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IN-SITU SECONDARY ELECTRON YIELD MEASUREMENT AT FERMILAB MAIN INJECTOR

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Abstract

Studies of in-situ Secondary electron yield (SEY) measurements of material samples at the Main Injector (MI) beam pipe wall location started in 2013. [1, 2] These studies aimed at understanding how the beam conditioning of different materials evolve if they function as MI vacuum chamber walls. The engineering run of the SEY measurement test stand was finished in 2014. From 2014 to 2016 the Fermilab accelerator intensity has increased from 24×10^{12} to 42×10^{12} protons. Beam conditioning of SS316L and TiN coated SS316L has been observed throughout this period. [3] Improvement of the data acquisition procedure and hardware has been performed. A deconditioning process was observed during the accelerator annual shut down in 2016.

THE SAMPLES AND TEST STAND

Two samples are studied in the experiment, stainless steel 316L (SS316L), the same material as the MI vacuum chamber, and Titanium Nitride (TiN) coated SS316L. The samples were installed in September 2014 and kept in the accelerator vacuum chamber ever since. They are curved pieces that are mounted on a floating arm. The samples make up part of the accelerator vacuum chamber wall so they are directly exposed to the operating accelerator and experience conditioning directly from the Electron Cloud generated. During measurements, the sample is retracted into the electrically isolated arm. A Kimball physics ELG-02 electron gun, kept in the same vacuum, directs an electron beam onto the sample and a Keithley 6487 Pico-Ammeter is used to measure the SEY of the sample.

During a measurement bias voltage is applied to the sample. The primary current I_p is measured by applying a +150V bias voltage to the sample that ensures recapture of all secondary electrons. The total current I_t is measured by applying a -20V bias voltage to the sample that repels all low energy secondary electrons. Then the secondary emission current is given by $I_{SEY} = I_t - I_p$. Then, the SEY can be calculated by the following equation.

$$SEY = \frac{I_{SEY}}{I_p} = \frac{I_t - I_p}{I_p} \quad (1)$$

Typical I_p, I_t and SEY vs incident energy from an actual measurement are shown in figure 1. This measurement was performed on September 2nd 2016 on SS316L. The system measures I_p at one point since I_p should only be determined by the electron guns. The I_t current is measured as the position of the gun electrons are varied across a 3×3 grid on the sample surface.

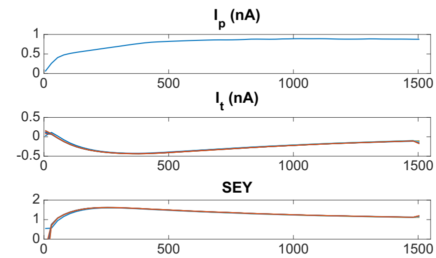

Figure 1: Typical I_p (nA), I_t (nA) and SEY vs incident energy (eV).

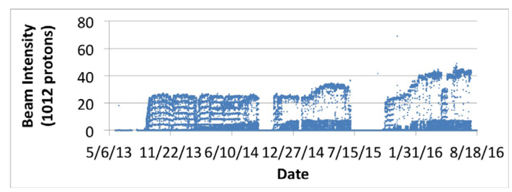

Figure 2: MI intensity from late May 2013 to Sep 2016.

The bias voltage induced leakage current is the major source of inaccuracy in this set up and has to be compensated. A long term study of the leakage current was performed and the result will be discussed later this paper.

SEY MEASUREMENT RESULTS

This measurement aimed to understand how the SEY evolves under the operation of MI. The peak SEY was measured at different typical operational MI beam intensities. These measurements also allowed the SEY to be known as a function of the MI integrated intensity (total exposure). The peak SEY was calculated by averaging all of the nine data points at each incident energy and then finding the maximum. The operational intensity of the MI over time is shown in figure 2. The intensity was steady during the first half of 2014 and started to gradually increase during the second half of 2014. There are two month annual shutdowns every year. In May of 2016, an accident happened that brought down the intensity, it was resolved and the intensity went back up.

Figure 3 shows the peak SEY data over time. The peak SEY decreased over time as expected. The 2015 annual shut down happened between July and November. Major deconditioning was observed during the annual shut down. The samples were kept in the MI vacuum chamber for the whole period. The SEY increased from 1.32 to 1.89 for TiN and from 1.55 to 1.97 for SS316L. When the intensity of the MI went down in May of 2016 to 28×10^{12} protons, a gentle

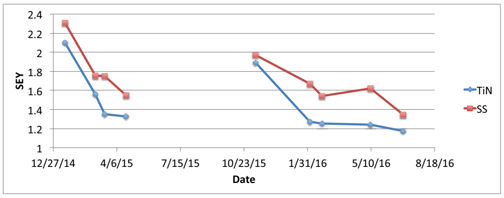

Figure 3: SEY over time for SS and TiN coated SS for two different machine runs.

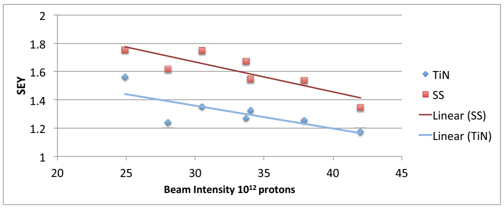

Figure 4: Typical operational beam intensity vs SEY for SS and TiN coated SS.

deconditioning was observed for the ss316L compared to TiN6.

Figure 4 shows the peak SEY versus the beam intensity reached during machine operation. These data include both 2015 and 2016 runs; a linear decrease of the peak SEY with beam intensity was observed. The TiN started with a lower SEY and conditioned faster. These data indicate how much conditioning can happen at different beam intensities. Around 30×10^{12} protons, the TiN reaches 1.3 peak SEY and the SS316L reaches 1.5 peak SEY. Around 52×10^{12}, the TiN reaches 1.18 peak SEY and the SS316L reaches 1.35 peak SEY.

Figure 5 shows the peak SEY vs integrated beam intensity (total exposure). The peak SEY conditioned to 1.18 for TiN and 1.35 for SS316L. This plot shows that the majority of the conditioning happens during exposure to the first 20×10^{19} protons for SS316L and the first 10×10^{19} protons for the TiN coated sample. As the beam intensity went up to 42×10^{12} protons, the same trend followed, as both TiN and SS316 conditioned further after exposure to 10×10^{19} protons.

The MI is scheduled to be turned on in December 2016 and will continue to run at 42×10^{12} proton intensity. In 2017, the MI is scheduled to upgrade to even higher intensities. Further conditioning studies will be carried out for both TiN and SS316L. Once the peak SEY of TiN and SS316 reach a

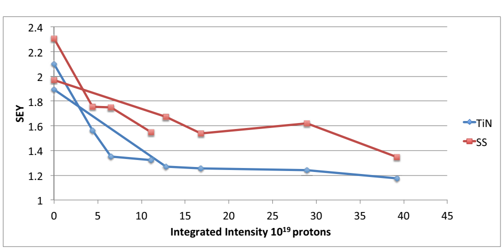

Figure 5: Integrated beam intensity vs SEY for SS and TiN coated SS for two different machine runs.

plateau at future MI intensities, the study of TiN and SS316l will be concluded and new samples of other material will be installed.

DECONDITIONING MEASUREMENT

Deconditioning, or an increase in the SEY of the samples, was observed during the 2015 accelerator shut down. This year, the MI was turned off on July 30th 2016 and will remain shut down until at least November 2016. This provides a perfect opportunity to do a more detailed study of the deconditioning of the samples.

Table 1: SEY Deconditioning Result

Date	TiN	SS
06-29	1.18	1.35
08-01	1.33	1.51
08-03	1.32	1.60
08-04	1.34	1.60
08-18	1.33	1.61
09-02	1.33	1.61
09-19	1.41	1.72

Table 1 summarizes the deconditioning measurement performed during the 2016 shut down. The first column is the measurement date, the second and third columns are the peak SEYs for TiN and SS316L samples. The last SEY measured before the shut down (taken Jun 29) was 1.18 on TiN and 1.35 on SS316L. The first day of access to the accelerator was 2 days after it was turned off. Assuming the SEY before the shut down had not changed much since June 29th, much of the deconditioning happened during those two days. The SEY settled at 1.33 for TiN and 1.6 for SS316L until the samples were retracted on Sep 10th. During the 2015 annual shut down, the SEY for TiN deconditioned to 1.9 and SS316L to 2. This difference could be explained by the fact that the samples were kept in the MI vacuum chamber. The MI vacuum chamber walls are all well conditioned after years of accelerator operation. During the 2015 shut down, when the deconditioning was observed, the samples were stored in the test stand arm vacuum chamber, where the chamber walls are not conditioned. Deconditioning was also observed this year after the samples were retracted. They will be stored in the test stand arm until the accelerator turns on again, so more deconditioning is expected to be observed in the future.

LEAKAGE CURRENT

Leakage current causes most of the inaccuracy in an SEY measurement and must be compensated. Figure 6 shows typical leakage current behavior. During a typical measurement, we wait 3 minutes for the leakage current to level out, then take the value of the leakage current measurement and subtract from the overall measurement. Separate corrections are done for the primary current I_p and total current I_t.

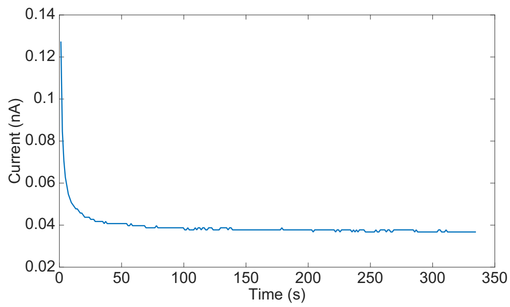

Figure 6: The current measured over a period of 5 minutes right after +150V bias turned on.

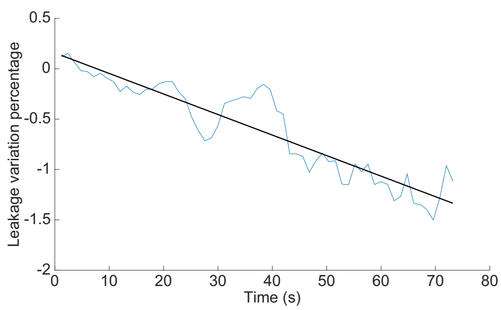

Figure 7: 'Settled' leakage current L_p starting 3 minutes after bias turned on, over same period of I_p measurement.

$$SEY = \frac{I_{SEY}}{I_p} = \frac{(I_t - L_t) - (I_p - L_p)}{I_p} \quad (2)$$

In order to estimate the inaccuracy caused by the leakage current, a series of leakage current measurements were done on a typical SEY measurement time scale. These measurements are gathered by performing normal SEY measurements while turning off the electron guns. Typical results are shown in figure 7 and figure 8 for L_p and L_t respectively. The L_p leakage current has a relatively stable value while a significant drop was observed for L_t. This is expected as the L_t measurement is 9 times longer than the L_p measurement (9 data points vs 1 data point). A linear fit was performed on the L_p data and a 4th order polynomial fit was performed on the L_t data. The leakage current total variation was calculated as the difference between the initial and final data point of the fits, the leakage current RMS variation was calculated by the absolute difference between data and fit. Table 2 shows the calculated total and RMS variations of the leakage current. The L_t have a 40% total variation while the RMS on both leakage currents have 1% variation. Quantification of the measurement inaccuracy due to the leakage currents and development of a better strategy of dealing with leakage currents is in progress.

CONCLUSION

Evolution of the Secondary Electron Yield (SEY) of SS316L and TiN coated SS316L samples in the environment of the Main Injector proton accelerator has been studied, and results from 2015-2016 are presented. The SEY of the samples steadily conditioned under beam operations to lower values; the lowest peak SEY reached was 1.18 for TiN and 1.35 for SS316L. The SEY values are expected to reach a low plateau after the MI upgrade, at which time the TiN study will be concluded. The SEY values of the samples have also been shown to decondition during periods when the accelerator is not operational. The study presented showed that after initial fast deconditioning, further deconditioning will be slow if the samples are retained in the evacuated, conditioned vacuum chamber. A leakage current study was done that shows a better strategy is needed for its compensation.

Table 2: Leakage Current Variations

Leakage current	total variation	RMS variation
TiN Arm, L_p		
$1.6nA$	$22pA$ (1.38%)	$8.4pA$ (0.53%)
$0.2nA$	$8.5pA$ (4.25%)	$16pA$ (8%)
$10nA$	$140pA$ (1.4%)	$14pA$ (0.14%)
TiN Arm, L_t		
$0.27nA$	$84pA$ (31.1%)	$4.1pA$ (1.52%)
$0.1nA$	$88pA$ (88%)	$2.6pA$ (2.6%)
$1nA$	$170pA$ (17%)	$6.6pA$ (0.66%)
SS316L Arm, L_p		
$5.7nA$	$160pA$ (2.81%)	$6.2pA$ (0.11%)
$01nA$	$4.5pA$ (0.45%)	$1.2pA$ (0.12%)
$0.3nA$	$0.1pA$ (0.03%)	$0.3pA$ (0.1%)
SS316L Arm, L_t		
$0.5nA$	$210pA$ (42%)	$3.8pA$ (0.76%)
$0.1nA$	$9pA$ (9%)	$0.2pA$ (0.2%)
$30pA$	$10pA$ (33.3%)	$0.1pA$ (0.33%)

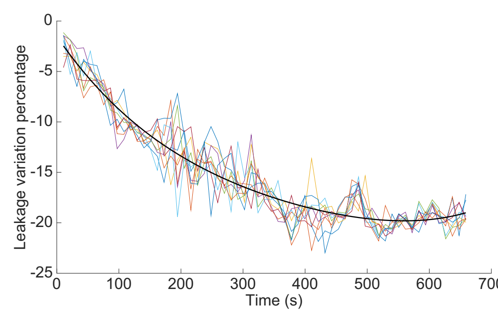

Figure 8: 'Settled' leakage current L_t starting 3 minutes after bias turned on, over same period of I_t measurement.

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