METAL AND SEMICONDUCTOR PHOTOCATHODES IN HZDR SRF GUN

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Abstract

Quality of photocathode in a photoinjector is one of the critical issues for the stability and reliability of the whole accelerator facility. In April 2013, the IR FEL lasing was demonstrated for the first time with the electron beam from the SRF gun with Cs_2Te at HZDR. Cs_2Te photocathode worked in SRF gun-I for more than one year without degradation. Currently, Mg photocathodes with QE up to 0.5% are applied in SRF Gun-II, generating CW beams with bunch charge up to 300 pC and sub-ps bunch length for the high power THz radiation. It is an excellent demonstration that SRF guns can work reliably in a high power user facility.

INTRODUCTION

As well known, the quality of photocathodes is a key part to improve the stability and reliability of the photoinjectors [5]. For SRF guns at HZDR, metal cathodes (copper, magnesium) and semiconductor phtocathode (Cs_2Te) are chosen as photocathode materials.

Copper is used as commissioning cathode in SRF Gun-II. But the work function of Cu (4.6 eV) is rather high and its QE of 1×10^{-5} at 260 nm is too low for the regular beam production. Magnesium is a metal with low work function of 3.6 eV, and its QE can reach 0.5% after ps UV laser cleaning. 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.

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. After we solve the problems of field emission and overheating during the last tests of Cs_2Te on Mo in SRF gun-II, it will be applied again with Cu substratum for the medium current generation.

MG CATHODES IN SRF GUN II

There are two Mg photocathodes have stably worked in SRF Gun II to provide moderate CW beam for ELBE radiation center. 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 effect and Schottky effect. Fig. 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.

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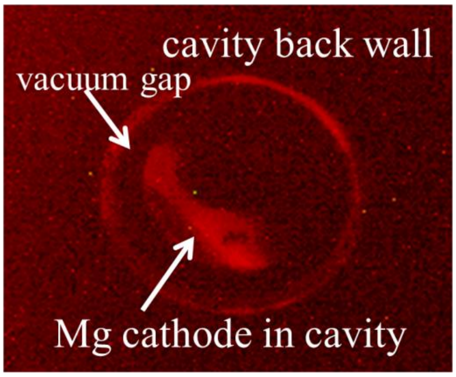

Figure 1: The image of Mg photocathode inserted into the cavity back wall. The bright circle is the opening of cathode hole, and inside this ring is the plug with spots induced by laser cleaning.

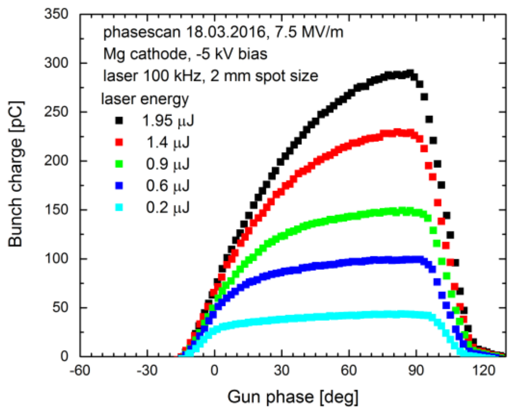

Figure 2: Bunch charge as the function of SRF gun phase.

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. Fig. 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 assumption 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.

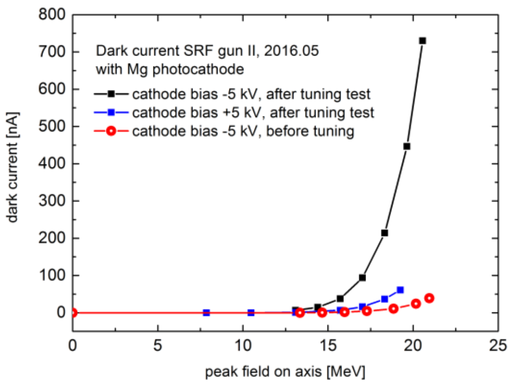

Figure 3: Dark current from the ELBE SRF gun II with Mg cathode.

LASER CLEANING

Our Mg cathode is a Φ 10 mm bulk plug of pure magnesium. The plug was mirror-like polished with different sizes diamond compound. And the polished cathode with a mean roughness of ca. 10 nm was de-oxided and cleaned, then installed in the cathode transport chamber, where cathodes can be stored and further treated.

Because after the chemical de-oxide process, the Mg plugs are shortly exposed in air, the QE of new Mg cathode was only 1.8×10^{-5} in our measurement. In order to reach clean Mg surface and reduce the surface work function, treatments in vacuum have to been performed.

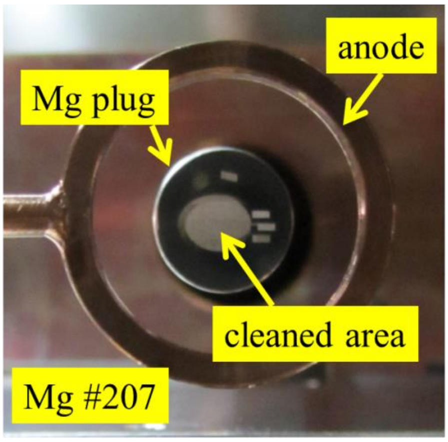

Figure 4: Photo of Mg photocathode #207 in transport chamber. This cathode has been cleaned for three times and used in gun twice for beam production.

Photocathode drive Laser has been used to burn off the MgO insulator layer in transport chamber. In fig. 4 in the center of plug an ellipse area was produced with laser cleaning. For this purpose, quartz windows and feed-through 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 is a UV laser with 263 nm (4.7 eV) wavelength, repetition rate of 100 kHz and ultra-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 30 μm radius. The power intensity of 2 W/mm^2 was found the best for cleaning. After the proper cleaning process, the fresh QE reached 0.3 %. After inserted into SRF gun, the Mg cathode was measured again, and QE in the SRF gun at a field of 11 MV/m can reach 0.1 %.

The cleaned surface has a shining silver color. Also the microscope view demonstrated the surface structure change (fig. 5). Virgin part is the polished mirror-like surface, and the cleaned part shows period wave structure induced by the scanned laser beam.

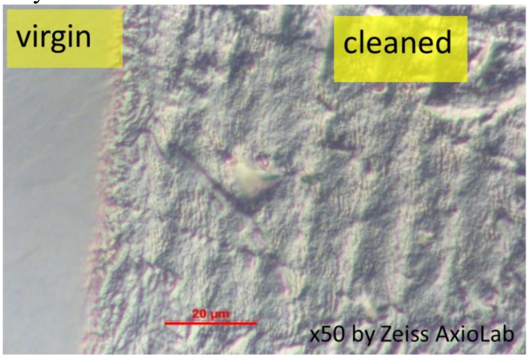

Figure 5: surface structure changes after cleaned with high intensity laser.

The cleaning process can be very well repeated. Mg photocathode #207 has been cleaned for three times and QE increased 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 photoinjector can finally reach. At HZDR new clean methods are under study, to reduce the work function of Mg cathode and to keep the surface smooth as polished.

A test stand has been built here for this purpose. A piece of Mg sample is fixed on an oxygen free copper holder, heated by a 100W halogen light from back side. The holder is isolated to the chamber, with a biased-anode in front, on which up to 1 kV voltage can be loaded. The 260nm 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 1×10^{-7} mbar.

Fig. 6 shows the result of heat cleaning performed on a commercial mono-crystal Mg sample, 1 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 the normal surface degassing happened and detectable photocurrent appeared and rose very slowly. 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 stop heating and the temperature dropped sharply down, QE kept rising at the first minutes and then degraded exponentially, which was due to the bad vacuum in the chamber.

Although metal Mg starts to evaporate in vacuum at low temperature, but in this experiment, the obvious evaporation of Mg was found actually at the end of the heating phase, nearly after two hours of continuous heating. This can be explained that the sample was covered by MgO layer, which can not be so easily removed from the surface. Probably 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 4.7 eV, then the QE increases in short time to 10^{-3}, the reported QE of pure Mg [8]. At the same time, strong evaporation from Mg surface starts appear.

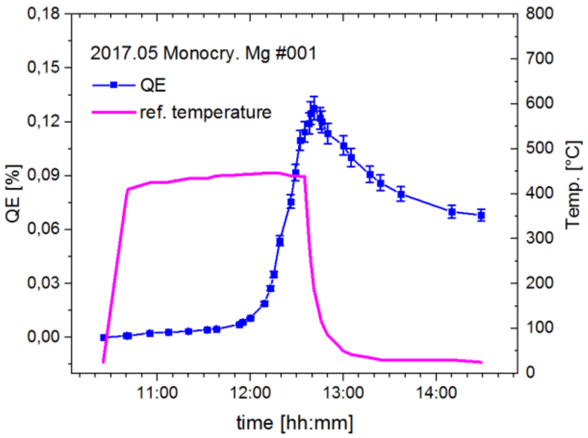

Figure 6: the result of heat cleaning for a commercial mono-crystal Mg sample, 1 mm thick with one side polished. 260 nm UV light was used for the QE measurement, and temperature was not the real sample temperature, but only a reference for this test stand.

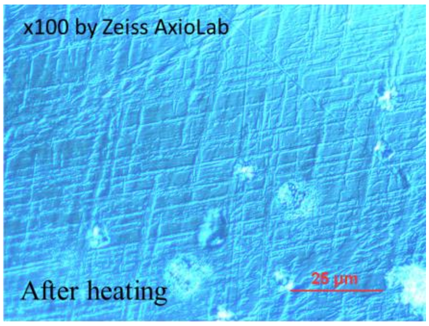

Figure 7: the topography of mono-crystal Mg sample soon after heating treatment (already exposed in air).

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

Another method, to use ion beam back bombardment, has also been planed for Mg cathode cleaning. Compared to the heat treatment, with ion cleaning method the cleaned area can be well controlled.

CONCLUSION

The metallic photocathodes provide us 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 then 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

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