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A Cu PHOTOCATHODE FOR THE SUPERCONDUCTING RF PHOTOINJECTOR OF bERLinPro *

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Abstract

The initial commissioning of the Superconducting RF (SRF) photoinjector is achieved with a Cu photocathode due to its robustness with respect to interactions with the SRF cavity of the injector. Here we present the preparation and characterization of a Cu photocathode plug and the diagnostics to insert the photocathode in the back wall of the SRF cavity. A polycrystalline bulk Cu plug was polished, particle free cleaned and characterized by x-ray photoelectron spectroscopy. During the transfer of the photocathode insert into the gun module the whole process was controlled by several diagnostic tools monitoring the insert position as well as RF, vacuum and cryogenic signals. We discuss the challenges of the photocathode transfer into an SRF cavity and how they can be tackled.

INTRODUCTION

The Helmholtz-Zentrum Berlin ERL project recently achieved an important milestone by demonstrating first beam from the SRF photoinjector alongside several major advances within the project [1]. First results of SRF gun commissioning are also presented at this conference [2]. For the operation of the photoinjector a photocathode plug exchange system was designed, which meets the requirements for the SRF environment. The design of the photocathode plug has been optimized in terms of avoiding field emission in strong acceleration fields. Due to the stringent requirements imposed by the operation of a photocathode in an SRF cavity and for optimized photoinjector beam dynamics, we defined the following specifications: particle free preparation, rms surface roughness < 100 nm, chemical purity of the surface, operation at cryogenic temperatures and vacuum pressure $< 1\times10^{-9}$ mbar. For commissioning purposes a polycrystalline bulk Cu was chosen as plug material, because of the easier preparation and handling compared to Cs-K-Sb photocathodes. Ultimately it is the goal for bERLinPro to use Cs-K-Sb photocathodes. The bulk Cu plug itself is used as a photocathode (after particle free preparation and removing the oxide layer) in combination with an UV-laser (257.5 nm).

Here we present preparation and characterization of the Cu photocathode and its insertion into the bERLinPro SRF photoinjector (Gun 1.0) using the photocathode infrastructure, which was presented last year [3].

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COPPER PHOTOCATHODE

In order to meet the requirements regarding the operation of a photocathode in the SRF environment the copper photocathode plug was particle free cleaned before it was introduced into UHV. The surface of the plug was furthermore cleaned under UHV conditions and checked in-situ by x-ray photoelectron spectroscopy (XPS). The following sections will describe the preparation, characterization and transfer to the SRF photoinjector. Figure 1 shows the ultra-smooth polished Cu plug sitting on an adapted flag-style sample holder.

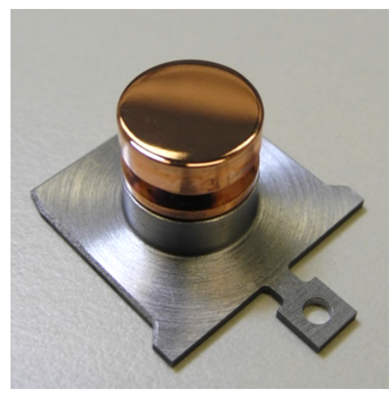

Figure 1: The flag style sample holder system with the polycrystalline Cu plug used as a photocathode for initial commissioning of the SRF-Photoinjector. The diameter of the plug is 10 mm.

Cu Plug Cleaning

An Cu plug has been manufactured in the desired design in the HZB workshop and the surface was polished to the nanometer roughness level. Figure 1 shows the Cu plug on an adapted flag style sample holder. Furthermore the cleanliness and the rim were inspected by optical microscopy, in order to identify particle contamination or coarse defects. The sample holder and the Cu plug were cleaned as described below: The plug and the sample holder were dry ice cleaned before put into the ISO 5 clean room where they were cleaned in isopropyl alcohol in an ultra sonic bath. Afterwards both were blown with ionized nitrogen until dry and no particles could be counted. The plug was sealed under dry nitrogen and transported to the photocathode lab. The plug was put in a citric acid solution to dissolve the native oxide layer and rinsed with ultra pure water and IPA.

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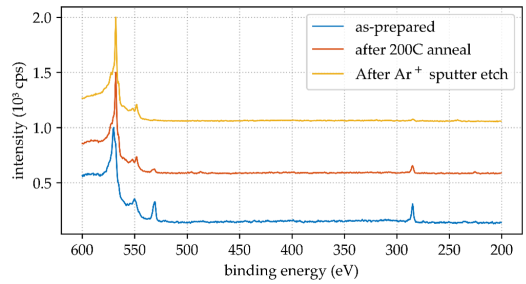

Figure 2: XP spectra (Al Kα) including the Cu LMM Auger transitions (> 540 eV), O 1s (531 eV), C 1s (285 eV) peaks taken after each preparation step.

The sample holder with plug was put into the UHV load lock and transferred into the preparation chamber. In Fig. 2 the x-ray photoelectron spectra are shown after each step. The plug was heated to 200°C for 20 min and Argon-ion etched at 2 kV and 10 mA for 20 min at $5{\times}10^{-6}$ mbar. From a witness Cu plug a rms roughness about 90 nm was determined. The plug was transferred into the vacuum suitcase (p= $5{\times}10^{-11}$ mbar) and connected to the transfer system at the gun module. The plug was mounted under UHV conditions onto the cathode insert and then inserted into the gun module, which is shown in Fig. 3.

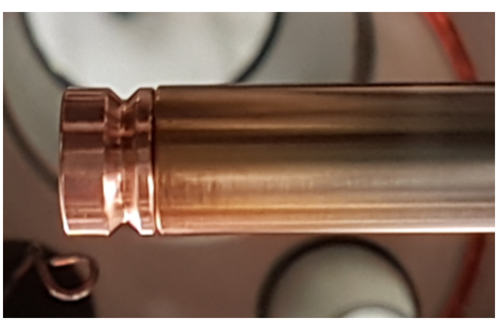

Figure 3: The cathode insert based on the HZDR-design with the exchangeable plug before insertion into the SRF-gun module. The bulk Cu plug is used as the photocathode for commissioning purposes for RF-operation and first electron beam. The color changes of the Cu-insert are due to the bake out of the transfer system for vacuum commissioning.

PHOTOCATHODE INSERTION

The cathode/cavity interface region is shown in the cross section image along with the copper plug in Fig. 4. After slowly opening the gate valve between the photoinjector and the transfer system, the insert was moved slowly from room temperature into the cold gun module (80 K cathoder cooler, 2 K gun cavity). During valve opening and motion of the insert the pressure was kept below $1{\times}10^{-9}$ mbar at all times. The horizontal manipulator carrying the cathode insert can be aligned with two xy-tables to avoid any contact of the insert with the surrounding. The Petrov filter is electrically isolated to apply a negative HV-bias voltage to the cathode insert to suppress multipacting. For the transfer the HV-connector for the bias voltage is combined with a short circuit detector, which gives a signal when the cathode insert is touching the walls in this region. If a signal occurred, the insert was centered. Three displacement position sensors (micro-epsilon, capaNCDT_6200) at the cathode cooler were mounted to measure the relative position between the cooler and the gun module. As soon as the insert arrives in the final position in the cone of the Petrov filter, the sensors give a signal based on the pushing force of the horizontal manipulator. In this case the Petrov filter was pushed 10 μm towards the gun cavity, when the insert was released from the horizontal manipulator. A camera equipped with a tele mirror lens is used to monitor the cathode arrival in the region of the Petrov filter as well as inside the back wall of the gun cavity, see Fig. 5. The cathode was illuminated with a diffused halogen light source from the side window in the first meter of the diagnostic beam line.

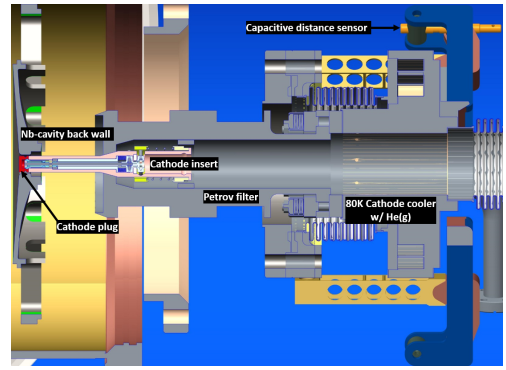

Figure 4: Cross section through the gun cavity - cathode interface region.

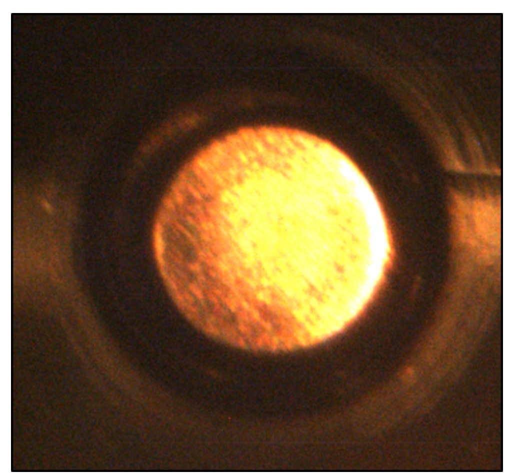

Figure 5: Camera image of the Cu plug after successful insertion into Gun 1.0 cavity.

Cathode Positioning

For the RF-power operation the cathode surface should be located behind the back wall of the cavity as indicated by beam dynamics studies and the expected RF heat load [4].

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The position of the cathode can be manually aligned with three rotary feed-throughs. A laser distance sensor (micro-epsilon, PR166-optoILR) was installed at the same viewport as the camera observation to measure the position of the plug surface with respect to the back wall of the Nb cavity. The results of the alignment is shown in Fig. 6.

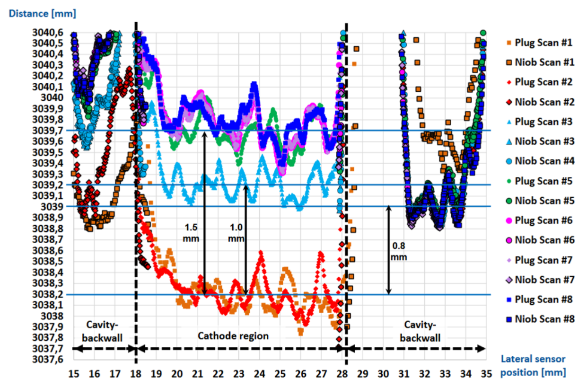

Figure 6: Laser distance measurement of the photocathode position with respect to the Nb-cavity back wall before and after alignment. The relative distances are in agreement with the signals of the capacitive distance sensors at the cathode cooler.

On the right hand side the position of the Nb-cavity back wall can be seen relative to the position of the Cu-cathode region in the middle. The cathode was moved stepwise into its final position about 0.7 mm behind the cavity back wall. The measured cavity back wall on the left hand side of the cathode region is different due to the limited field of view while scanning the laser along a straight line across the cathode. For the measurement of the cathode region the scanning laser had to be attenuated because of the high reflectivity of the polished Cu plug surface.

QE MAP INSIDE THE GUN

During the commissioning phase of Gun 1.0 a QE map was measured, which is shown in Fig. 7. At this time the cathode was already retracted behind the back wall of the cavity related to Fig. 6. The wavelength of the UV-laser was 257.5 nm with a power of 7.31×10^{-4} W. The laser with a spot size of 1.9 mm was scanned over the cathode/cavity interface region. The map was taken at 7 MV/m LLRF field amplitude. A negative cathode bias voltage of 2 kV was applied. The photocurrent and dark current were measured with the Faraday cup in the first meter of the diagnostic beam line [5]. The QE over the whole area was about 10^{-5}, which is in agreement with QE measurements in other RF and SRF photoinjectors [6–8].

LESSONS LEARNED

For the commissioning process of Gun 1.1 at bERLinPro we will consider a dummy plug to align the photocathode position with respect to the Nb-cavity back wall before RF-operation. The plug surface should not be too smooth to

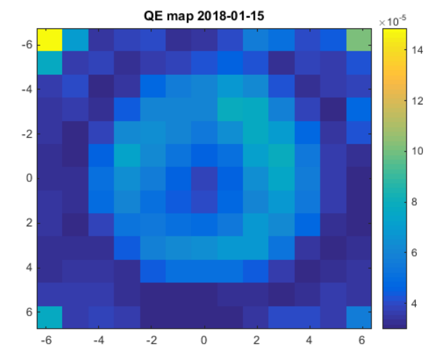

Figure 7: QE map (12 mm × 12 mm) of the Cu photocathode inside the gun. The diameter of the plug is 10 mm and the laser spotsize was 1.9 mm. A QE of in range of 10^{-5} was measured over the whole area.

avoid reflection for the distance laser. Tests on different plug materials are ongoing. The position of the plug is very critical in terms SRF cavity contamination and furthermore RF heat load can lead to the evaporation of the semiconducting thin film photocathode. We will further improve the tools of the transfer system for the plug exchange on the cathode insert and the fast exchange of the complete cathode insert. Based on our experience with Gun 1.0 we will continue with a gun mock-up system to test the cathode insert exchange and investigate the cathode cooling and different metals for the cathode plug. The thermal management inside the gun based on the heat load of the laser and the RF-power is a very important issue for the SRF gun operation. The vacuum of the transfer system and close to the gun cavity was optimized to the low 10^{-10} mbar regime to handle Cs-K-Sb photocathodes for the future operation at bERLinPro.

CONCLUSION

For bERLinPro a complete photocathode infrastructure has been built during the last three years including the preparation and analysis system for Cu and Cs-K-Sb photocathodes, transfer systems to load and unload the vacuum suitcase and to insert the photocathode into the back wall of a superconducting Nb-cavity. A Cu photocathode has been prepared and the insertion was demonstrated, which led to the first electron beam for commissioning purposes. We continue refurbishment and finishing the infrastructure (e.g. photocathode laser) to be ready for the operation of Cs-K-Sb photocathodes in SRF-photoinjector in the bERLinPro accelerator hall in 2019.

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