SEM FIELD EMISSION PROBE SURFACE SCIENCE STUDY *

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Abstract

We are designing and fabricating an electron microscope-based high electric field current emission probe to study topographic material features which will enable us to better understand and further advance the technology of high-brightness photocathode rf guns and enable the study of high gradient phenomena. The scanning electron microscope (SEM) current probe system will provide an important diagnostic tool allowing cathodes and high gradient surfaces to be evaluated before and after testing and will help identify and understand the relationship between high field emission locations and vacuum breakdown, non-uniform emission, surface cracking, and hotspots.

INTRODUCTION

After decades of rf breakdown research, a common acknowledgement among researchers is that a better understanding of what is happening on the surface at a microscopic level needs to be the impetus for future studies. Cathode and accelerator research have both entered into a difficult era of challenging physics that will likely only be overcome by better understanding the physics and chemistry that is taking place on the surface. The electron microscope field emission (FE) probe will enable raster scanning field emission characterization of cathode surfaces and high gradient structures in hopes of better understanding topics such as the early onset of field emission which leads to breakdown, non uniform cathode emission, hotspots, and the impact of surface roughness. The current probe system will also be used to evaluate the FE characteristics on a variety of materials. This work is being funded by the SLAC Laboratory Directed Research and Development (LDRD) program for a period of two years. The generalized two year plan for this program is:

Year 1: (Sept. 2010 - Sept. 2011)

- Design and develop the electron microscope-based high electric field current emission probe system to study topographic material features and their impact on cathodes and high gradient structures.
- Evaluate planar test samples in order to calibrate and optimize the system.

Year 2: (Sept. 2011 - Sept 2012)

- Work with non-planar geometries using existing components.
- Conduct analysis on pre- and post-tested components (e.g. cathodes and high gradient structures) at various stages of processing.

SYSTEM DEVELOPMENT STATUS

A Kleindiek piezo motion-controlled FE probe was recently installed into SLAC's ASPEX PSEM-76 LS scanning electron microscope. An additional port hole was added to the center of the SEM vacuum chamber drawer for mounting a vacuum feed through flange to accommodate control and data acquisition signals (Fig. 1). The signal from the probe is fed through a vacuum compatible triax cable.

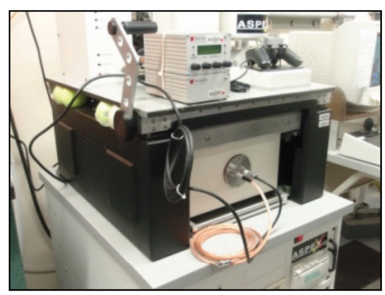

Figure 1: SEM with vacuum feed through flange mounted on vacuum chamber drawer.

A photograph of the field emission probe assembly mounted inside the SEM vacuum chamber is shown in Figure 2. The probe is shown in position to examine a copper accelerator iris insert that has been mounted on the SEM's 5-axis motorized sample stage. The sample stage is eucentric with five degrees of placement freedom, while the probe is independently mounted and has three independent degrees of freedom. This wide latitude of sample and probe placement will allow Fowler-Nordheim measurements with distance and angle as variables. The FE current probe will detect features that exhibit early onset of field emission. The probe can then be retracted and existing characterization techniques in the SEM (secondary electron imaging, x-ray elemental analysis, and elastic electron backscatter) will remain operational. This will allow us to study emission sites that are problematic in a high power environment

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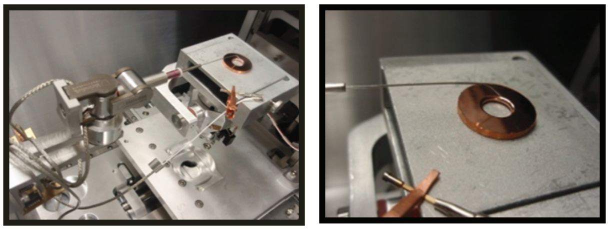

Figure 2: Field emission probe assembly mounted inside the SLAC ASPEX PSEM-76 vacuum chamber.

and to possibly find ways of eliminating them on future components. The control electronics for the FE probe allows for various movement speeds and has coarse and fine displacement. The voltage and current working maximums for this probe system are 1250V and 1μA. A low current measurement cable has also been installed that has a minimum detected current of 1pA.

Our first SEM image of the tungsten field emission probe tip is shown in Figure 3 alongside a copper accelerator iris insert. The FE probe has an isolated probe tip and we currently have on order probe tips with a tip radius as small as 100nm. During the initial start up phase a larger probe tip is being used. The two SEM images at the bottom of Figure 3 show the probe tip in contact with the surface for contact mode gap distance measurements. The high magnification SEM image is blurry but will be improved when the current SLAC SEM is replaced in early 2012 for a high resolution Zeiss Schottky Field Emission Sigma VP SEM. The Zeiss SEM is a variable pressure scanning electron microscope with energy dispersive X-ray spectroscopy and has a resolution of 1.5 nm at 15kV. This will enable us to image and evaluate emission sites with much better clarity. The new SEM will have a high precision 5-axis motorized stage that can support samples up to 11 lbs with a maximum sample size of approximately 14 inches in diameter.

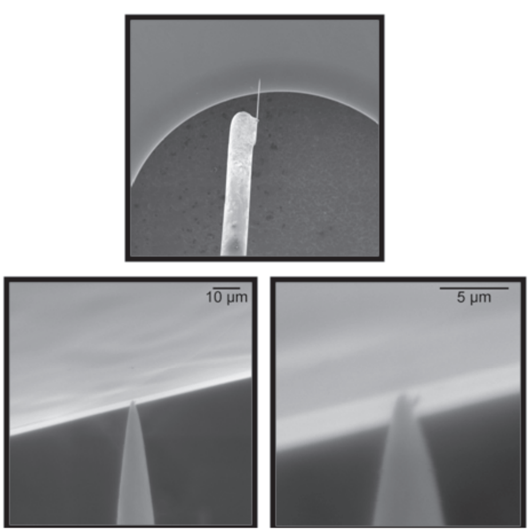

Figure 3: Tungsten field emission probe tip. The SEM images on the bottom show surface contact of the FE probe on an accelerator iris insert.

During our initial studies the tip to surface distance, which is a critical parameter in the Fowler-Nordheim determination of the geometrical enhancement factor (will be measured in contact mode. Next year, non-contact gap distance measurements will be made using two techniques. We plan to order a Questar QM-100 Optical Long Distance Microscope, which has a resolution of 1.1μms at a working distance of 15 cm. To measure gap distances of $< 1\mu$m, we will follow the procedure set forth by E. Mahner and coauthors in Ref. [1] which is done by reducing the gap distance while electronically monitoring the emission current. The applied voltage controller will adjust the tip voltage to keep the field emission current constant. The resulting voltage versus gap spacing should be linear and by extrapolating to zero voltage the gap distance can be determined. The development phase of the FE probe system is almost complete. The data acquisition computer for this system has been configured and software programming is now being implemented that will interface the field emission probe with a Keithley 6487 picoammeter.

FUTURE PLANS

The first test samples to be evaluated will be an accelerator iris insert (Fig. 2) and copper disk coupons like that shown in Figure 4. In general, planar surfaces will be used for the initial data acquisition, calibration, and optimization stages.

One of the strongest benefits of this system will be the ability to analyze demountable and clamped high power components before and after various stages of processing. The SEM has been used in the past to analyze the surface of post mortem demountable cathodes like those shown in Figure 5. The cathode on the left side (Fig. 5), and discussed in more detail in Ref. [2], was the first copper cathode installed in the LCLS RF gun and was in operation for over a year. SEM analysis on the surface of this cathode showed particle contamination and surface damage due to RF breakdown that occurred during RF processing of the gun and cathode. The circular perturbations in the SEM image resulted from attempts at laser cleaning. The FE probe

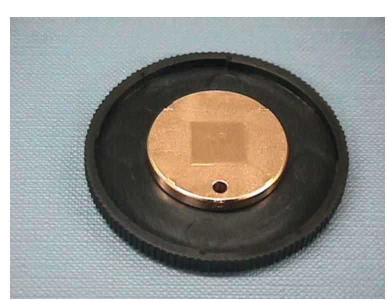

Figure 4: Initial test samples for this study will use copper coupons similar to the one shown here.

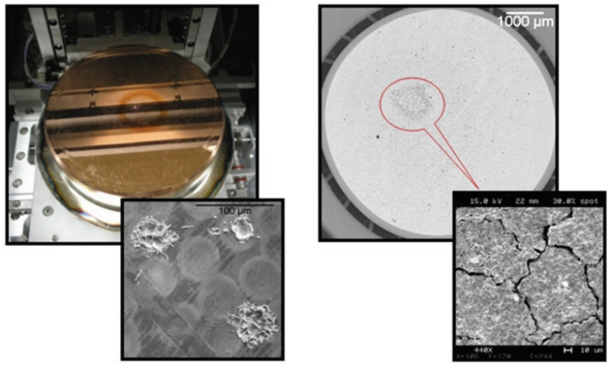

Figure 5: LCLS cathode (left) showing rf breakdown that occurred during processing. Circular surface perturbations are due to laser cleaning. SSRL cathode (right) removed from system due to emission hotspot has surface fracturing due to thermal fatigue.

system will be used to help identify possible causes of RF breakdown, non-uniform cathode emission, and hot spots like that shown in the SSRL cathode on the right of Figure 5 where surface fracturing due to thermal fatigue is evident. The current probe will also be used to evaluate initial surface conditions, compare fabrication processes and differences in materials, and to determine the impact of processing procedures like laser cleaning.

After the field emission probe system has been developed and optimized for planar surfaces, we will include complex geometries such as accelerator structures. We will initially begin the field emission analysis of non-planar geometries by working with components that have already been tested. The clamped single cell geometry in Figure 6 which is shown inside the SEM vacuum chamber is an ideal candidate for this study. A significant number of high power rf tests on single cell structures and cavity pulsed heating samples have been conducted at SLAC [3, 4]. These unique platforms have allowed an economic method of testing different cell geometries, materials, and preparation techniques with a fast turn-around time. Understanding and limiting field emission is a necessary step in overcoming the gradient limitations prevalent in high gradient structures. The clamped single-cell geometry will allow evaluation of the high gradient surfaces at various stages of processing. This type of iterative process will provide important information on surface features that initiate early field emission and will help identify their involvement in localized RF breakdown which can lead to premature catastrophic failure.

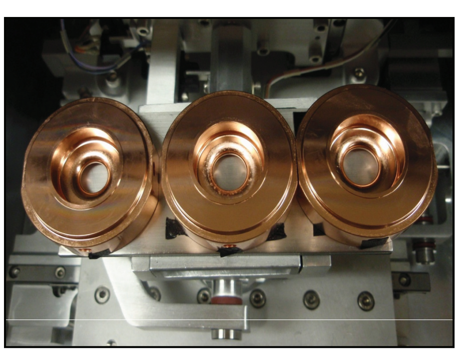

Figure 6: Clamped single-cell structure.

SUMMARY

SLAC's high rf power operation facility will be enhanced by adding in-SEM field emission measurement capabilities. The addition of a FE current probe will be used to identify the field emission characteristics of cathodes and pre- and post-rf operated particle accelerating structures with the goal of understanding, identifying, and eliminating roadblocks that limit their operation. The ability to evaluate the field emission properties on a wide variety of parts, materials, surface finishes, and coatings can provide important information that can lead to advancements in both cathode and high gradient research. Initially, this system will be used to evaluate components that have already been fabricated and tested at SLAC and will be followed by field emission characterization of different fabrication processes and materials, and the study of rf components at various stages of processing.

REFERENCES

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