9 in order to highlight the small variations between points (note that all of the values shown in Figure 9 are within 10% or so of one another).

The last measurements in Figure 9 (gray bars, marked with an asterisk in the legend) were done after a total of 63 days of accelerator operation plus 14 days with the sample under vacuum without beam (at a pressure of order 10^{-8} torr). These last measurements show a small increase in the peak SEY. This may be due to surface contaminants having been slowly removed from the surface in the presence of the beam, with a small amount of recontamination from residual gas in the 2 weeks without beam.

CONCLUSION AND FUTURE WORK

For TiN-Al samples and bare Al6061 alloy samples, we observed a weekly decrease in SEY peaks for both the 45° system and the horizontal system. The main processing

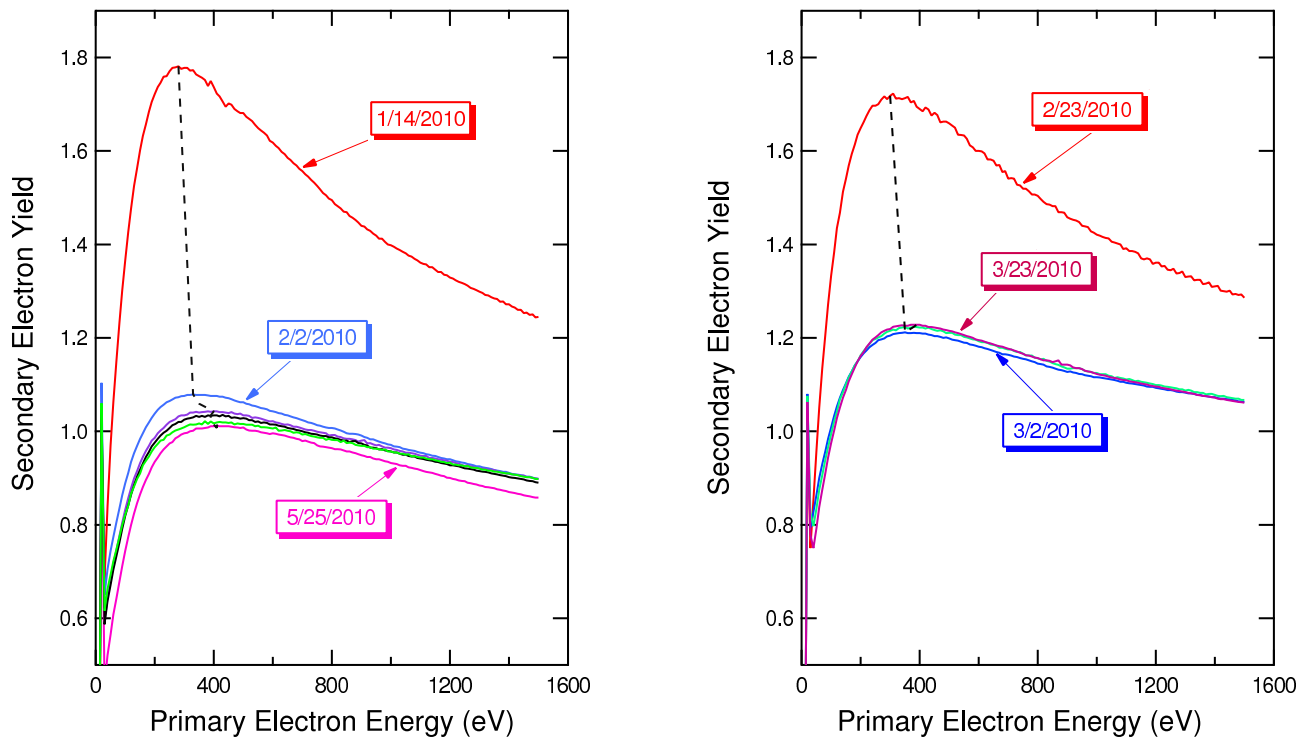


Figure 5: Repeated measurements of SEY as a function of energy for TiN-Al samples in the horizontal station (left) and the 45° station (right).

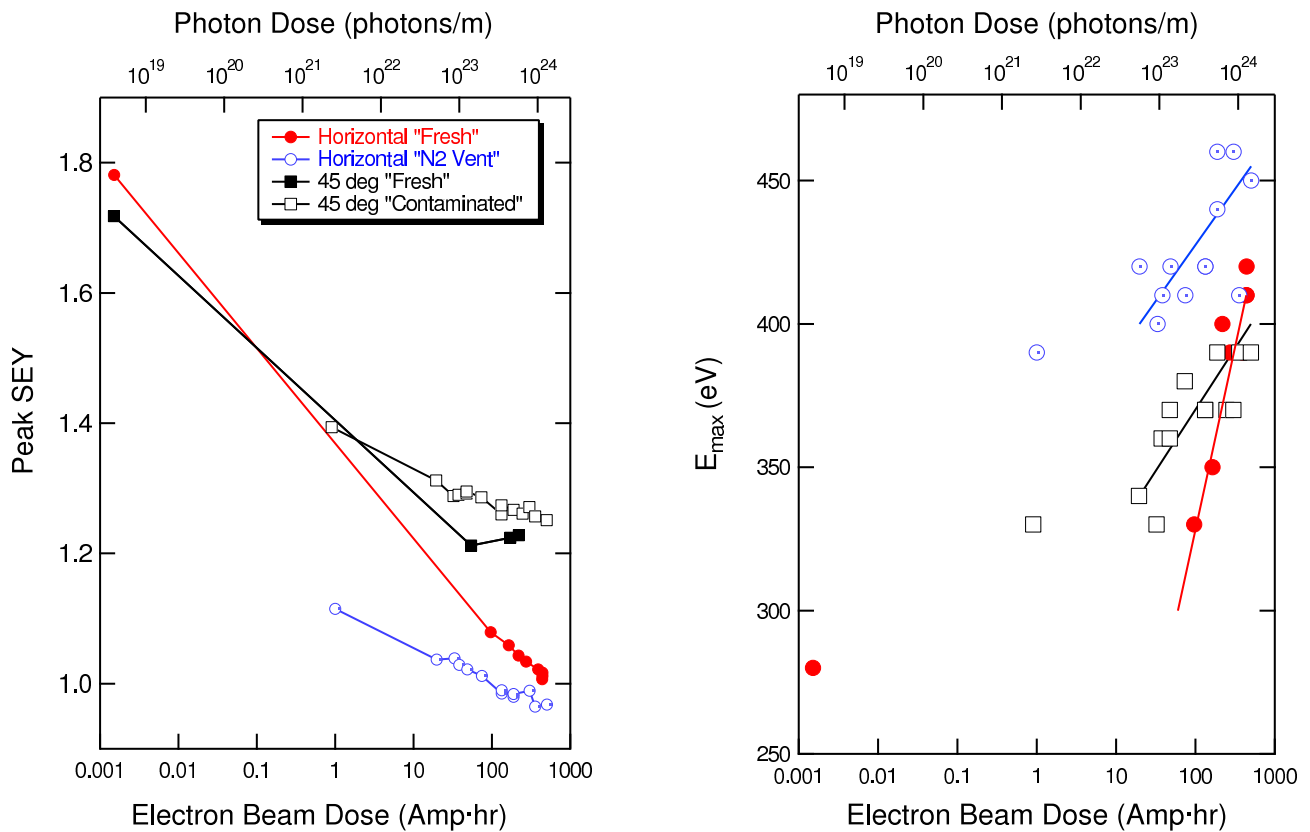


Figure 6: Progression of SEY peak (left) and corresponding energy (right) for TiN-Al samples in the horizontal and 45° stations.

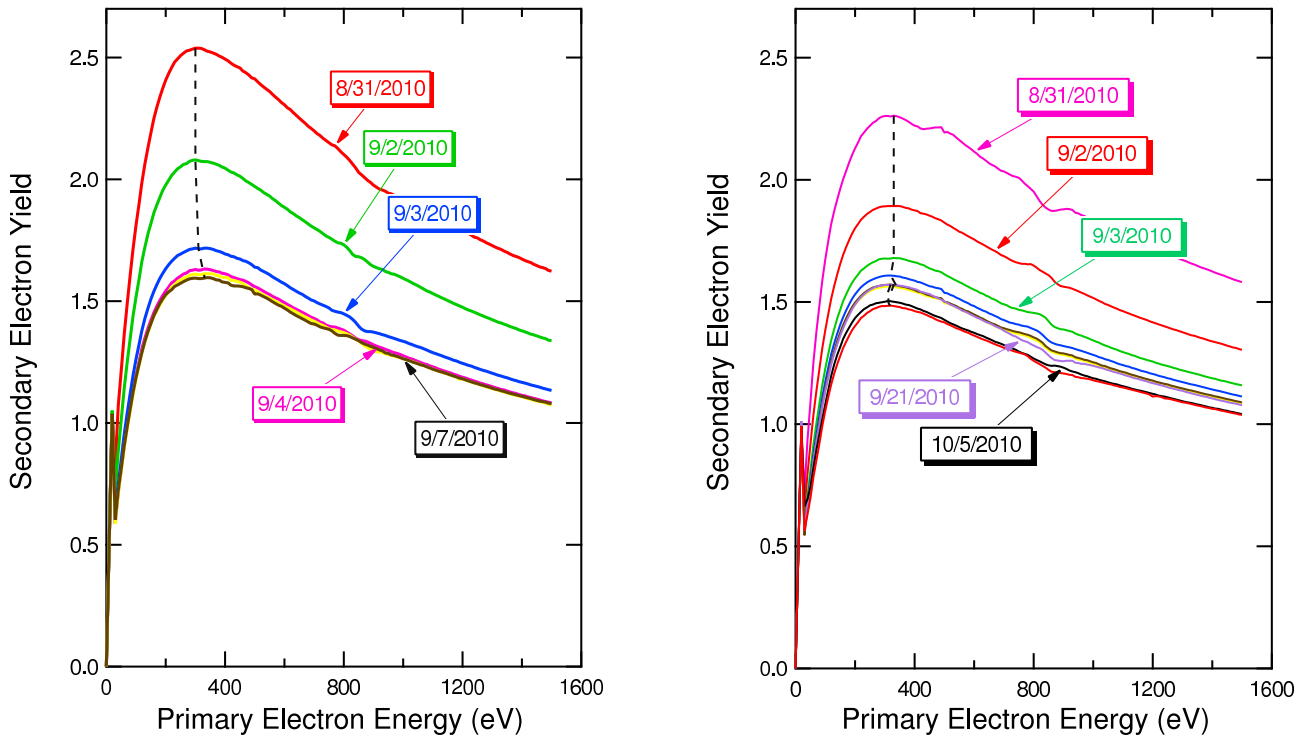


Figure 7: Repeated measurements of SEY as a function of energy for Al6061-T6 samples in the horizontal station (left) and the 45° station (right).

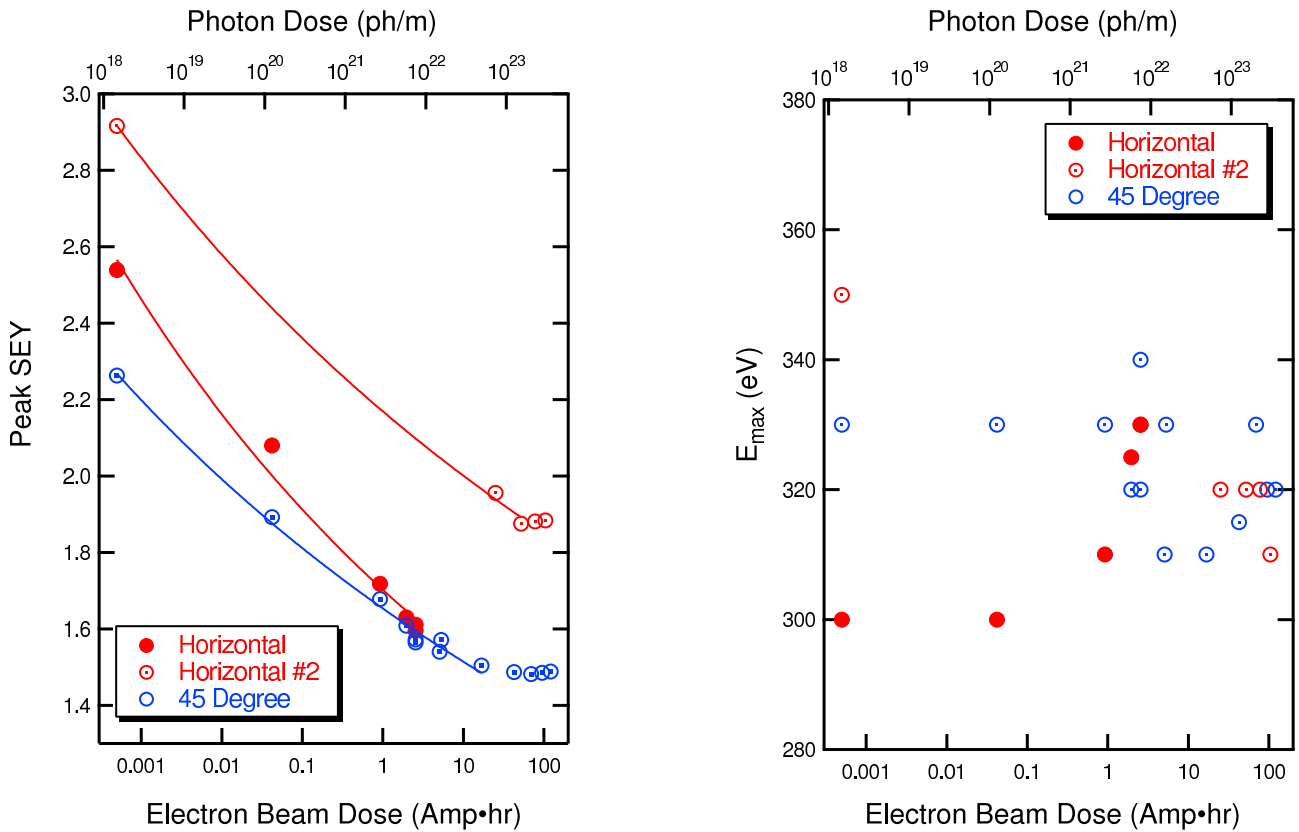


Figure 8: Progression of SEY peak (left) and corresponding energy (right) for Al6061-T6 samples in the horizontal and 45° stations.

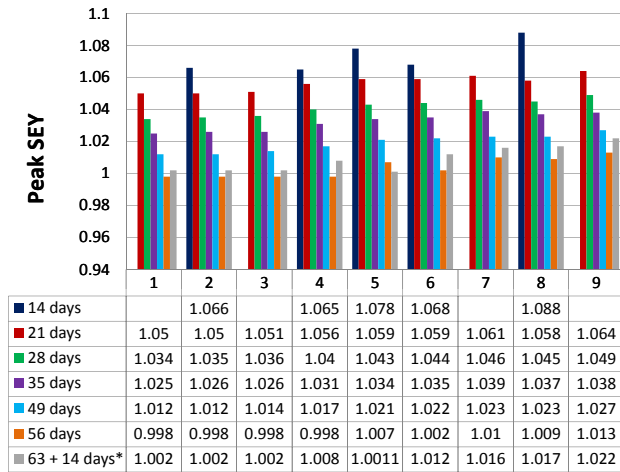


Figure 9: Measured SEY peaks of all 9 grid points for the TiN-Al sample in the horizontal system. Different colors correspond to different measurement times.

occurred within the first two weeks, with a total photon dose of 10^{22} photons/m, while, after that, the SEY decrease was about 1% per week. For Al6061, we observed that the SEYs after processing are lower than the minimum SEY value of 1.8 for Al6063 reported by SLAC [4].

We are able to observe a small dependence of the SEY on the angle of the incident electron beam. This indicates that the statistical errors are small enough for us to be able to resolve differences of a few percent.

Initially, TiN-Al samples were installed in an “as received” condition and the processing was monitored. When one sample was exposed to nitrogen gas, the peak SEY increased and then slowly improved to about the same value as had been reached previously. With “as received” samples, we observed differences in the sample processing between the horizontal and 45° systems. For bare Al, the processing rates were different; for TiN-Al, the samples reached different peak SEY values after about 9 weeks of exposure. We plan to check the reproducibility of these results and do additional checks for systematic effects. We are designing additional experiments to determine whether SR bombardment or electron cloud bombardment is the main source of processing.

We are working on mitigating the effects of the drift in the electron gun current. 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 at a given gun energy, then change the bias voltage to measure I_t at the same energy, before stepping to the next energy and repeating the process. However, when we switch the biasing voltage from 150 V to -20 V, we must account for the charging and discharging of the capacitance of the SEY system and cables connecting the picoammeter to the sample, which can dramatically distort the current readings. The charging and discharging of the cables and SEY system can take on the order of several minutes. Using our normal scan-

ning method, the biasing voltage is only switched twice, adding just a few minutes to the total 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 for this method may be prohibitively long. Consequently, we are investigating SEY system modifications to reduce the stray capacitance and a measurement algorithm with longer energy intervals between changes in the bias voltage.

We have done preliminary measurements on amorphous carbon-coated samples from S. Calatroni and C. Yin Vallgren (CERN), and diamond-like carbon (DLC) coated samples from S. Kato (KEK). An issue we are addressing with the DLC samples is the charging of the insulating surface. Initial measurements have shown a distortion in the SEY curve due to charging of the sample. We can mitigate the charging effect with longer waiting times between energy points to allow the sample to discharge. We are developing software to automate this process.

We plan to do an in-situ comparison of Al6063 and Al6061 alloys to resolve the cause of the discrepancy between our measurements of peak SEY and previously reported results. Other future work will include the study of additional materials, including samples cut from an extruded, aged (30+ years) 6063 aluminum CESR chamber. In addition, we plan to perform in-situ measurements of SEY for materials coated in non-evaporable getter (NEG) thin film, and continue to study amorphous carbon and diamond-like carbon samples.

We have built and tested two additional in-situ SEY systems for studies in the Main Injector at Fermilab.

REFERENCES

- [1] M. Pivi *et al.*, in *Proceedings of the 2005 Particle Accelerator Conference*, p. 24–28.
- [2] M. T. F. Pivi *et al.*, in *Proceedings of the 2008 European Particle Accelerator Conference*, p. 691–693.
- [3] Y. Suetsugu *et al.*, in *Proceedings of the 2010 International Particle Accelerator Conference*, p. 2021–2023.
- [4] F. Le Pimpec *et al.*, “Electron Conditioning of Technical Aluminum Surfaces,” Tech. Rep. LCC-0153/SLAC-TN-04-051, SLAC (Sep. 2004).
- [5] M. A. Palmer *et al.*, in *Proceedings of the 2010 International Particle Accelerator Conference*, p. 1251–1255.
- [6] F. Le Pimpec *et al.*, “Secondary Electron Yield Measurements of TiN Coating and TiZrV Getter Film,” Tech. Rep. LCC-0128/SLAC-TN-03-052 (v2), SLAC (Aug. 2004).
- [7] F. Le Pimpec *et al.*, *Nucl. Instrum. Methods Phys. Res.* **A551**, p. 187–199 (Jul. 2005).
- [8] K. G. McKay, in *Advances in Electronics*, L. Marton, Ed., Academic Press, New York, vol. I, p. 65–130 (1948).