NOVEL UHV SCANNING ANODE FIELD EMISSION MICROSCOPE (SAFEM) FOR DARK CURRENT INVESTIGATIONS ON PHOTOCATHODES*

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Abstract

We have constructed a novel UHV scanning anode field emission microscope (SAFEM) as part of the systematic quality control of freshly prepared photocathodes at DESY. It is designed to achieve dc surface fields of at least 200 MV/m. In addition it provides the localization of field emitters with a spatial resolution of about 1 µm. In this contribution we report on completed construction of the SAFEM.

INTRODUCTION

One major issue of operating laser driven rf guns with high gradients and high duty cycles as electron sources for free electron lasers like FLASH or the future European XFEL is the dark current emitted from the gun body and the photocathode. It is lost at various places along the beam line and part of it even reaches the undulator. When dark current is lost electromagnetic radiation and neutrons are created and may damage diagnostic components and electronic devices close to the beam line. Imperfect photocathode regions with enhanced field emission and their contact area to the rf cavity are considered as main dark current sources at typical macroscopic electric surface fields of about 40-60 MV/m.

In photocathode rf guns, dark current is defined as "unwanted electrons generated in the absence of the driver-laser pulse." Due to the exponential increase of field emission current with the local electric field according to the Fowler-Nordheim relation [1], the most sensitive regions for dark current can be estimated from calculation of the field distribution in the cavity. MICROWAVE STUDIO [2] 3D calculations of the field distribution in the gun cavity and a part of the coaxial rf input coupler show presence of a strong surface field at the cathode area (1) and the irises (2) (Fig.1) [3].

ASTRA [4] simulations of the beam dynamics of dark current from high field strength regions show that electrons starting at the cathode area can be accelerated downstream, while field emitted electrons from other sources, like iris or the entrance to the coupler, cannot leave the coupler [3]. However, they are able to locally heat up the cavity surface and may create secondary electrons. Therefore, carefully conditioning and EFE investigations of the cavity surface are necessary [5, 6]. The source of field emission current from the cathode area is, however, not studied carefully yet.

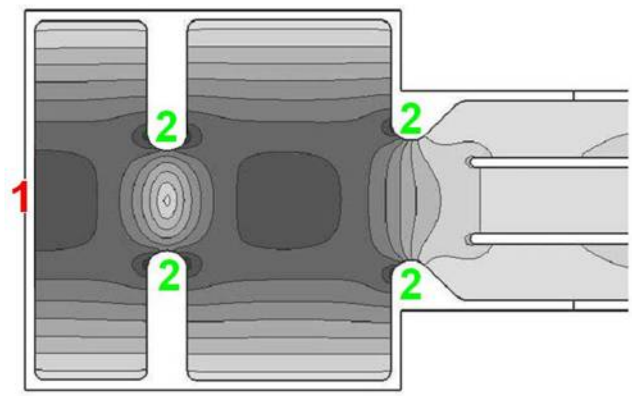

Figure 1: Contour map of the electric field amplitude in the cavity and a part of the coaxial coupler [1].

FLASH and the European XFEL demand high accelerating gradients and long rf pulses at the gun. Therefore the amount of dark current can be comparable to the electron beam or even higher [3, 7]. For illustration in figure 2 an Ce:YAG image of the dark current together with the photoelectron beam (central spot) obtained just after the gun exit of FLASH is shown. The rf forward power at the gun was P_{for} = 3.2 MW and the main solenoid current 298 A. Figure 3 shows for the same operational conditions the dark current only [8]. A strong emitter is visible and the location is assumed to be at the edge of the cathode plug or the rf contact spring area. In addition a dark current spot exactly at the beam position is present.

In order to ensure low field emission photocathodes, investigate dark current sources in detail and to improve cathode handling technique, a novel UHV scanning anode field emission microscope (SAFEM) has been developed as part of the systematic quality control of freshly prepared photocathodes at DESY.

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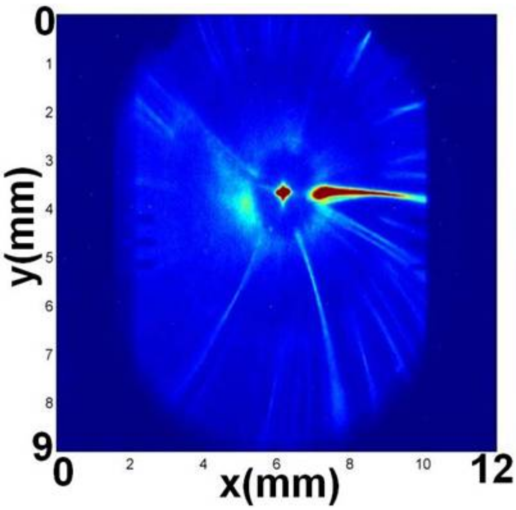

Figure 2: Electron beam and dark current image.

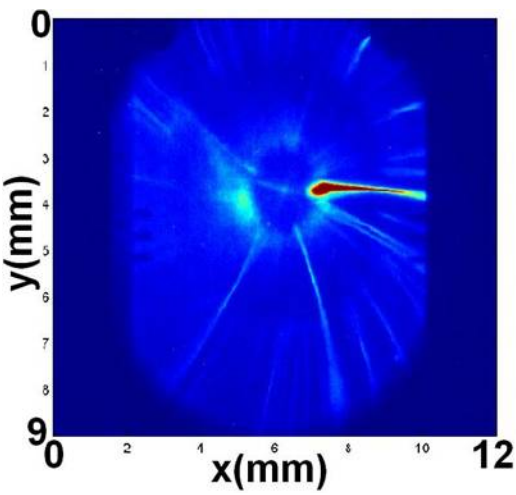

Figure 3: Dark current image.

CONSTRUCTION OF THE SAFEM

The SAFEM is developed to be a part of a complex set-up consisting of a preparation system for Cs_2Te photocathodes, the systematic quality control, and a transport system to deliver photocathodes to a gun. Cathode movement inside the system is based on a transfer system compatible to the ones used at the DESY photo-injectors.

Besides field emission studies on photocathodes one additional aim of the SAFEM is the investigation of cathode handling inside rf guns. Therefore as cathode holder inside the SAFEM a copy of a gun back plane has been constructed including the rf contact spring (Fig. 4). The back plane consists of Copper and the spring of CuBe with a silver coating. To simplify the scanning procedure a design where the anode of the microscope is scanned over the sample was chosen. The name “Scanning Anode” was exactly chosen to underline this construction.

Main requirements to the SAFEM are:

– 10^{-10} mbar working pressure
– 25 x 25 mm^2 scanning range
– at least 200 MV/m achievable dc field
– electrode gap control

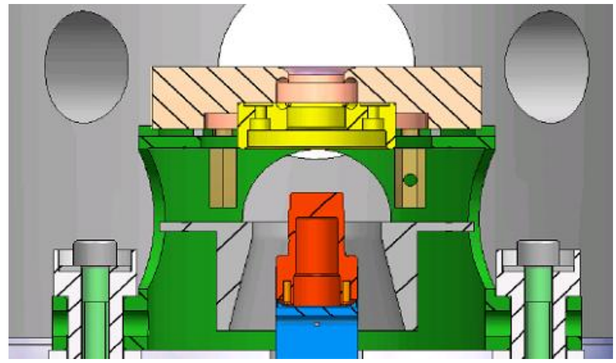

Figure 4: Scheme of the cathode holder inside the SAFEM with Cu back plane.

The high vacuum requirements are related to the property of Cs_2Te, being very sensitive to the vacuum conditions.

The three dimensional scanning system has been constructed on the basis of three UHV compatible sliding tables MTS-65 from Micos [9]. Control of the scanning system is done through a special “SMC corvus” 3D controller and a computer via GPIB interface. Key parameters for the sliding stages are:

- 25 mm working moving range
- 0.1 µm resolution
- 10^{-10} mbar working pressure.

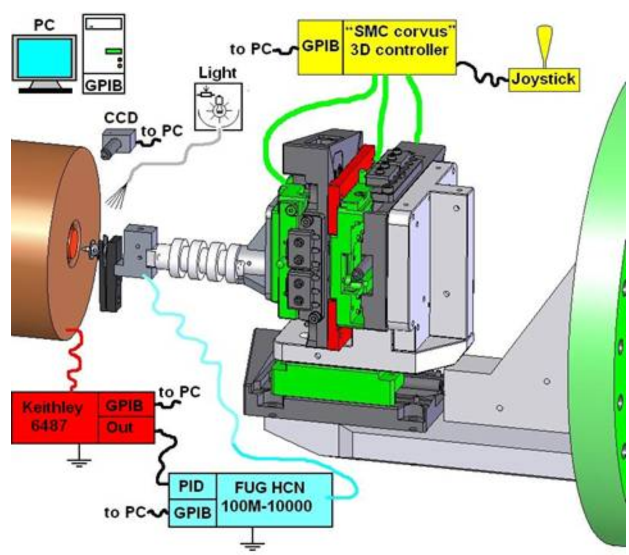

Figure 5: Scheme of the SAFEM including electrical connections.

As voltage source a 10 kV (± 0.1 V, 10 mA) power supply from FUG [10] (HCN 100M-10000) with fast PID regulation is used. Using a 20 kV electrical feedthrough on DN40CF flange and CuBe springs the voltage is

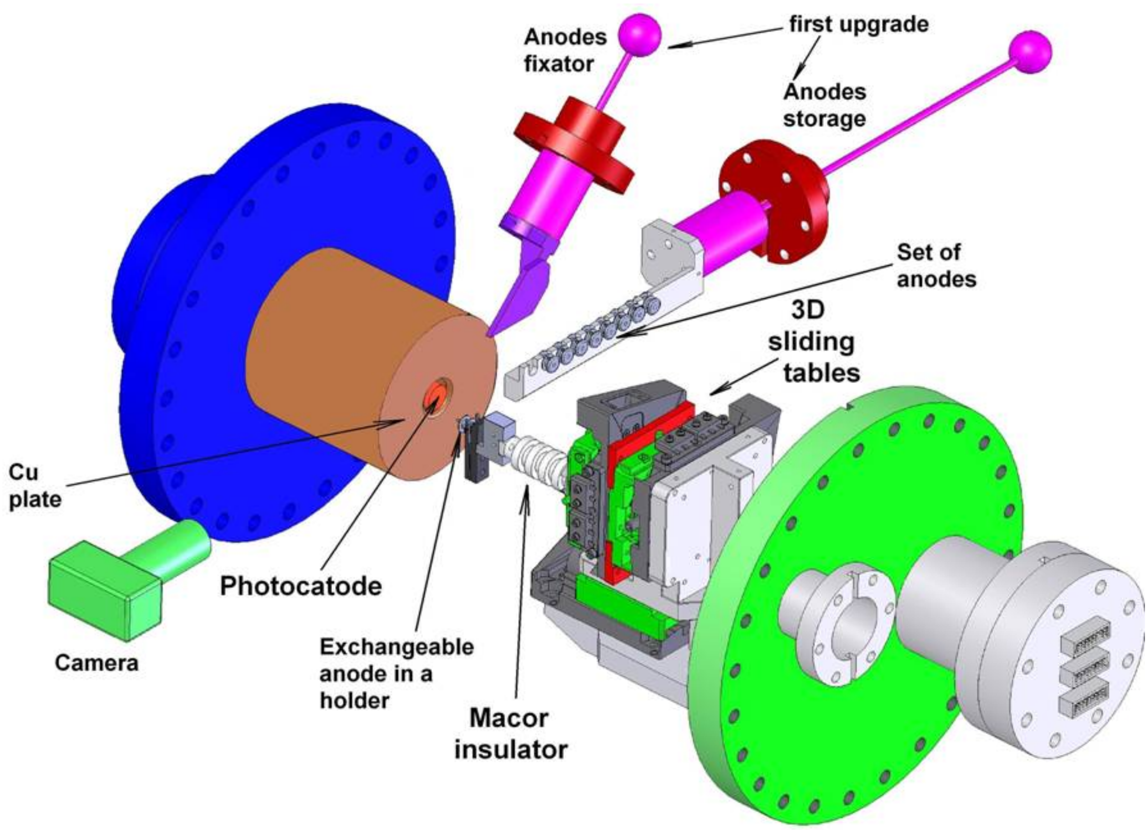

Figure 6: Inner view of the SAFEM already including the future anode exchange option.

supplied to the anode. The anode holder and 3D scanning system is electrically isolated using a massive Macor insulator of ribbed form for reduced surface leakage current (Fig. 5, 6)

The field emitted current is measured between ground potential and the photocathode using a picoammeter Keithley 6487 [11]. Electrical connection from the insulated cathode/back plane compound is done via standard feed through.

In order to control the electrode gap a CCD camera in combination with a macro zoom lens and bright light source for illumination are used. The camera and light source are placed outside the chamber and focused on the electrode gap through view ports.

Control of the SAFEM in measurement mode is fully automated on the basis of LabView [12], while communication to all instruments is based on GPIB interfaces.

The required vacuum is achieved by the use of standard UHV materials for the chamber and a combination of ion getter pump (IGP) and titanium sublimation pump (TSP).

Final properties of the SAFEM will be:

- direct transfer of photocathodes between preparation chamber, SAFEM and transport box
- 10^{-10} mbar working pressure
- optical electrode gap control down to 5 µm resolution
- imaging of potential emitter distribution over the photocathode surface and the back plane
- 25 x 25 mm^2 scanning range
- detailed field emission investigation of individual emitters
- 1 µm scanning resolution
- 0 - 10 kV, ± 0.1 V applied voltage (with fast PID regulation), correspond to 0 - 200 MV/m at around 50 µm gap
- ± 1 fA current resolution
- fully automated measurement control based on PC/LabView.

OUTLOOK

After first commissioning of the SAFEM it will be finally included into the preparation and quality check set-up.

In an already planed upgraded stage the SAFEM will be equipped with an anode exchange system. This will give the opportunity to choose between 9 anodes of different radius without breaking the vacuum.

ACKNOWLEDGEMENTS

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REFERENCES

[1] H. Fowler, L.W. Nordheim, Proc. Royal Soc. (London) A119, 173 (1928).
[2] MicroWave Studio, CST GmbH.
[3] H. Jang-Hui, Dissertation, University of Hamburg (2005).
[4] K. Flöttmann, "ASTRA User Manual", www.desy.de/~mpyflo/Astra documentation.
[5] P. Kneisel and B. Lewis, Proceedings of the 7-th Workshop on RF Superconductivity, Gif sur Yvetter, France, edited by B. Bonin (1995), p.311.
[6] A. Dangwal et al., J. Appl. Phys. 102, 044903 (2007).
[7] H. Jang-Hui, K. Flöttmann, W. Hartung, Phys. Rev. ST – AB 11 (2008), 013501.
[8] S. Schreiber, S. Lederer, P. Michelato, L. Monaco, D. Sertore, J.H. Han, Proceedings of FEL08, Gyeongju, Korea, p552.
[9] Micos GmbH, http://www.micos.ws
[10] FUG ElektronikGmbH, http://www.fug-elektronik.de
[11] Keithley Instruments GmbH, http://www.keithley.de.
[12] National Instruments, http://www.ni.com