ISIS@MACH ITALIA

Science and Technology Facilities Council
ISIS Neutron and Muon Source

# Experiment Proposal

Experiment number GP2023003

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|---|---|---|---|
| **Principal investigator** | Professor Alessandro Cianchi, University of Rome Tor Vergata , ITALY | | |
| **Co-investigator** | Professor Enrica Chiadroni, Sapienza University of Rome, ITALY | | |
| **Co-investigator** | Dr Luigi Faillace, INFN-LNF - Frascati, Rome, ITALY | | |
| **Co-investigator (*)** | Dr Mario Galletti, Universitá di Roma Tor Vergata, ITALY | | |
| **Co-investigator** | Dr Andrea Liedl, INFN, ITALY | | |
| **Co-investigator** | Dr Riccardo Pompili, INFN, ITALY | | |
| **Co-investigator** | Dr Giovanni Romanelli, University of Rome Tor Vergata, ITALY | | |
| **Co-investigator** | Professor Marco Laurati, CSGI, ITALY | | |
| **Co-investigator** | | | |
| **Experiment title** | GISAXS characterization of cathodes for photoinjectors | | |
| **MRF Instrument** | **SAXS Xenocs Xeuss** | **Days requested:** | 2 |
| **Access Route** | Direct Access | **Previous GP Number:** | GP2022013 |
| **Science Areas** | Materials, Physics | **DOI:** | - |
| **Sponsored Grant** | None | **Sponsor:** | - |
| **Grant Title** | - | **Grant Number:** | - |
| **Start Date** | - | **Finish Date:** | - |
| **Similar Submission?** | - | | |
| **Industrial Links** | - | | |

**Non-Technical Abstract**

High brightness machines, like Free Electron lasers, are driven by photoinjectors. The quality of the electron beam extracted from the source is paramount for the whole machine's performance. Copper cathodes are widely used, as electron sources, for their reasonable quantum efficiency, robustness, simple treatment, and implementation. However, copper cathodes, exposed to strong electric fields and continuously bombarded with high-intensity lasers, can degrade their quantum efficiency. To this end, we have performed preliminary experiments at IM@IT investigating the morphology of our copper cathodes, using SEM - EDX and Profilometry, which evidenced structures up to the micrometer scale. To complement these characterizations, we propose to study the same cathodes, either after having been used or without exposure to the laser, with GISAXS.

**Publications**

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**ISIS neutron and muon so** | **IM@IT E-platform:** No

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|---|---|
| **Instruments** | **Days Requested:** |
| **Access Route** | **Previous RB Number:** |
| **Science Areas** | **DOI:** |
| **Sponsored Grant** | **Sponsor:** |
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# Sample record sheet

**Principal contact** Dr Mario Galletti, Universitá di Roma Tor Vergata, ITALY
**MRF Instrument** **SAXS Xenocs Xeuss** **Days Requested:** 2
**Special requirements:**

## SAMPLE

| | | | |
|---|---|---|---|
| **Material** | Cu Oxygen free 99.95% exposed to RF | - | - |
| **Formula** | Cu | - | - |
| **Forms** | Solid | | |
| **Volume** | 50 cc | | |
| **Weight** | 500 g | | |
| **Container or substrate** | - | - | - |
| **Storage Requirements** | limited exposure to air required | - | - |

## SAMPLE ENVIROMENT

| | | | |
|---|---|---|---|
| **Temperature Range** | 300 - 300 K | - | - |
| **Pressure Range** | 0 - 1000 mbar | - | - |
| **Magnetic field range** | 0 - 0 T | - | - |
| **Standard equipment** | None | - | - |
| **Special equipment** | - | - | - |

## SAFETY

| | | | |
|---|---|---|---|
| **Prep lab needed** | Yes | - | - |
| **Sample Prep Hazards** | - | - | - |
| **Special equip. reqs** | - | - | - |
| **Sensitivity to air** | No | - | - |
| **Sensitivity to vapour** | No | - | - |
| **Experiment Hazards** | - | - | - |
| **Equipment Hazards** | - | - | - |
| **Biological hazards** | - | - | - |
| **Radioactive Hazards** | - | - | - |
| **Additional Hazards** | - | - | - |
| **Additional Details** | - | - | - |
| **Sample will be** | Disposed of by instrument scientist | - | - |

**Scientific Background**

High brightness machines, like free electron lasers, are driven by photoinjectors. The quality of the electron beam extracted from the source is paramount for the whole machine's performance. Copper cathodes are widely used, at electron sources such as SPARC_LAB (INFN, Italy) [1], for their reasonable quantum efficiency, robustness, simple treatment, and implementation. However, copper cathodes, exposed to strong electric fields and continuously bombarded with high-intensity lasers, can degrade their quantum efficiency for several reasons. The most common problem is surface contamination, mainly due to carbon ions, but also thermal stress can induce dislocations inside the material, leading to extrusion, creating a tip where the electric field can grow up, thus causing a dangerous discharge. The change in quantum efficiency or, even worse, the difference in this parameter point by point can dramatically affect the beam properties, degrading the emittance and producing poor radiation source performances.

To better understand the degrade in quantum efficiency of copper cathodes, surface analyses can be used to estimate both contamination and thermal-induced roughness before and after exposure to the RF laser, as well as after nanomachining [2]. The nanomachining process consists in diamond milling and blowing with dry nitrogen. This procedure reduces the roughness of the cathode surface to about 5 nm and prevents surface contamination introduced by other techniques, such as polishing with diamond paste or the machining with oil. While during use and exposure to high-energy lasers the roughness can increase to several micrometres, resolution of experimental techniques to characterise the surface of copper cathodes needs to span over several spatial scales.

Here, we propose to complement preliminary characterizations of exposed copper cathodes at the micrometre spatial scale, with a characterization of the roughness at the nanometre scale using Grazing-Incidence Small Angle X-ray Scattering (GISAXS) using the SAXS/WAXS/GISAXS instrument of the Medium Range Facility 1 - FOURDIM.

**Previous Characterizations**

Previous characterizations, using the Small Research Facilities available at the ISIS@MACH ITALIA laboratories of the unit at University of Rome Tor Vergata (GP2022013), have shown the presence of a series of craters at the micrometre scale, whose frequency of appearance decreases going from the centre of the copper cathode, where the high-intensity laser hits the surface more often, towards the border. Such trend can be appreciated looking at the series of SEM images in Figure 1. A detail of a region with several craters, each with average dimensions of the order of 10 micrometres, is provided in Figure 2 using both secondary and back-scattered electrons. The roughness level in a region including a crater was measured using a profilometer to about 2 µm, while in a region just outside the border of the crater to about 60-80 nm, a value approaching the one for a recently nano-machined surface. However, such value of roughness is approximately at the resolution limit of the profilometer, and the estimate of the roughness in regions further away from the beam centre becomes limited by the instrument resolution.

**Proposed Experiment**

We propose to perform a GISAXS experiment using the SAXS Xenocs Xeuss instrument at the MRF1 – FOURDIM of the CSGI – University of Florence Unit of ISIS@MACH ITALIA. By analysing the SAXS patterns in the grazing incidence geometry as a function of the distance from the cathode centre, we aim at measuring the roughness value at the nanometre scale, checking whether it approaches the nominal value of few nanometres, obtained after nanomachining, in the outer regions where the high-intensity laser is expected to have created a negligible number of craters. Experiments will be performed on both an exposed copper cathode and on a nanomachined one. We expect the SAXS patterns to be dominated by the roughness contribution, as the cathode is about 2 cm thick and only composed of copper. A distorted wave Born approximation (DWBA) will be used to analyse the roughness distribution [3] in the 1 – 100 nm range.

To perform this experiment, we request 2 days of the GISAXS instrument at the MRF1 – FOURDIM facility.

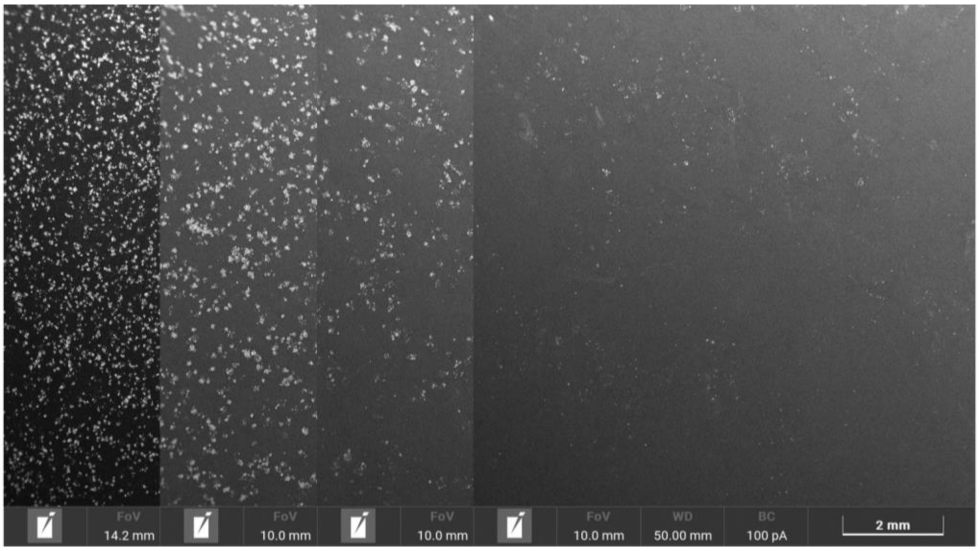


*Figure 1 – Series of SEM images of the copper cathode surface, moving from the centre (left image) to the outer region (right image) showing the different frequency of craters.*

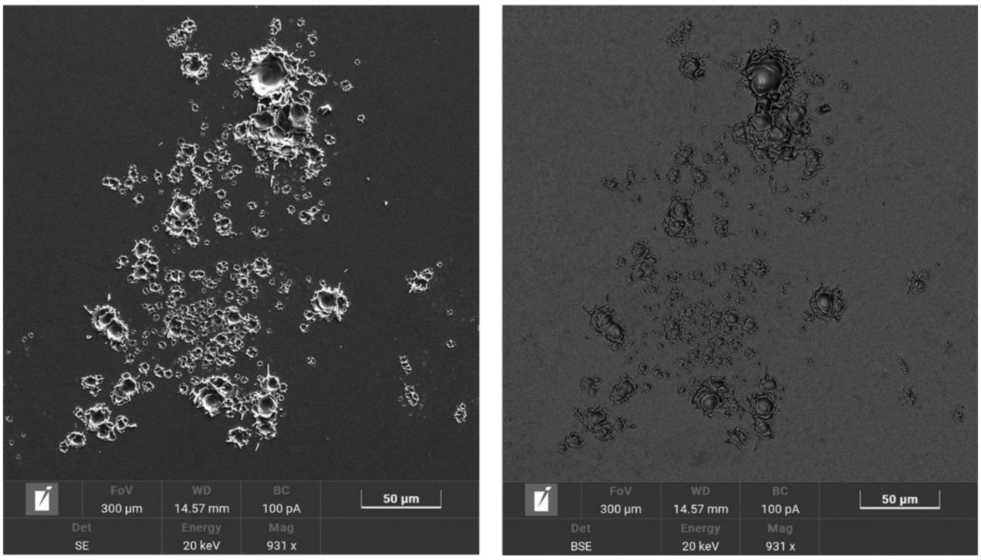


*Figure 2 – SEM images of the copper cathode surface showing craters at the micrometre scale using secondary (left) and back-scattered electrons (right).*

**References**

[1] https://w3.lnf.infn.it/acceleratori/sparc_lab/
[2] J. Scifo et al, Nucl. Inst. Meth. A., 909, 2018, 233-238 https://doi.org/10.1016/j.nima.2018.01.041
[3] S. K. Sinha, E. B. Sirota and S. Garoff, Phys. Rev. B38, 2297 (1988). https://doi.org/10.1103/PhysRevB.38.2297