INVESTIGATIONS TO REDUCE FIELD EMISSION IN PRODUCTION SRF CAVITIES AT JLAB*

T. Wang†, J. Mammosser, L. Phillips, R. Rimmer, TJNAF, Newport News, VA 23606, USA

Abstract

Field emission remains the dominant setback in cavity production at Jlab. We will present our results in investigating field emission performance from witness samples incorporated in various cavity production processes. Drying experiments that show distinct patterns of particulate residence on cavity surface will be presented along with corresponding results from production cavities. A new high-throughput apparatus to facilitate FE measurement and QC in production is well under way in design and will be described.

INTRODUCTION

Although particulate contaminant has been identified as the main cause of field emission (FE), the lack of consistency in FE performance remains the dominating impediment in cavity production at Jlab [1]. Facility upgrades and procedure changes have been carried out over the years, however, the benefit is not always clear and their effect on FE performance has not been experimentally investigated. Therefore, a series of tests has been done to study the current procedure with respective to FE utilizing witness samples. The first set of data will be presented.

WITNESS SAMPLES FOR SNS CAVITY PRODUCTION

The source of particulates during various stages of cavity processing, the effectiveness of cleaning procedures, and the possibility of particulate disturbance during the final evacuation need to be investigated in order to obtain a better control of the field emission problem. Witness samples were incorporated in a number of Spallation Neutron Source (SNS) production cavities for the above purposes. The sample setup in cavities is illustrated in Fig.1. All samples are ~1" in diameter.

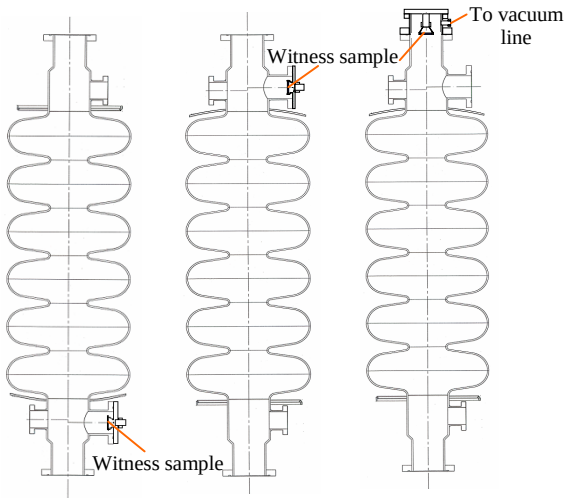

Figure 1: Witness sample setup for SNS production cavities: for BCP etching process (left), for HPR process (middle), and for combined HPR, evacuation plus RF vertical test process (right).

Witness Samples for Chemical Etching Process

To monitor the BCP chemical etching process, we mounted Nb witness samples on the FPC flanges of SNS cavities, as shown in Fig. 1. As with the cavities, four samples were pre-etched (with new acid) to remove ~100 μm from the surface prior to their installation. They were then BCP etched respectively in the cavities to remove various 20 - 50 μm before being rinsed and taken off the cavities for FE measurement by Scanning Field Emission Microscope (SFEM) [2]. The cavities were oriented with the FPC flange at the bottom during BCP. The cavities went on to be high pressure rinsed, assembled and vertically tested.

Results from the first series of tests are listed in table 1 along with the vertical test results of each respective cavity. Among the FE sites identified from each sample, ~10 of the strongest were analyzed with SEM/EDS.

Table 1: Witness sample tests for chemical etching with SNS production cavities

Sample No.	#91	#92	#94	#95
Number of FE sites	31	58	53	48
Lowest FE field (MV/m)	56	53	57	38
μm-sized particulates?	N	Y	Y	Y
Composition of particulates	N/A	"O, Nb" "Al, O, Nb"	"O, Nb" "Al, O, Nb" "Ti, Nb" "Ti, O, Nb"	"O, Ca, Nb" "Si, O, Nb" "O, Mg, Fe, Nb" "SS, C, Nb", etc.
SNS cavity No.	MB24	MB21	MB24a	MB03c
E_{pk} at FE onset (MV/m)	13.6	13.6	10.8	34.7
Max E_{pk} reached (MV/m)	25.7	19.0	14.9	42.3

*Work supported by the U.S. Department of Energy, Contract No. DE-AC05-84ER40150.
†tong@jlab.org

A typical FE scan result is shown in Fig. 2 along with an electron microscopic photograph of an emitter. All identified FE sites are μm-sized particulates except on sample #91, where FE sites are consistent surface features that resemble burst micro-bubbles, and Ti was detected everywhere on the sample surface. The source of Ti needs further investigation, however, this sample is not considered to be representative of common cavity surface. From the results on the other three samples, one will note that the density of FE sites are comparable at 48-58 per sample, but the lowest emitting field (yield 2 nA current) varies from 38-57 MV/m, which is not unexpected due to the randomness of particulate shape. The studied sites on sample #92 and #94 have similar and limited foreign composition, however, sites on #95 contain a wide variety of foreign elements. This inconsistency in particulate composition seems to indicate an inconsistency in the acid purity or the original cavity surface condition. The high density of field emitting particulates will rely on HPR to remove.

As shown in table 1, direct correlation was not observed between sample measurement and cavity performance because the sample didn't go through HPR, assembly and evacuation with cavity. Such tests will be carried out in the future in the hope of establishing the correlation.

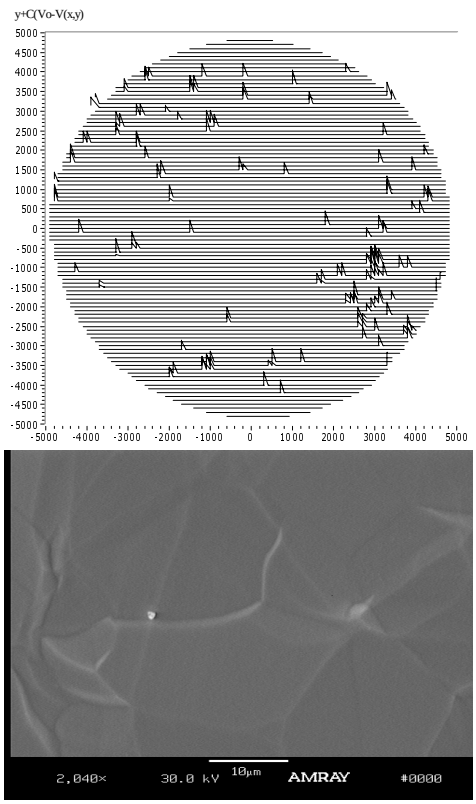

Figure 2: Typical FE scan result from a witness sample for BCP process (top). Also shown is an electron microscopic photograph of an emitter containing Nb, Al, O, C (bottom).

Witness Samples for high Pressure Rinse Process

Five Nb witness samples were installed on the FPC flanges of five SNS cavities, as shown in Fig. 1, and went through the first stage HPR of 2 hr with all the other ports of the cavities blanked off. The samples were then taken off the cavities in a class-10 cleanroom, placed in tightly closed clean containers and transferred to an off-line class 1000 cleanroom for FE measurement. The cavities would go on to the second stage HPR for an additional 2 hr after pre-assembly. Two of the cavities were vertically tested afterwards, while the other three were string-assembled into a cryomodule and were tested horizontally. All samples were pre-qualified by SFEM to be completely or nearly free of FE up to 140 MV/m, and they were then measured again by SFEM after the HPR with cavities. The cavities were oriented with FPC flange on top during HPR, except in one case when the cavity was flipped upside down.

Results from these tests are listed in table 2. After HPR (with high pressure filter removed awaiting for replacement), all samples maintained their FE-free performance or exhibited fewer FE sites. This result further confirmed that HPR is effective at removing particles. It also indicated that HPR didn't degrade a FE-free, flat sample even though the HPR water surely contains a certain number of particles. However, on the much larger and curved surface area of cavities, the same conclusion may not be applicable, which will be discussed in a following section.

Table 2: Witness sample tests for high pressure rinse with SNS production cavities

Sample No.	#84	#84	#84	#83	#81
Number of FE sites before HPR	3	0	0	0	0
Lowest FE field (MV/m)	61	N/A	N/A	N/A	N/A
Number of FE sites after HPR	0	0	0	0	0
SNS cavity No.	MB02	MB07	MB02	MB01	MB06

Witness Sample for Evacuation Process

To study the effect of particle disturbance during vacuum pump-down, we designed an extension tube to be mounted to the beam pipe flange next to the FPC. A pre-qualified sample (free of FE up to 140 MV/m), was installed inside the extension and in the path of vacuum line so that the sample would be exposed to any particles stirred up by evacuation. The extension tube was made of Nb, and the sample holder and tightening collar were made of SS and brass, respectively. The assembly was

carefully cleaned prior to sample installation to avoid cross contamination. The cavity was oriented with the sample on top for HPR, then it was flipped for evacuation and rf test. Finally the sample along with the extension was taken off the cavity for FE measurement.

The FE measurement from this sample is plotted in Fig. 3. After the process, 12 new emitters appeared which are all μm-sized particles. The strongest emitter emits at 26 MV/m, and contains O and Nb. Other FE sites contain "Ag, Cu, Ti", "O, C, Pb", "O, Al", "Fe, Ni, Cu, O", etc. Since the original sample was free of FE up to 140 MV/m, if assuming that after HPR the sample largely maintained its cleanliness as experimentally indicated in the previous section, then the evacuation process may be responsible for stirring up the particulates that originated from cavity surface or vacuum line. One should note that the sample may not be collecting the same number of particulates as if the sample were not present, because the sample restricted the conductance. The corresponding cavity, MB21, performed badly, only reached 19 MV/m peak surface field, with FE onset at 13.6 MV/m peak surface field.

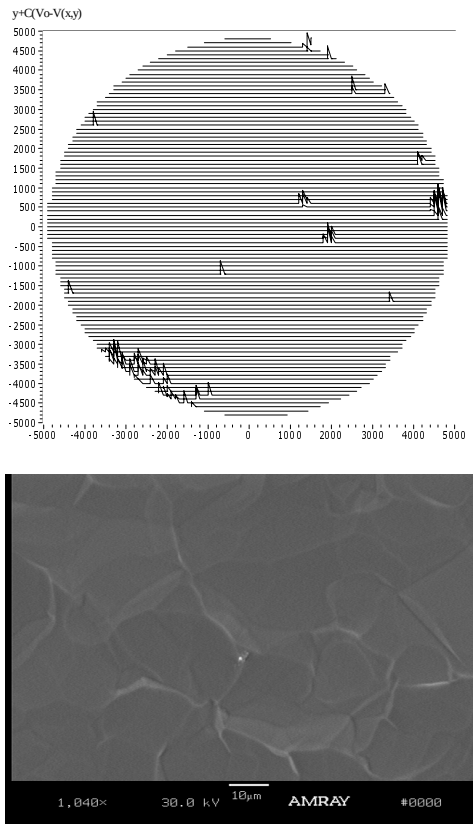

Figure 3: FE scan result from the witness sample for combined HPR, evacuation and vertical RF test process on SNS cavity MB21. Also shown is an electron microscopic picture of an emitter which contains Nb, Ag, Cu, Ti.

DRYING AND CLEANING EXPERIMENT WITH ARTIFICIAL CONTAMINANT

Various labs have used different approaches to dry cavities after high pressure rinse, for example, applying heat to the cavity while pumping out the vapor, using warm filtered nitrogen gas to blow dry cavities, rinsing with methanol or ethanol to remove water before vacuum evacuation, or air-drying in a Class-10 cleanroom. Previous experiments showed that the air-drying process itself didn't create new FE sites from chemical reaction between water and residual acid or from water drops attracting and nucleating on dust [3][4]. It was also indicated that extended exposure to airborne particles in a Class-10 cleanroom for up to 3 days didn't degrade the free-from-FE performance of witness samples placed inside of a single-cell mock cavity either. However, if there is a fairly large number of particulates dissolved in the remaining water drops after the final HPR, either from the water system or originating from the cavity surface and were not removed by HPR, where the particulates reside on the cavity when the cavity is dried will have an effect on the cavity's FE performance. Therefore, drying experiments with artificially induced particulate contamination were conducted on a plastic multi-cell, a Nb single-cell and a Nb multi-cell cavity.

Fluorescent polymer microspheres of 0.482 μm dia. were mixed with DI water to form a solution. The solution was poured into a cavity with its ports blanked off, then the cavity was shaken well in order for the solution to cover most of the cavity surface. Finally the solution was drained out, and the cavity was placed vertically or horizontally until dry. UV light was used for the observation of fluorescence in dark room. We observed that the microspheres reside on the surface within dried droplets and have preferential distribution at the iris rather than at the equator for vertically dried cavities. Refer to Fig. 4 for the comparison of distribution patterns of fluorescent microsphere droplets.

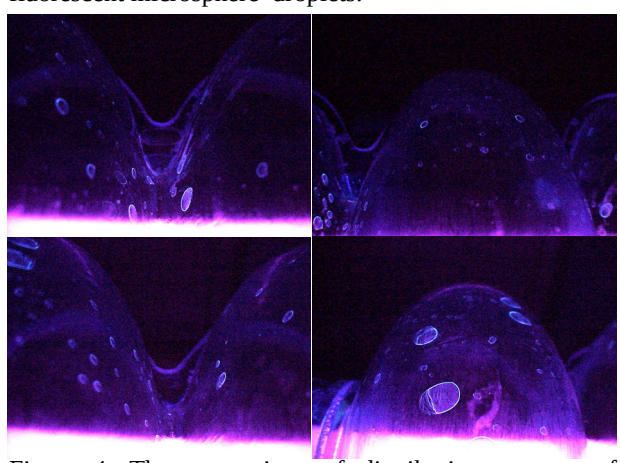

Figure 4: The comparison of distribution patterns of fluorescent microsphere droplets on vertically dried (top left: at iris; top right: at equator) and horizontally dried (bottom left: at iris; bottom right: at equator) plastic cavities.

At the bottom half of horizontally dried cavities, droplets concentrate at the equator; while at the upper half cavity, there is no significant preferential distribution. Therefore, horizontal drying may help to reduce particulate concentration at iris, —the region with the highest electric field, which in turn may reduce cavity FE. Tests on single-cell and multi-cell Nb cavities showed similar patterns.

In light of this finding, we changed the drying orientation of the last four FEL3 cavities to horizontal drying. After tests, these cavities exhibited an average FE onset of 17.5 MV/m, 7.3 MV/m higher than the rest vertically dried FEL3 tests, and 9 MV/m higher than vertically dried SL21 cavities, which are the same shape and configuration as FEL3. Refer to Fig. 5 for the performance comparison of FEL3 and SL21 cavities. Further tests are needed to confirm the benefit of horizontal drying.

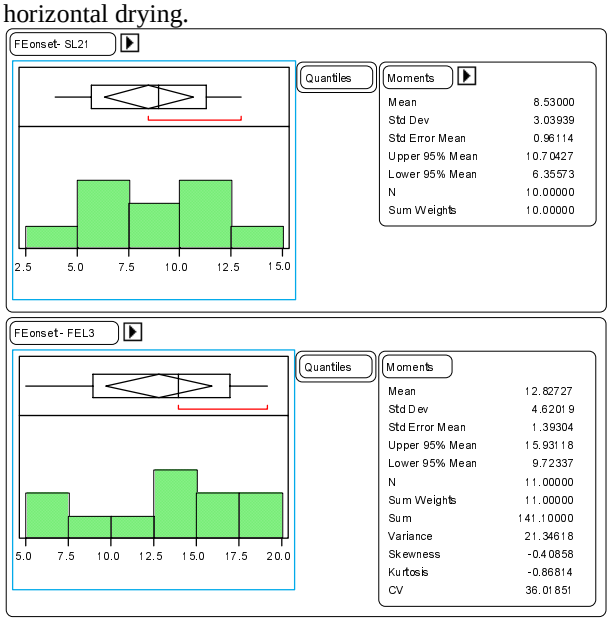

Figure 5: Performance comparison of FEL3 and SL21 cavities.

HPR on such contaminated plastic cavities showed that it is more effective at cleaning the iris than the equator, however, after a total of 2 hour multi-pass HPR, none of the fluorescent droplets were still visible from either vertically dried or horizontally dried cavities, except at the end group ports. This further confirmed that HPR is effective at removing a high density of surface particles.

A NEW APPARATUS FOR HIGH-THROUGHPUT FE MEASUREMENT

In order to facilitate FE measurement on a large number of witness samples anticipated for SNS and other projects, a new high-throughput FE measurement apparatus has been designed. Up to 4 samples of ~1" dia. can be loaded to a UHV chamber at once through a load lock. Samples are mounted on a rotary linear tilt stage. When a sample is rotated to beneath a phosphor screen, which is connected to a +40 kV power supply, a high electric field can be established between the grounded sample and the screen. If using a gap of 0.4 mm, a maximum electric field of 100 MV/m can be achieved. Field emission from the sample can be observed from and recorded by a CCD camera placed above the screen. A Keithley picoammeter is used to measure the total FE current. The setup is illustrated in Fig. 6. Compared to the SFEM currently used for FE scan, this apparatus can offer a significantly improved throughput, suited for in-line process monitoring and quality control in cavity production. SFEM will still be used for in-depth analysis when needed to complement the new apparatus with its high spatial resolution, low detectable threshold, individual site measurement, and microscopic and compositional characterization capability.

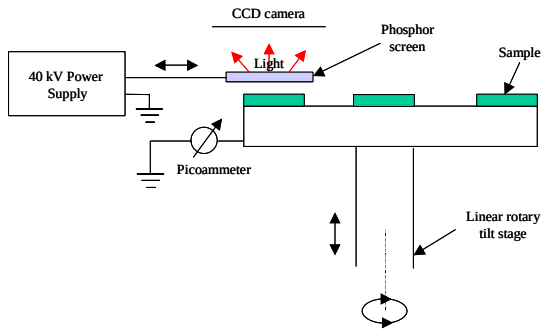

Figure 6: The high-throughput FE measurement apparatus.

SUMMARY

Witness samples were incorporated in various preparation stages of some SNS production cavities aiming at understanding the process with respect to FE. The first series of tests showed a large number of FE particulates after BCP; confirmed the effectiveness of HPR at removing FE particulates; and indicated the possibility of particle disturbance during evacuation. Further tests are needed to confirm the benefit of horizontal drying in reducing FE. The construction of a new high-throughput FE measurement apparatus is underway.

ACKNOWLEDGMENT

We would like to thank the other members of the Particulate Task Force: Peter Kneisel, A-M. Valente, T. Rothgeb, A. Wu et al. for valuable discussions.

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