# IMPROVEMENT OF PHOTOEMISSION EFFICIENCY OF MAGNESIUM PHOTOCATHODES

R. Xiang†, A. Arnold, P. Michel, P. Murcek, J. Teichert, HZDR, 01328 Dresden, Germany
P. Lu, H. Vennekate, TU Dresden & HZDR, 01328 Dresden, Germany
P. Patra, IUAC, New Delhi, 110067 India

*Abstract*

To improve the quality of photocathodes is one of the critical issues in enhancing the stability and reliability of photo-injector systems. Presently the primary choice is to use metallic photocathodes for the ELBE SRF Gun II to reduce the risk of contamination of the superconducting cavity. Magnesium has a low work function (3.6 eV) and shows high quantum efficiency (QE) up to 0.3 % after laser cleaning. The SRF Gun II with an Mg photocathode has successfully provided electron beam for ELBE users. However, the present cleaning process with a high intensity laser (activation) is time consuming and generates unwanted surface roughness. This paper presents the investigation of alternative surface cleaning procedures, such as thermal treatment. The QE and topography of Mg samples after treatment are reported.

## INTRODUCTION

SRF Gun II has been installed at the HZDR ELBE radiation center since May 2014 [1]. The main design was based on SRF Gun I [2], but with a modified 1.3 GHz Nb cavity [3] and a superconducting solenoid at the cavity exit [4]. The commissioning phase with a copper cathode was very successfully, delivering about 0.2 pC / bunch at 100 kHz repetition rate for first beam experiments.

As well known, the quality of photocathodes is a key part to improve the stability and reliability of the photoinjectors [5]. For ELBE SRF gun II, semiconductor phtocathode $Cs_2Te$, metal cathodes copper and magnesium are chosen as photocathode materials. Driven with UV laser $Cs_2Te$ (with band gap 3.3 eV + electron affinity 0.2 eV) has shown good QE and long life time in the SRF gun I. The work function of copper (4.6 eV) is much higher, so its QE of $1\times10^{-5}$ is too low for the regular beam production. Magnesium is a metal with low work function of 3.6 eV and its QE can be much higher than copper. Although it has lower QE than $Cs_2Te$, Mg has the advantage of long life time, reliable compatibility, good QE and little risk of contamination to niobium cavity.

## Mg CATHODES IN SRF GUN II

Two Mg photocathodes have stably worked in SRF Gun II to provide moderate CW beam for ELBE radiation centre. Figure 1 shows the Mg cathode in the SRF gun cavity. The bright ring is the opening of cathode hole on the cavity back wall, and inside this ring is the plug with spots induced by laser cleaning.

The photoemission of Mg cathode in the SRF gun is dominated by space charge and Schottky effect. Figure 2 plots the extracted photoelectron bunch charge as the function of the launch phase (gun phase). In the case of low bunch charge, the Schottky effect plays the main role, and the bunch charge is ascending in the plateau range. But with increased laser pulse energy, the space charge effect becomes stronger in the photoemission process.

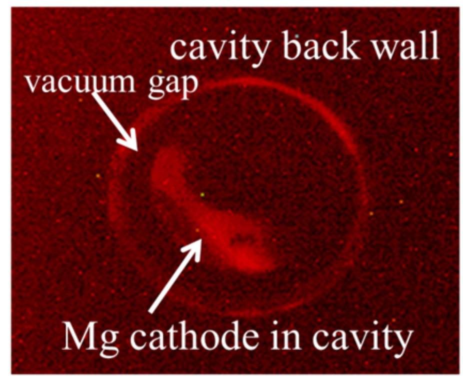


Figure 1: The image of Mg photocathode inserted into the cavity back wall. The bright circle is the opening of cathode hole, and inside this ring is the plug with spots induced by laser cleaning.

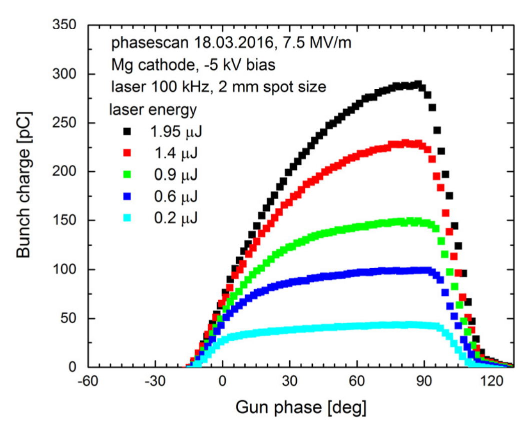


Figure 2: Bunch charge as the function of SRF gun phase.

Cathode position related to niobium cavity is able to be tuned in-situ to optimize the beam emittance. However, during this process the rf field on cathode plug changes according to the distance between the cathode plug surface and the cavity opening. Unexpected field emission appeared after one experiment with cathode tuning. Figure 3 plots the dark current measurement in SRF gun with Mg photocathode, which shows obvious increase after the tuning test, and the effect of the cathode bias. The as-

† email address: r.xiang@hzdr.de

sumption is that either there are new field emitters from Mg cathode to cavity or there are old field emitters on cavity activated by the cathode movement.

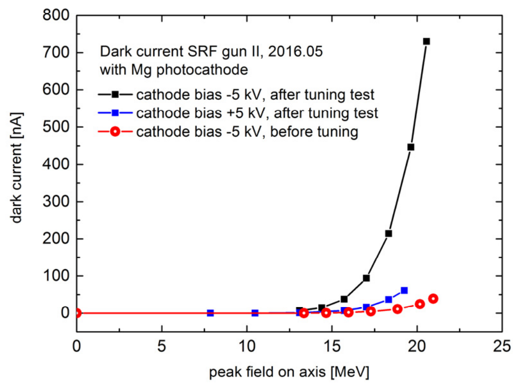


Figure 3: Dark current from the ELBE SRF gun II with Mg cathode.

## LASER CLEANING

Our Mg cathode is a Φ 10 mm bulk plug of pure magnesium. The plug was mirror-like polished with different sizes of diamond compound. Subsequently the polished cathode with a mean roughness of ca. 10 nm was de-oxide, cleaned and installed into the cathode transport chamber, where cathodes are be stored for further treatment.

Because after the chemical de-oxide process, the Mg plugs are shortly exposed in air, the QE of new Mg cathode was only $1.8\times10^{-5}$ in our measurement. In order to reach clean Mg surface and reduce the surface work function, treatments in vacuum have to been performed.

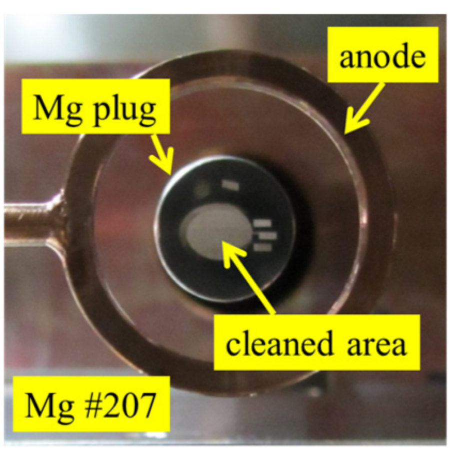


Figure 4: Photo of Mg photocathode #207 in transport chamber. This cathode has been cleaned for three times and used in gun twice for beam production.

Photocathode drive laser has been used to burn off the MgO insulator layer in transport chamber. In Fig. 4 the ellipse area in the centre of plug was produced with the laser cleaning. For this purpose, quartz windows and feedthrough were installed at the transport chamber. The gun laser was focused and guided into the transport chamber and scanned in the center of Mg surface.

The laser has a wavelength of 258 nm (4.8 eV), a repetition rate of 100 kHz and short pulses of 10 ps. For the cleaning, the mean power was set to 100 mW. With a movable focusing lens the laser spot size on the cathode could be accurately adjusted down to a radius of 30 µm which results in an intensity of 2 W/mm$^2$ for optimal cleaning. After the proper cleaning process, the fresh QE reached 0.3 %. After inserted into SRF gun, the Mg cathode was measured again, and the QE reached 0.1 % with a field of 11 MV/m on cathode surface.

The cleaned surface has a shining silver color, and the microscope view demonstrates the surface structure change (as shown in Fig. 5). The virgin part is the polished mirror-like surface while the cleaned part shows period wave structure induced by the scanned laser beam.

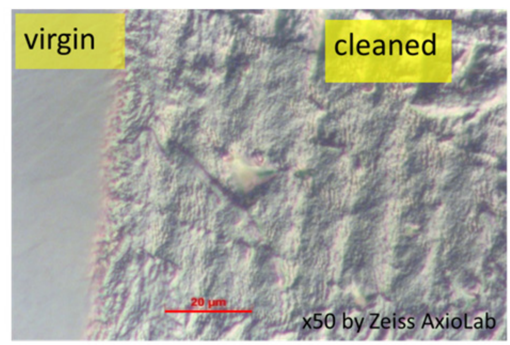


Figure 5: Surface structure changes after cleaned with high intensity laser.

The cleaning process can be very well repeated. Mg photocathode #207 has been cleaned for three times and QE increased by 2-3 orders. Cleaned Mg is very sensitive. It kept stable in transport chamber (with $10^{-9}$ mbar vacuum) and also during the SRF gun operation. Another experiment showed cleaned Mg cathode in $10^{-8}$ mbar vacuum lost 60 % of its QE in one day.

## HEAT TREATMENT

From Fig. 5 one can find the obvious roughness increase after cleaning with high intensity laser beam. This roughness will induce higher thermal emittance for the photoelectrons, which defines the best emittance a photo injector can finally reach. At HZDR new clean methods are under investigation, to reduce the work function of Mg cathode and to keep the surface smooth as polished.

For this purpose, a test stand has been built, in which a piece of Mg sample is fixed on a holder made of oxygen free copper, heated by a 100 W halogen light from back side. The holder is isolated to the chamber and has a biased-anode in front of it, which can be loaded up to 1 kV voltage. The 260 nm UV light from LED illuminates the sample through a quartz window, and the photocurrent is detected with a Keithley Picoampere-meter. For the first tests, only a turbo pump was used to evacuate the chamber to $1\times10^{-7}$ mbar.


ISBN 978-3-95450-182-3

Figure 6 shows the result of the heat cleaning performed on a commercial mono-crystalline Mg sample, 2 mm thick with one side polished. The temperature was measured with a K-sensor close to the quartz bulb of Halogen light, between the sample holder and light source. At beginning normal surface degassing resulted in a low and very slowly rising photocurrent. After the sample was continuously heated for one hour, the photocurrent increased quickly, in the following hour QE was enhanced from $10^{-5}$ to $10^{-3}$. After heating the temperature dropped down sharply but the QE kept rising at the first minutes and then degraded exponentially, which was due to the bad vacuum in the chamber.

As well known, metal Mg starts to evaporate in vacuum at temperature lower than 400°C, but in this experiment, the obvious evaporation of Mg was found only at the end of the heating phase, nearly after two hours of continuous heating about 400°C. This might be explained that the sample was covered by MgO layer, which prevented evaporation at beginning. However during the heating process O defuses slowly into the bulk Mg and leaves more Mg on surface, so the work function on surface reduces slowly till it is lower than 4.8 eV, then the QE increases in short time to $10^{-3}$, the reported QE of pure Mg [6]. At the same time, strong evaporation from Mg surface starts appear.

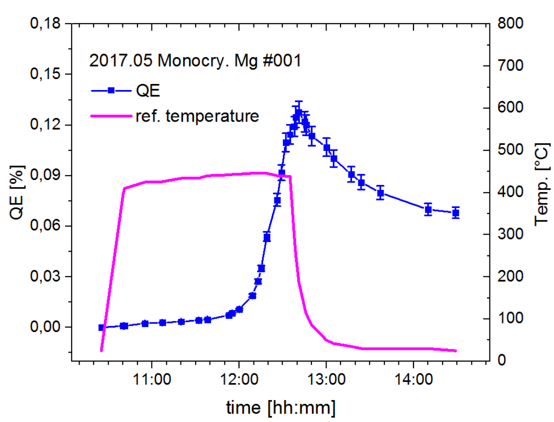


Figure 6: The result of heat cleaning for a commercial mono-crystal Mg sample, 1 mm thick with one side polished. 260 nm UV light was used for the QE measurement, and temperature was not the real sample temperature, but only a reference for this test stand.

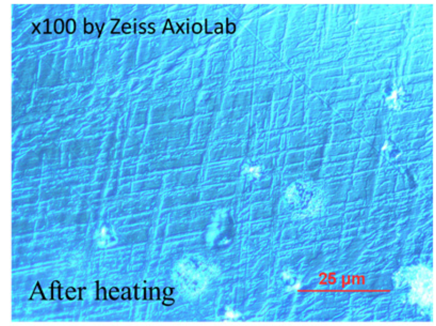


Figure 7: the topography of mono-crystal Mg sample soon after heat treatment (already exposed in air).

The fresh surface after heat cleaning was mirror-like, and the topography of the sample was recorded with microscope before and soon after the heat treatment (as shown in Fig. 7). After exposed in air for one day, tiny dark spots appeared on the surface.

Another method, to use ion beam bombardment, is being planned for Mg cathode cleaning as well. Compared to heat treatment, the cleaned area can be well controllable.

## CONCLUSION

The metallic photocathodes provide another alternative to semiconductor photocathodes for SRF guns, especially Mg cathode for medium bunch charge application. From our experience, Mg cathode is safe for the niobium cavity and can produce up to 300 pC bunch charge.

Two different cleaning methods on Mg cathodes are reported in this work. Laser cleaning produces QE as high as 0.3 %, but it induces rough surface on the cathodes. Heat cleaning is developed to improve the QE to 0.1 % and at the same time keep surface homogeneous and smooth. Further studies will be performed to modify this heat treatment in view of surface physics and material characters during the process.

## ACKNOWLEDGEMENT

We would like to thank the whole ELBE team for their help and assistance with this project. The work is supported by the European Community under the FP7 programme (EuCARD-2, contract number 312453, and LA3NET, contract number 289191) and by the German Federal Ministry of Education and Research (BMBF) grant 05K12CR1.

## REFERENCES

[1] J. Teichert et al., in Proc. FEL'14, pp. 881-884.
[2] A. Arnold, Nucl. Instr. Meth. A 93 (2008) 57.
[3] A. Arnold et al., in Proc. LINAC'14, pp. 578-580.
[4] H. Vennekate et al., in Proc. SRF'15, 13.-18.10.2015, pp. 1235-1239.
[5] R. Xiang, J. Teichert, Physics Procedia 77 (2015), pp. 58-65.
[6] R.A. Loch, Master Thesis, Univ. of Twente, 200.