# SECONDARY ELECTRON YIELD OF NB RF CAVITY SURFACES

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*Abstract*

Multipacting continues to be a significant issue in the performance of superconducting RF cavities. In order to better understand multipacting behavior observed in these cavities, we have carried out measurements of secondary electron yield (SEY) on Nb samples that have been given different elements of standard KEK cavity treatments. These include electropolishing to 100μm depth, 700˚C annealing, further electropolishing of 15μm, rinsing with ordinary or ozonized water, and 150˚C baking with final exposure to air, nitrogen, or argon. Measurements were made with a specially adapted SEM that allows detailed measurements of SEY as a function of position. We find varying degrees of SEY uniformity on sample surfaces, and clear differences in SEY for differing surface treatments.

## 1 INTRODUCTION

The phenomenon of multipacting, or the resonant emission of electrons from cavity and coupler walls under the influence of RF fields, continues to be a troublesome problem in particle accelerator construction and operation. While it can generally be reduced to tolerable magnitudes by various construction and RF processing techniques, the latter in particular can be uncertain and time-consuming. Thus any knowledge of fundamental conditions that affect multipacting can be useful.

Multipacting depends in an essential way on the secondary electron yield of the surfaces involved. The lower the yield, the less serious the multipacting. A number of studies of the SEY of Nb, the material of choice for today's superconducting accelerator cavities, have been carried out over the years. However, conditions of measurements as well as methods of cavity surface treatment vary considerably from one laboratory to another. In view of continuing difficulties with multipacting at KEK, it was felt useful to carry out studies of the SEY of Nb samples that had undergone some of the treatments used in the former TRISTAN and the present KEKB accelerators. In this paper we report the results of such studies.

## 2 EXPERIMENTAL TECHNIQUES

Measurements were carried out with an experimental setup that consists of a commercial SEM modified for SEY determination as shown in Fig. 1. The SEM beam acts as the primary current source; its 0.1-μm spot (when focused) is scanned in a raster pattern, normally 0.1 mm square. The primary current $I_p$ is measured with a Faraday cup that can be interposed between electron gun and sample; it is normally set to 1.00 nA. The beam is pulsed on for 1.5 ms every 32 ms. With this low duty cycle and the low primary current (giving an estimated dose of 10 nC/mm$^2$ for each measurement), changes in SEY due to electron bombardment during measurement were found to be negligible.

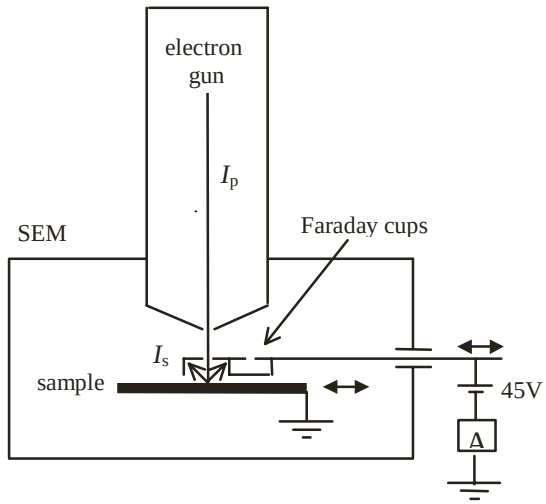


Figure 1: Measurement apparatus. With the Faraday cups in the position shown, the ammeter is measuring the secondary current $I_S$.

The secondary current $I_S$ is measured by interposing another Faraday cup between electron gun and sample, this one facing the sample, with a hole to allow the primary beam to pass and a +45V bias to ensure that secondary electrons with energies less than this value will be collected. The secondary electron yield $\delta$ is then calculated as $\delta = I_S/I_P$.

The SEM vacuum during measurements was typically $10^{-5}$ torr. To minimize residual gas effects, samples were generally placed in the apparatus only long enough to make a set of measurements, normally less than a half hour. Initial measurements, made when the standard oil-sealed SEM forepump was used, showed increases in SEY with a time constant of about an hour; replacing the forepump with an oil-free pump reduced this effect to a tolerable level.

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The energy $E$ of the primary beam could be varied from over 10 keV down to 1 keV and, with some difficulty, as low as 500 eV. While the peak in the $\delta(E)$ curve for Nb is typically at a somewhat lower energy than 500 eV, our accessible energy range proved sufficient for purposes of comparison between differently prepared samples.

Samples of Nb, 10mm×20mm×2.5mm in size, were cut from a sheet of Nb produced by Tokyo Denkai (as used for TRISTAN cavities; RRR ~150). As a 7mm diameter hole in one end was needed for mounting in the electropolishing apparatus, SEY measurements were confined to a 10mm×10mm area.

## 3 RESULTS

### *3.1 Uniformity*

The main goal of our work was to study the behavior of $\delta$ as a function of the various standard processing procedures used in the production of Nb KEKB cavities. We began, however, by investigating the variation of SEY over a given sample's surface. (We have found no reports in the literature on the uniformity of SEY on surfaces typical of those of RF cavities.)

A check of uniformity was made by sampling $\delta$ at a fixed primary energy (normally 1 keV) on a 5×5 grid of points with a spacing of 1mm. Fig. 2 shows representative results. The variations shown from point to point are real, most being significantly larger than our estimated reproducibility of 1% (see below).

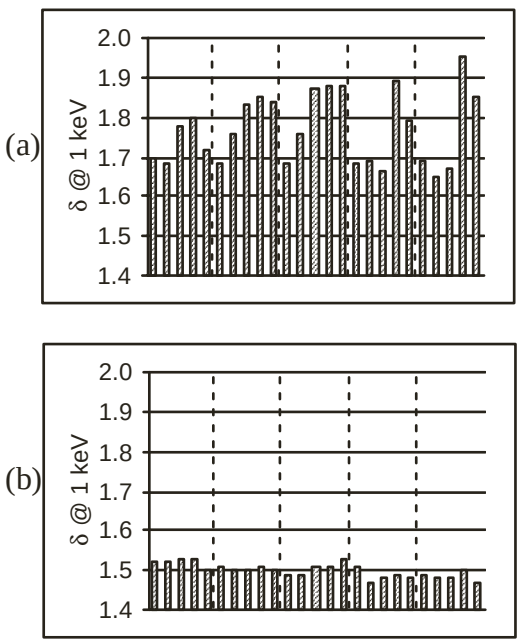


Figure 2: Spatial variation of $\delta$. On each plot, the first 5 bars show $\delta$ at 5 points 1mm apart on a line near the top of the sample; the next 5, on another line 1 mm below that; etc. (a) A sample after 100µm EP; (b) the same sample after 700˚C annealing.

Because of these variations, we decided to characterize the effects of various treatments on SEY by continuing to measure on a grid of points at a fixed representative incident energy, as above. Ideally, this energy might best have been at or near the peak of the $\delta(E)$ curve; because of limitations of our measurement system, we chose the energy of 1 keV.

### *3.2 Reproducibility*

To check the reproducibility of our results, we made a set of $\delta$(1keV) measurements on a 5×5 grid of points on a particular sample. The sample was then moved to a different position on the SEM sample holder; with the aid of the SEM $xy$ positioning facility we attempted to re-measure the same grid of points. The result is shown in Fig. 3; it suggests an overall reproducibility of the order of 1%.

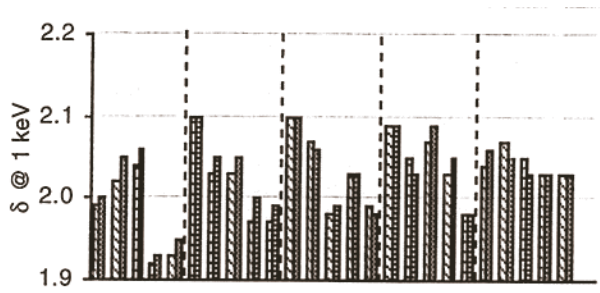


Figure 3: Reproducibility of measurements. Each pair of bars shows values measured at nominally the same spot after the sample has been repositioned on the sample holder.

### *3.3 Results for KEK preparation procedures*

A number of samples were taken through various steps of standard KEK cavity preparation procedures:

- Electropolishing (EP) to a 100µm thickness
- 700˚C anneal for 2 hrs in a vacuum of $10^{-6}$ torr, followed by exposure to 1 atm of air
- EP of an additional 15µm
- Rinsing in ordinary or ozonized water
- 150˚C bake for 24 hrs, followed by exposure to 1 atm of nitrogen, air, or argon

To check for effects from the imperfect SEM vacuum, some samples were not measured until just before the 150˚C bake. These samples gave results that were not significantly different from other samples also measured during earlier stages of the sequence. Nevertheless, we tried to minimize the time a given sample was left in the SEM during each measurement.

Fig. 4 shows our main results. Each data point plotted is obtained as follows: (1) For a given sample we calculate the average of the $\delta$(at 1keV) values measured across our standard 5×5 grid of positions (omitting

occasional outlying points resulting from superficial particles or other surface anomalies). (2) These sample averages are in turn averaged over two or more samples that received nominally identical treatment. In the following we comment on several features of the plot:

*EP100μm:* The large error bar results from a high degree of scatter of individual measurements on these samples. We suspect problems with the EP process used.

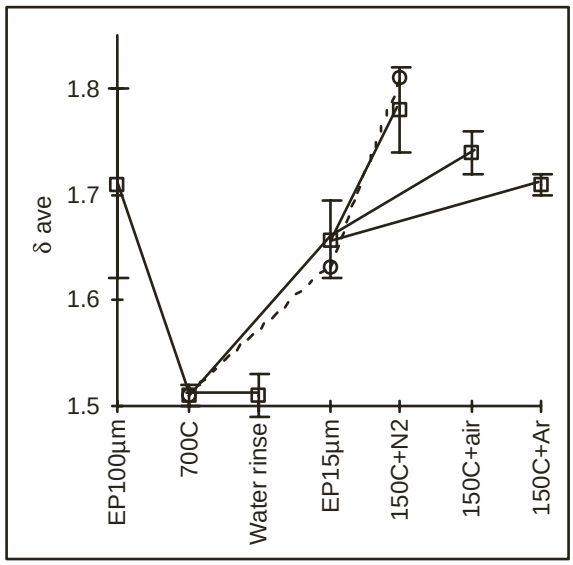


Figure 4: Average $\delta$ at 1keV as a function of sample treatments. To the right of the 700C point, dashed (solid) lines connects points made on samples rinsed with ozonized (ordinary) water after the final EP.

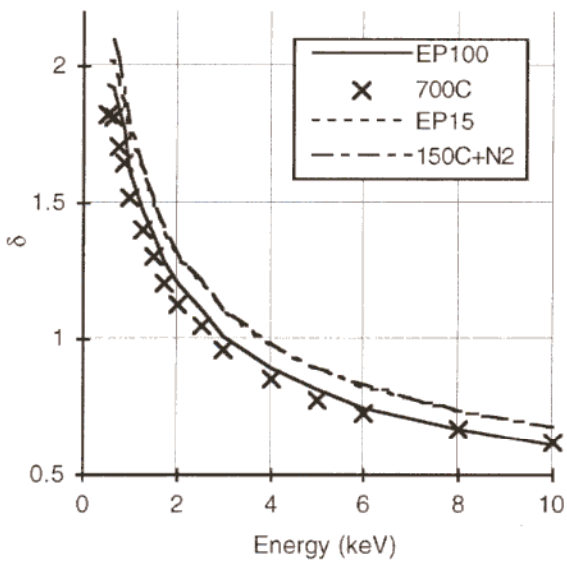


Figure 5: SEY as a function of energy, for a representative sample. (This sample was rinsed with ordinary water after the final EP.)

*700˚C anneal:* This is evidently effective both in reducing the overall $\delta$ and in increasing its uniformity. The point represents 7 different samples.

*Water rinse:* A simple rinse of the annealed sample with pure water has no discernable effect.

*EP15μm:* Values shown were measured after rinsing with ordinary or ozonized water. This subsequent EP increases $\delta$ similarly when followed by either ordinary or ozonized water rinsing.

*150˚C baking and venting:* Again, these treatments tend to increase $\delta$, with the gas used for the final exposure having a small but possibly significant effect.

Plots of the full $\delta(E)$ for "typical" points on a representative sample are shown in Fig. 5. The overall shape changes very little if at all as a function of sample treatment; the curves appear nearly to have reached their maxima at our lowest accessible energy of 500 eV; the ratio of $\delta$(500eV) to $\delta$(1keV) is nearly constant, 1.19 ±0.02.

## 4 COMMENTS

Our measurements have shown that a 700˚C anneal is effective in reducing $\delta$, and that subsequent EP and baking (while important in cavity processing for other reasons) tend to increase secondary emission. Further, the effect on $\delta$ of ozonized water rinsing, used in the KEKB cavity production process, appears minimal as compared with ordinary water rinsing. Finally, the effect on $\delta$ of the gas used for venting after the final 150˚C bakeout, while not strong, is consistent with other work that has shown that venting with $N_2$ (as opposed to air or Ar) can degrade the performance of a cavity[9].

## 5 ACKNOWLEDGEMENTS

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