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THERMAL LOAD STUDIES ON THE PHOTOCATHODE INSERT WITH EXCHANGEABLE PLUG FOR THE bERLinPro SRF-PHOTOINJECTOR

J. Kuehn*, N. Al-Saokal, M. Buerger, M. Dirsat, A. Frahm, A. Jankowiak, T. Kamps, G. Klemz, S. Mistry, A. Neumann, H. Ploetz, Helmholtz-Zentrum Berlin für Materialien und Energie, Germany

Abstract

For the operation of an SRF photoinjector a well-functioning and efficient cooling system of the photocathode is necessary. A test experiment was set up of the photocathode cooling system based on the original components, which we call thermal contact experiment (TCX). We present the results of our thermal load studies on the photocathode insert with exchangeable photocathode plug. The goal was to test all components before they are installed in the cold string of the bERLinPro SRF-Photoinjector to ensure the operation of very sensitive semiconductor photocathodes. The tests include the investigation of the cooling performance, the thermal load management and the mechanical stability of the photocathode insert.

INTRODUCTION

Since 2012 the Helmholtz Zentrum Berlin is working on the Berlin Energy Recovery Linac Prototype as one of its future projects led by the Institute of Accelerator Physics and the Institute of SRF - science and technology [1]. An important milestone was achievd by the commissioning of the SRF photoinjector and the first electron fired from a copper photocathode in 2018 [2, 3]. After the decommissioning of the SRF photoinjector for the refurbishment of the gun cavity it was found that the photocathode insert was damaged due to high thermal load based on RF losses during operation. Based on our experience the plug holding mechanism was improved and had to be tested. Our study is motivated to ensure a safe operation of the bialkali antimonide semiconductor photocathodes and to avoid the contamination of the SRF cavity of the photoinjector when bERLinPro is commissioned.

SRF PHOTOINJECTOR

Inside the module the cathode insert is cooled by 80 K gaseous helium. For bERLinPro it is foreseen to run the SRF photoinjector with Cs-K-Sb photocathodes as electron source. A few nanometer thick films of this material are grown on a polished molybdenum plug inside the photocathode production system, which the is transported under UHV conditions to the SRF photoinjector via a vacuum suitcase. At the photocathode exchange system on the gun side, the plug is mounted on the cathode insert, which is then moved carefully from room temperature into its final position inside the RF filter at 80 K [4]. Fig. 1 shows the cross section of the SRF photoinjector. The cathode insert carries the photocathode plug, which has to be aligned very precisely in the RF-filter with respect to the back wall of the half cell cavity, because the position of the cathode is very critical for the operation. The position of the photocathode should be about 1 mm behind the back wall of the cavity to avoid its overheating and contamination of the cavity. A laser distance measurement system has been set up up to investigate the photocathode position in detail inside the photoinjector.

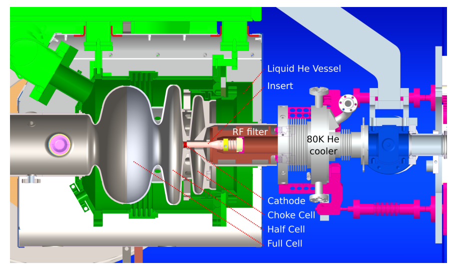

Figure 1: Cross section of the SRF photoinjector showing the cavity geometry together with the cathode section [5].

Thermal Load Estimation

Simulations by A. Neumann (HZB Institute of SRF - science and technology) have been carried out to determine the heat load on the cathode plug from RF-power losses inside the gun module. It has been found, that if the cathode position is about 1 mm behind the back wall, losses of about 5 W can be expected. During operation of the photoinjector the photocathode is illuminated with a 515 nm photocathode laser. For the 100 mA high current goal of bERLinPro and an assumed photocathode quantum efficiency of about 1%, a laser power of 25 W is needed. In total a heat load of about 30 W was estimated for the high current scenario with a retracted photocathode.

THERMAL CONTACT EXPERIMENT

Based on the design of the SRF-photoinjector shown in Fig. 1 a test experiment has been set up to study the thermal contacts in Fig. 2.

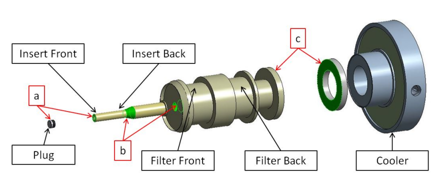

Figure 2: Three interfaces: a - plug/insert, b - insert/RF-filter, c - RF-filter/cooler.

In this experiment a modified cooling unit for liquid nitrogen has been used because of the easier handling in the

* julius.kuehn@helmholtz-berlin.de

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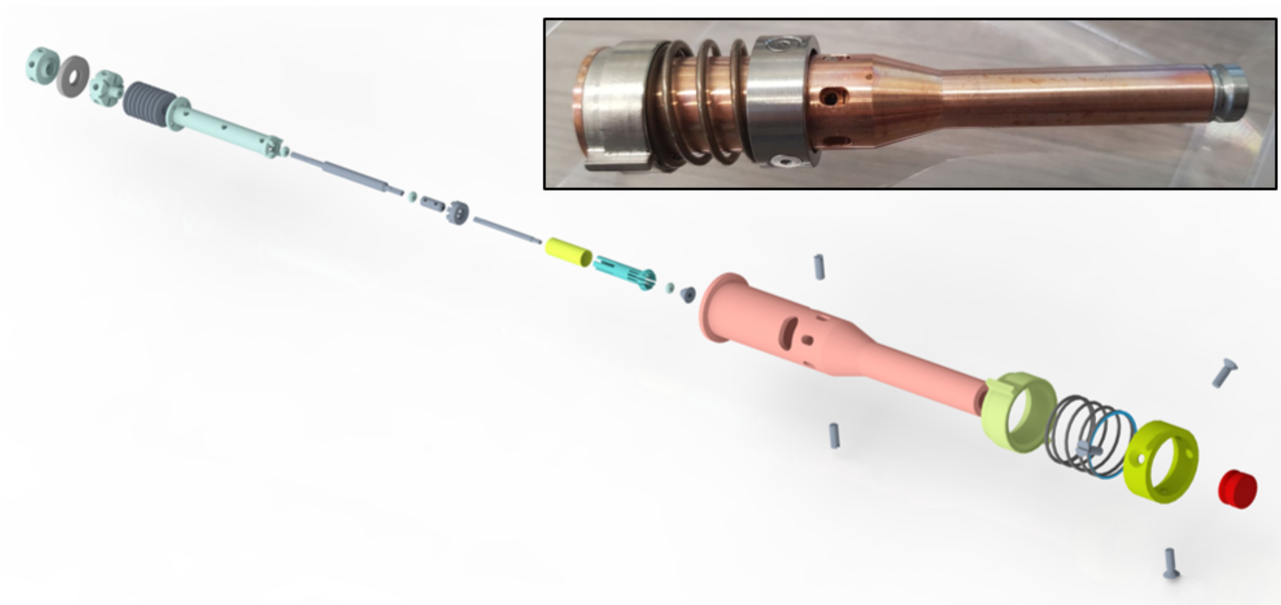

Figure 3: A photograph of the assembled 7111 cathode insert for the SRF photoinjector and the exploded drawing.

laboratory compared to the 80K gaseous helium cooling system which is integrated in the cryo feedbox of the gun module.

Photocathode Insert

The design of the bERLinPro photocathode insert is based on the development for the SRF photoinjector operated at HZDR-ELBE facility. In Fig. 3 an assembled insert is shown together with it exploded view. The outer shape is the same as at HZDR, but for the plug holding and exchange mechanism the inside is more complex. For instance the force of the spring plates has do be carefully adjusted to achieve on one hand good thermal contact of the plug on the insert and on the other hand the release of the plug the the manipulator of the cathode exchange system has to work smoothly.

Experimental Setup

In Fig. 4 the 3D drawing of the experimental configuration is shown. Compared to the photoinjector cold string the cooling is done by filling the cooler with liquid nitrogen. In total eight PT100 sensors are used to measure the temperature at the plug, on the cathode insert, the RF-filter and at the cooler. The sensors were mounted as close as possible next to the interfaces. In this configuration it is possible to study the thermal gradient in detail from the plug to the cooler when the system is heated. A plug-adapter has been used for a Lake Shore 100 W cartridge heater. The motion of the insert due to cooling and heating has been observed with a distance sensor (Micro-Epsilon capaNCDT6200) mounted in front of the insert. In Fig. 5 a photograph of TCX-setup is shown on the left. In the center there is an image showing the experiment inside the vacuum vessel and the photograph on the right shows the distance sensor. An example for the measurement is presented in Fig 6. The colored lines represent the signals for the temperature sensors and the black line shows the signal from the distance sensor. In this experiment the power of the heater was raised to about 30 W after the system was cooled down. One can clearly follow the motion when the system is cooled down and that the insert moves when it gets warm. The insert motion is reversible when the system is cooled down again.

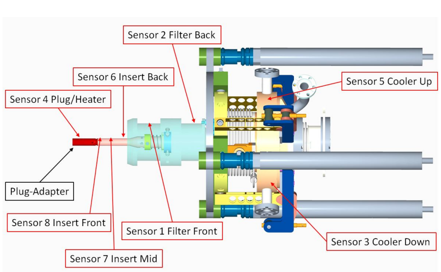

Figure 4: 3D-drawing of the thermal contact experiment.

RESULTS

In this study we tested two inserts (7110 and 7111) and two RF-Filters (Gun1 and TCX) with each other and tried to tune the thermal contact with the force of the bayonet spring and the plate springs inside the insert. The design of 7110 and 7111 is similar. The Gun1 RF-Filter was part of the cold string during the SRF-photoinjector commissioning with a copper photocathode plug and the TCX RF-Filter was the spare part that we had in house. Both inserts were manufactured with respect to the angle of the cone of the RF-filter.

In Fig. 7 the plug temperature is plotted for different power values in order determine the limit of each insert/RF-filter combination. For this experiment the room temperature was set as the limit for the final plug temperature. We found that

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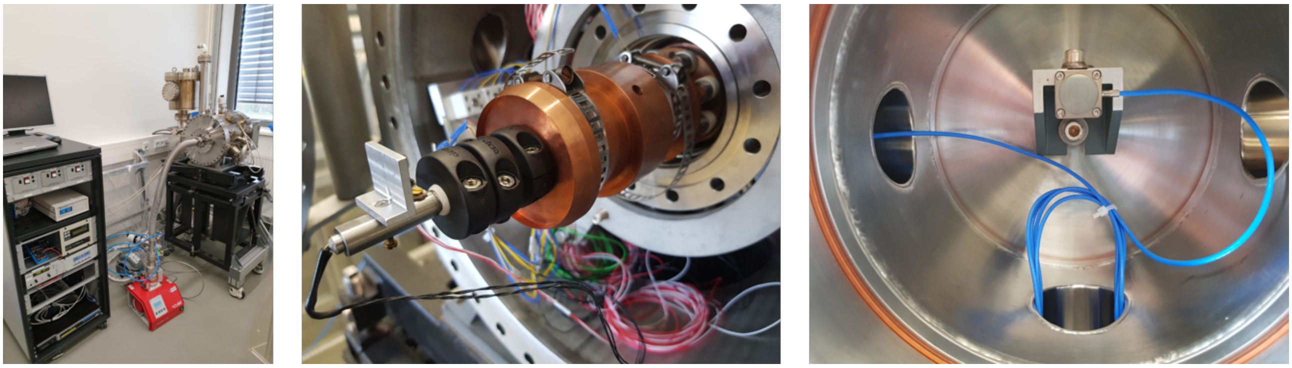

Figure 5: Overview of the TCX-setup: (left) Vacuum chamber, (center) Insert inside the RF-filter with heater and sensors and position marker for distance measurement, (right) distance sensor.

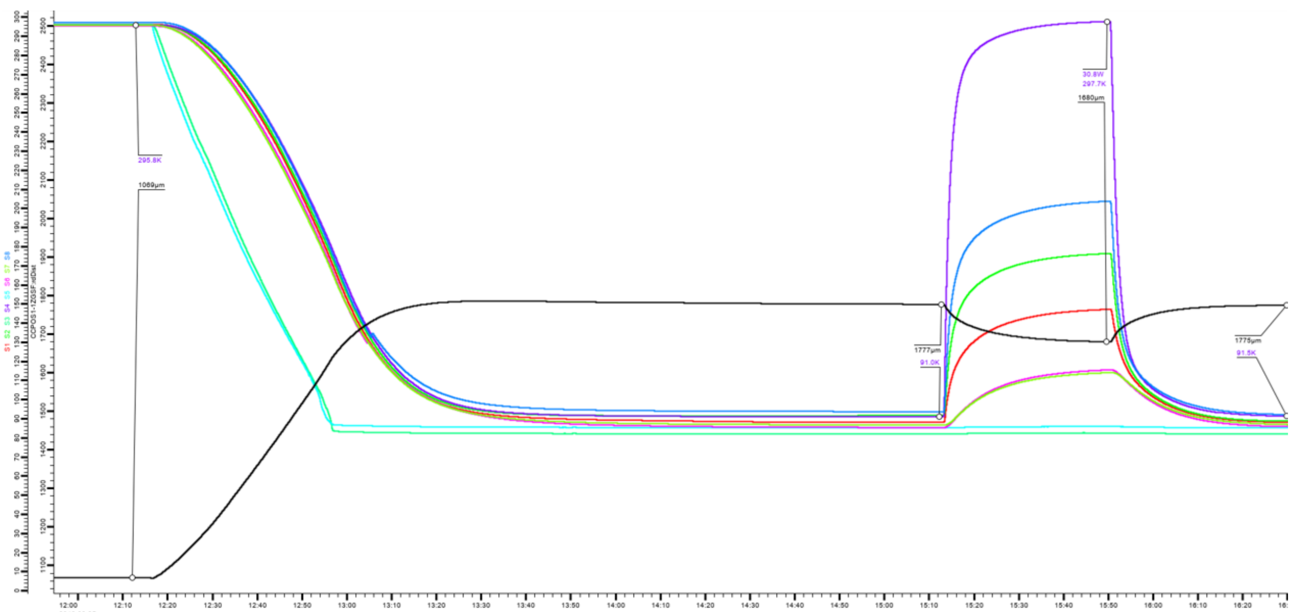

Figure 6: An example plot of the thermal contact measurement procedure. First the experiment is cooled down with liquid nitrogen until the equilibrium is reached. The movement of the cathode insert can be followed via the signal from the distance sensor (black). After the equilibrium is reached, the power of the heater was raised until room temperature is reached at the plug, which also causes movement in the opposite direction.

a heat load about 30 W is necessary to heat the plug up to room temperature and this is similar for all insert/RF-filter combinations.

Heat Transfer Coefficients

Based on the temperature differences at each interface for different power levels the heat transfer coefficients were calculated for each transition. The heat transfer coefficients for the configurations shown in Fig. 7 are plotted in Fig. 8. Even if the observed plug temperatures are similar the heat transfer coefficients for the plug/insert interface differ from about 6500 W/Km^2 up to 9900 W/Km^2.

Insert Motion

In Fig. 9 the insert motion measured with the distance sensor is plotted depending on different power levels. It was observed, that the insert moves reversible when it is heated and cooled. In total the insert has moved about 100 μm when a heat load of about 30 W was applied. With respect to

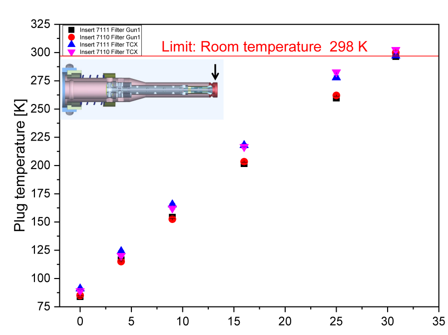

Figure 7: Different plug temperatures at different powers for two inserts and two RF-filters.

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the cathode position inside the photoinjector the plug moves towards the cavity back wall when it gets warm.

Identification of Pairing

For safety reasons an additionally 20% offset was defined which results in an acceptable heat load of 25 W inside the gun for the photocathode plug. After finishing all tests in the configuration as the insert has been used inside the gun with respect to the plate springs and the bayonet springs. In order to lower the temperature at the plug when 25 W heat load are applied the forces of the plate springs (TF) and of the bayonet spring (D) were increased. Fig. 10 shows the results of varying the plate springs and the bayonet spring for the inserts 7110. It was observed that for insert 7110 and 7111 the temperature at the plug was the lowest in the Gun1 RF-filter (about 260 K at 25 W). Insert 7110 could be optimized by using the D252 bayonet spring (2.52 N/mm) and a plate spring package with a force of 103 N to achieve a similar low temperature in the the TCX-RF-filter as in the Gun1 RF-filter with the D172 bayonet spring and a plate spring package force of 80 N.

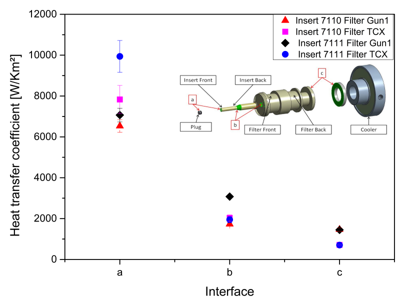

Figure 8: Heat transfer coefficients calculated for each thermal contact.

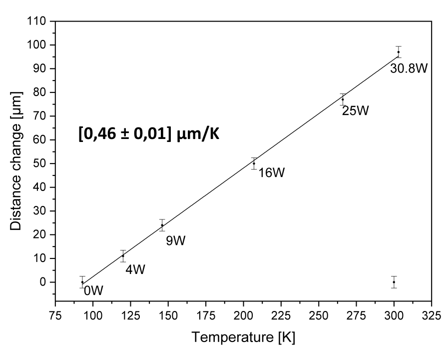

Figure 9: Movement of the insert with increasing thermal load.

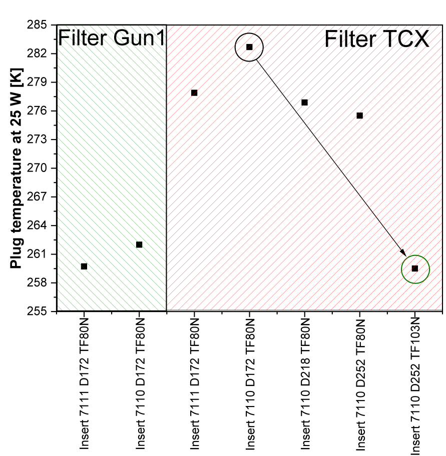

Figure 10: Overview of the tested components with different spring configurations for a heat load of 25 W with respect to the plug temperature.

CONCLUSION

Based on our measurements we can narrow down the working window for the SRF photoinjector with respect to laser power and RF power losses to avoid the overheating of the cathode insert and loss of the semiconductor cathode. The cathode insert in its latest design can handle a thermal load of about 30 W and the plug exchange mechanism is still working after several iterations of heating and cooling. With the goal of operating bERLinPro in the first stage at a lower current, we expect that we can use the cathode insert without any damage due to operation and harm for the gun cavity. We are planning to pursue the experiments with the 80 K He(g) cooling system to get closer to the operating conditions of the SRF photoinjector. This experiment helps us to optimize our cathode section components after manufacturing in more detail.

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