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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 [1]. 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. For SRF guns at HZDR, metal cathodes (copper, magnesium) and semiconductor photocathode (Cs_2Te) are chosen as photocathode materials.

The design is shown in the Fig. 1. The metal plug (ϕ 10mm, 7 mm long) can be photoemission material or the substratum with a deposited photoemission layer. The copper stem is used to cool down the plug to LN2 temperature, which is realized by cotact the conus area to a liquid N2 reservoir. The bayonet and spring can fix the cathode body on to the cold reservoir. The whole cathode is isolated to the SRF cavity, so that a bias can be loaded on the cathode to suppress the multipacting around cathode stem or reduce the dark current from the cathode [2].

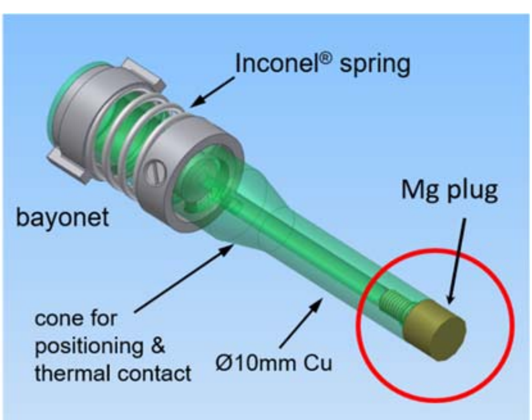

Figure 1: Design of photocathode in the SRF gun II.

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.

CU CATHODE IN SRF GUN II

During the assembling of SRF gun cavity in the cleanroom, an oxygen free copper plug was installed in the cavity. The copper plug had been polished with diamond suspension, and then cleaned with alcohol in ultrasonic bath. Figure 2 is the photo of this copper cathode after use. The pattern on surface is believed from the flash during the rf commissioning.

Figure 2: The copper cathode after used in the SRF gun II. A radius of 0.3mm is used to reduce the field enhancement on the sharp edge. The pattern on surface is believed from the flash during the rf commissioning.

This Cu cathode helped to finish the successful commissioning for first beam [3]. There was no obvious multipacting problem with copper cathode. The maximum field on cathode surface is 14.6 MV/m, and the dark current from cathode was 53 nA. Difference parameters of SRF gun were measured with this cathode. A low transverse emittance of 0.4 mm·mrad for 1 pC bunch charge was achieved with this cathode.

Copper cathode is proved being safe for SRF gun. 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.

MG CATHODES IN SRF GUN II

As metallic photocathode, Mg is a safe choice for SRF gun. There have been several Mg photocathodes stably working in SRF Gun II since 2016. Figure 3 shows the QE measurement of the Mg #216 in the SRF gun II. A record

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QE of 0.5% is achieved with this cathode. The photoemission of Mg cathode in the SRF gun is dominated by space charge effect and Schottky effect. Fig. 4 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.

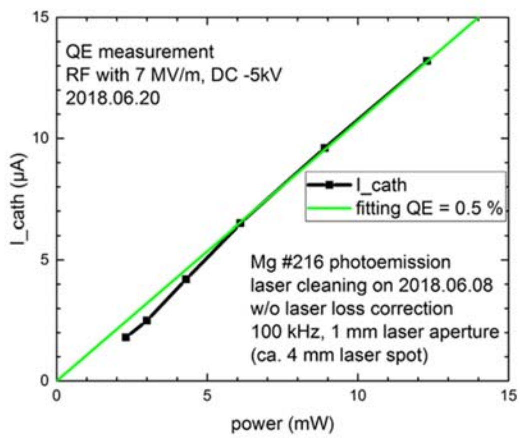

Figure 3: The image of Mg photocathode inserted into the cavity back wall. The bright circle is the opening of cathode hole, and inside this ring is the plug with spots induced by laser cleaning.

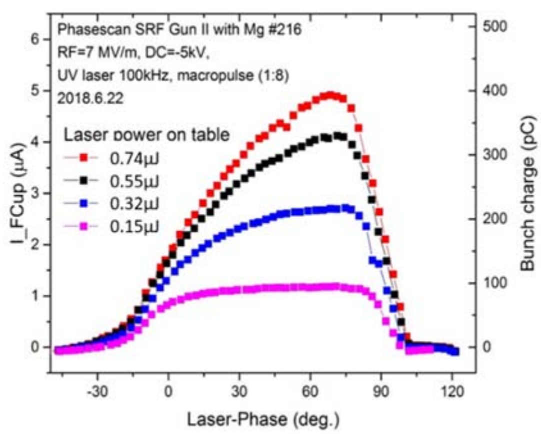

Figure 4: Bunch charge versus laser arriving phase. Max. bunch charge can reach 400 pC.

A key technology for good Mg cathode is the laser cleaning. The 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, cleaned and blown with filled N2, then installed in the cathode transport chamber, where cathodes can be laser cleaned and stored.

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.

Photocathode drive Laser has been used to burn off the MgO insulator layer in transport chamber. The laser is a UV laser with 263 nm (4.7 eV) wavelength, repetition rate of 100 kHz and ultra-short pulses of 3 ps. For the cleaning, the mean power was set to 100 mW. With a movable focusing lens the laser spot size on the cathode can be accurately adjusted down to 30 μm radius. The power intensity of 2 W/mm^2 was found the best for cleaning. 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 [4].

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

The cleaning process can be very well repeated, and one Mg photocathode is possible to be cleaned for several times. Figure 6 shows the results of the QE measured in transport chamber with DC bias. Cleaned Mg is very sensitive. It kept stable in transport chamber (with 10^{-10} mbar vacuum) and also during the SRF gun operation. Another experiment showed that cleaned a Mg cathode in 10^{-8} mbar vacuum lost 60% of its QE in one day.

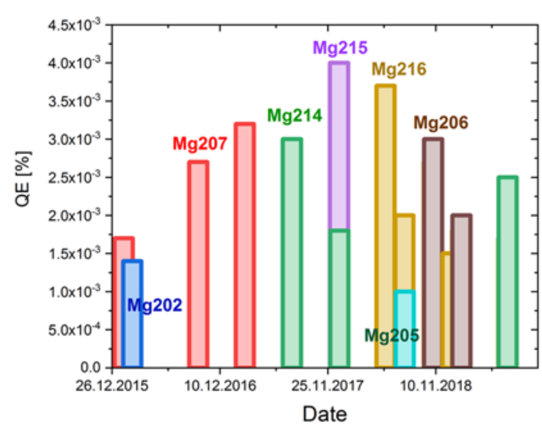

Figure 6: The statistic of the Mg cathodes at HZDR. Measured with DC bias in transport chamber.

Cs_2Te PHOTOCATHODES

HZDR has long history of preparing Cs_2Te [5]. For the Cs_2Te cathode, the plug in Fig. 1 is changed to Molybdenum, and Cs_2Te is deposited on the tip of Mo plug, which is screwed on the cathode body.

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Up to now more than 40 Cs_2Te photo cathodes have-been produced at HZDR photocathode laboratory. The typical QE of the fresh cathodes are from 8% to 15%. Before 2014, there were 8 cathodes ever worked in the SRF gun I. The QEs in the gun are normally about 1%, and the life time can be months. For example, cathode #17.04.2012 Cs_2Te had fresh QE of 8.5%, and the QE dropped down to 0.6% after it was transferred to gun. Nevertheless, it provided beam time more than 2100 h ours, totally extracted charge more than 264 C.

However, in 2016 we tried twice Cs_2Te photocathodes in SRF gun II. Both cathodes ran well in the first two weeks and delieved good beams. But then the cathode lost QE suddenly. At the same time, the field emission from cavity increased dramatically and camera showed the Cs_2Te layer disappeared, which means the temperature of plug surface was over 300ºC at that moment (see Fig.7). The shift of resonant frequency of cavity also gave clue that the cathode position changed in those events.

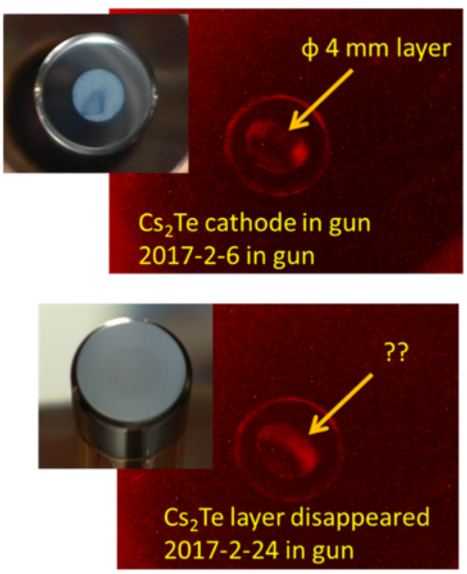

Figure 7: One Cs_2Te cathode lost film in the SRF gun-II due to overheating. Top: the Mo plug with Cs_2Te layer in center. Bottom: the layer disappeared in the gun and lost photoemission.

A systematic study has been performed since 2016. Through CST simulation and experiments on test bench, the main reason the screw connection method between the Mo plug and Cu stem, which have different thermal expansion coefficient (Cu: 16 m/(m·K), Mo: 5 m/(m·K),). During the cathode preparation, the cathodes were heated up to 400ºC for surface cleaning and 120ºC for deposition. And the same cathodes were cooled down to LN2 temperature in SRF gun. This temperature difference makes big deformation of the thread structure, leading the bad thermal transfer from plug to copper cooling body.

One solution to solve the thermal problem is to use the same materials for the plug and cathode stem. So the next Cs_2Te will be deposited on Cu instead of Mo substratum.

CONCLUSION

The metallic photocathodes provide us a safe solution 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. Laser cleaning produces QE as high as 0.5 %, but it induces rough surface on the cathodes.

For high bunch charge and high current operation, Cs_2Te photocathode will be used in SRF Gun II. The next step is to demonstrate the deposition of Cs_2Te on copper plug and finally to provide a safe semiconductor photocathode for SRF Gun II at HZDR.

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