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EFFECTS OF PLASMA PROCESSING ON SECONDARY ELECTRON YIELD OF NIOBIUM SAMPLES

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Abstract

Impurities deposited on the surface of niobium (Nb) during both the forming and welding of accelerator cavities add to the imperfections of the sheet metal, which then affects the overall performance of the cavities. This leads to a drop in the Q factor and limits the maximum acceleration gradient achievable per unit length of the cavities. The performance can be improved either by adjusting the fabrication and preparation parameters, or by mitigating the effects of fabrication and preparation techniques used. We have developed the experimental setup to determine the Secondary Electron Yield (SEY) from the surface of Nb samples. Our aim is to show the effect of plasma processing on the SEY of Nb. The setup measures the secondary electron energy distribution at various incident angles as measured between the electron beam and the surface of the sample. The goal is to determine SEY on non-treated and plasma treated surface of electron beam welded samples. Here we describe the experimental setup, plasma treatment device, and fabrication and processing of the Nb samples.

INTRODUCTION

Apart from the accelerated beam particles, cavities under operating conditions contain a small amount of free charged particles. The number of particles inside the cavity is increased due to the Secondary Electron Emission (SEE). Free particles are accelerated by receiving energy from the electromagnetic field confined inside the cavities. Under specific conditions those particles can impact the surface of cavities and create additional free electrons. An increase in the quantity of the free electrons in a confined space of a cavity can cause a detrimental effect on the accelerated particles and thus limit the effectiveness of cavities. Multiplication of electrons is called multipacting (MP) and leads to the high power losses and heating of the cavity walls [1]. Energy consumed by the increasing number of electrons prevents the increase of the accelerating field by increasing the power input.

Substantial research effort on the topic of SEE to date has determined that SEY is highly dependent on the surface treatment. It has been shown that exposure of the material surface to increased temperatures progressively reduces the SEY [2, 3]. Various surface coatings have also shown the ability to reduce the SEY on various substrate materials [4, 5, 6, 7]. The scrubbing effect of the continuous exposure of the surface to electron beam has been noticed on the copper samples [8]. The effect of air exposed metal surfaces on SEY is shown in [9]. Exposure of the Nb to glow discharges of various gasses changed the SEY curve compared to the untreated surface [2].

SEE depends on the energy dissipated by the primary electrons near the surface. Our analysis of energy spectra of secondary electrons indicates that the fraction of the dissipated energy of primary electrons reaches the maximum at the primary energies that produce the maximum yield. It can be illustrated by a case of typical SEE energy distribution and SEY from a clean Nb coupon.

Total energy returned to the field has been carried equally by true, back-diffused, and elastically reflected secondary electrons, although their number distribution is more shifted toward low energy. Overall relative energy feedback carried by the secondary electrons is

$$\Gamma = \frac{1}{E_p}\int_0^{E_p} f_P\left(E_p, E\right)dE \cong 0.3 \quad for \quad E_p = 200\,eV. \quad (1)$$

That is, only 30% of the primary energy has been returned to the field and 70% is dissipated in the Nb coupon. We have analyzed this energy balance for a number of metal targets, whereby we have been restricted only to experimental data on the secondary electron energy distribution. For example, the available data for copper show that maximum dissipation into the target coincides with the maximum yield (see Fig. 1).

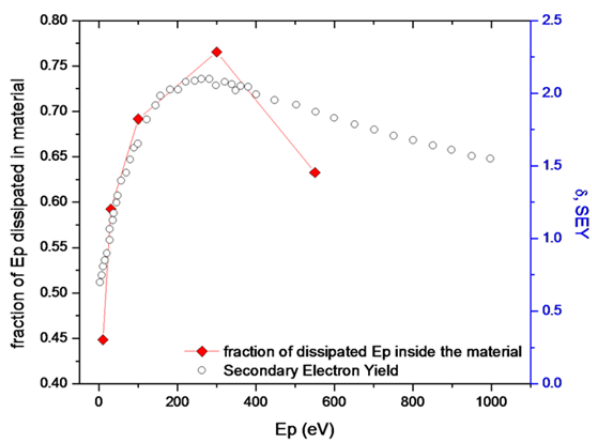

Figure 1: Energy dependence of the fraction of dissipated primary electron energy compared to the SEY curve for conditioned copper.

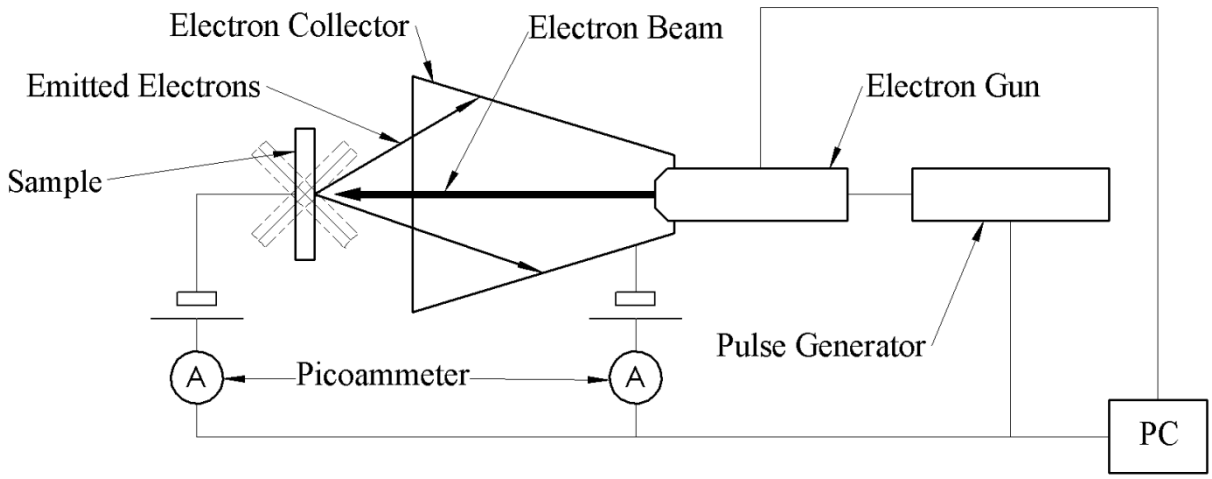

Figure 2: Sketch of the experimental setup for measuring the SEY.

We have compiled more data on copper, iron, silver and nickel [10] and all are showing a similar trend, although in the limited energy range. Since there are no new measurements on metals, and hardly any at all on dielectrics, it is one of our objectives in the proposed work to establish a more abundant database for the energy balance in SEE, depending on the surface treatment of Nb and other metals of interest.

Here we are presenting the experimental setup for measuring the SEY and plans for future measurements.

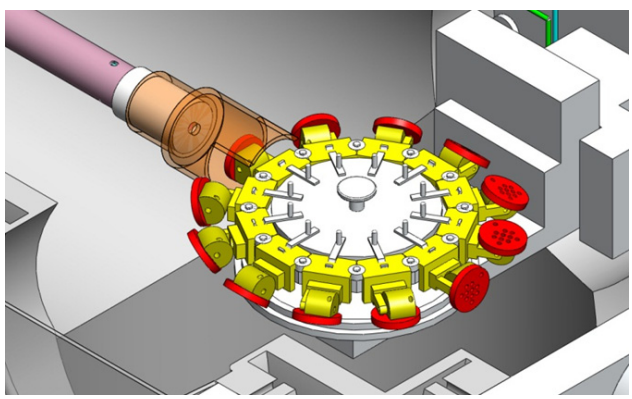

Figure 3: A 3D model of the specimen stage with 12 mounted samples, and an electron gun with a collector.

EXPERIMENTAL SETUP AND PROCEDURE

A dedicated experimental setup was developed to measure the SEY from Nb samples. The schematic of the experimental setup is shown in Fig. 2. The experimental setup consists of several subsystems including, the vacuum pump system, the sample manipulation system, electron gun system, and measurement system. Vacuum system consists of a scroll pump, a turbo molecular pump and an ion pump, which provide the base pressure of $2 \cdot 10^{-9}$ Torr. The sample manipulation system is a combination of the Physical Electronics PHI 15-610 specimen stage and a custom made automatic control system. The specimen stage allows mounting of up to 12 samples on a sample holder (see Fig. 3). Two samples are set so their surface is perpendicular to the incident electron beam and the remaining samples have been evenly distributed and set so that surface forms the range of +80 and -80 degrees around the direction of electron beam. Setting the samples in such a way allows us to measure the SEY at various incident angles of the electron beam with respect to the sample surface. The sample holder can be moved in 3 orthogonal directions with micrometer precision allowing the accurate positioning of the sample in front of the electron beam. The specimen stage can be rotated as well. The combination of the specimen stage motions allows us to measure SEY on multiple points of all 12 samples mounted. The electron gun used to provide the electron beam is a Kimball Physics ELG-2 with a EGPS-1022 power supply. The energy range of this electron gun is from 1 eV to 2 keV. The measurement system is comprised of a custom made titanium collector and Keithley 6482 dual channel picoammeter. The purpose of the custom made collector is to encompass the sample under examination as much as the design and space inside the vacuum chamber allows. Due to the geometry and limitations of the specimen stage motion collector is not able to capture all electrons leaving the surface of the sample at more extreme angles of incidence. Two channels of Keithley 6482 are providing the current measurement from the collector and the sample. The measurement of the SEY can be performed in a continuous or in a pulse electron beam mode. Pulsing of the electron beam is achieved by the use of a separate pulse generator.

SAMPLE FABRICATION AND PREPARATION

During the fabrication process, Nb cavities are exposed to a significant amount of heat applied during the welding process of two cavity halves. In order to determine the effect that applied the heat has on the SEY of the Nb surface, appropriate samples need to be fabricated. Two

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types of samples are going to be used in determining SEY. Both samples are going to be made from high purity Nb. The first sample type will be a simple disc of 20 mm in diameter and 3 mm thickness. The second sample type will include a weld across its surface and will be made in same dimensions as the first type. Both of the samples will be cut with a water jet to avoid inducing additional heat on the samples. The samples will go through preparation process after cutting. The preparation process will be similar to the one that cavities are subjected to and to the extent that can be applied to flat samples. Sketches of samples are shown in Fig. 4. SEY will be measured on both types of samples as received after the preparation process. For the second part of the analysis, the samples will be exposed to plasma in a commercial plasma cleaning machine made by Plasma Etch. The second measurement of the SEY will be performed to determine the effect of the plasma. Our goal is to determine how the SEY changes across the surface in the area of weld. To achieve this, SEY will be measured on the base metal, heat affected zone, and weld face zone. Additional measurements will be performed to determine the effect of plasma across these surface areas on the samples.

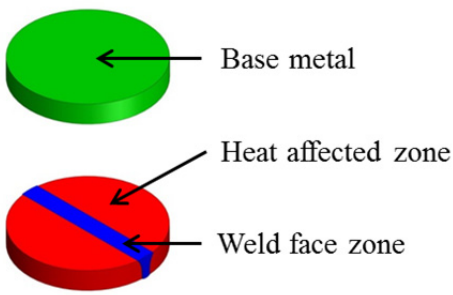

Figure 4: Sketches of the two types of samples.

MEASUREMENT OF SEY

SEY (δ) is determined by simultaneously measuring the current on the collector and the sample. The sum of the collector current (i_c) and the sample current (i_s) is the current of the primary electron beam (i_p). This allows us to track the changes in primary electron beam current on each energy level during measurement. Ratio of the collector current and the primary electron beam current determines the SEY [11]. SEY is determined as the radio of collector and primary beam current:

$$\delta = \frac{i_c}{i_p} = \frac{i_c}{i_c + i_s}. \qquad (2)$$

CONCLUSION

The experimental setup for measuring the SEY has been developed. Future measurements will include the angular dependence of SEY of Nb for base metal Nb as well as samples with a weld across their surface. SEY on both type of samples will be measured before and after plasma cleaning. Our goal will be to characterize the SEY changes of Nb surface with respect to different surface states and make a quantitative and qualitative comparison of obtained data.

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