HIGHLIGHTS ON METALLIC PHOTOCATHODES USED IN SRF GUN

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Abstract

For the accelerator-based light sources and the electron colliders, the development of photoinjectors has become a key technology. Especially for the superconducting radio frequency cavity based injector (SRF Gun), the searching for better photocathodes is always a principal technical challenge. To use metallic photocathodes for ELBE SRF Gun is the primary choice to prevent cavity contamination. In this contribution, we will report the investigation of Magnesium (Mg) in ELBE SRF gun, including laser cleaning treatment and the measurement on quantum efficiency, Schottky effect, dark current and damage threshold.

INTRODUCTION

The development of top quality photocathode electron guns has become one of the key technologies for modern light sources and large collider facilities based on electron accelerators.

At the HZDR ELBE radiation center the SRF Gun-II was installed in May 2014 [1]. The 1.3 GHz cavity of fine grain niobium [2] and the superconducting solenoid are its key points [3]. During the installation, a copper cathode was mounted in the cavity. And all of the gun commissioning activities were performed with this copper cathode [4], which had very low quantum efficient (QE), but provided about 0.2 pC / bunch at 100 kHz repetition rate for the first beam experiments. The kinetic energy of CW beam electrons was 4 MV/m with E_{acc} of 8 MV/m, and the best emittance is about 0.3 µm measured with both slit scan and quadrupole scan.

As well known, the quality of photocathode is critical in improving the stability and reliability of the photoinjector system [5]. Cs_2Te and magnesium are two types of cathode materials for ELBE SRF gun II. Semiconductor photocathode Cs_2Te has shown good QE and long life time in the SRF gun-I [6]. Mg is a metal with low work function of 3.6 eV, similar to that of Cs_2Te. Compared to Cs_2Te, it has the advantage of long life time, reliable compatibility of high rf field, good QE and little risk of contamination to niobium cavity [7]. To use metallic photocathodes for ELBE SRF Gun is the primary choice to prevent the cavity contamination.

MG CATHODE PRODUCTION

Our Mg cathode is an Ø 10 mm bulk plug of pure polycrystalline magnesium. The plug was mirror-like polished with different sizes diamond compound. Care must be taken to assure the plug thickness is 8 mm with an error less than 0.3 mm. The polished cathode with a mean roughness of ca. 10 nm was de-oxided and cleaned, then stored in filtered dry N_2 till installed in the cathode transport chamber, where cathodes can be further treated and stored.

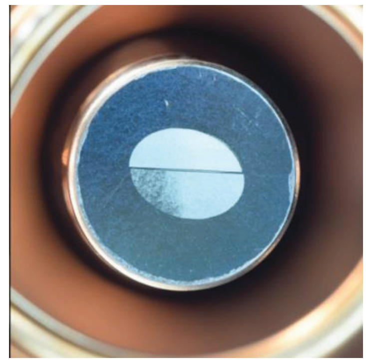

Figure 1: A photo of Mg cathode after laser cleaning.

Even with the chemical de-oxide process, the QE of Mg cathode was only 1.8×10^{-5} in our measurement. Laser has been used to burn off the MgO insulator layer. 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 an Ø 4 mm area in the center of the Mg surface. Fig. 1 shows the Mg cathode surface with the efficiently cleaned area. The cleaned surface had a shining silver color. Also the microscope view demonstrated the surface structure change.

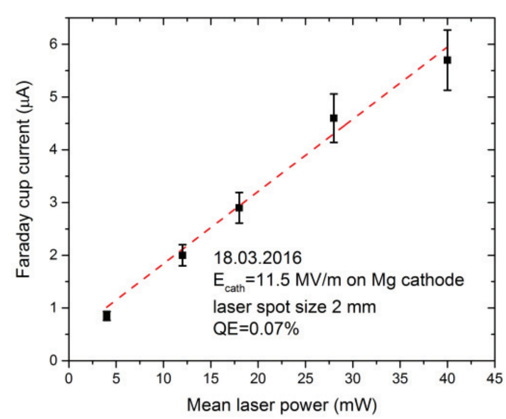

Figure 2: QE measurement for Mg cathode in SRF gun.

The gun laser has the 263 nm (4.7 eV) wavelength, a repetition rate of 100 kHz and ultra-short pulses of 10 ps. During the cleaning, the mean power was set to 100 mW.

With a movable focusing lens the laser spot size on the cathode could be fine adjusted down to 30 μm radius. After a large number of experiments, a threshold of laser power intensity of 2 W/mm^2 was found. Cleaning with laser power below 2 W/mm^2 led to no obvious improvement of QE, and above this threshold surface damage (strong ablation) appeared on the cathode. After a proper cleaning process, the fresh QE reached the level of 10^{-3}. After inserted into SRF gun, the Mg cathode was measured again. Fig 2 presents the QE measurement (0.07%) for the Mg cathode in the SRF gun at a field of 11 MV/m on the cathode.

The cleaning process could be very well repeated. In our experiment, QE of Mg cathode increased 1-2 orders of magnitude because of the removal of the surface MgO insulator layer (high work function 4.2 eV). Besides, the QE improvement could also be benefit from the plasmon enhanced photoemission due to the roughness (nm level) [8]. Cleaned Mg is very sensitive. It kept stable in transport chamber (10^{-9} mbar vacuum) and in the SRF gun operation, but could lose 60% of QE in 10^{-8} mbar vacuum in one day.

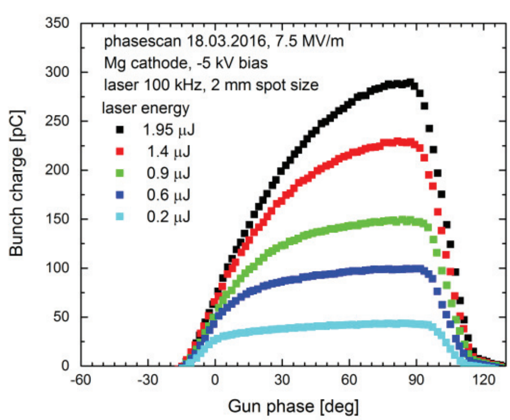

Figure 3: Charge as the function of the SRF gun phase.

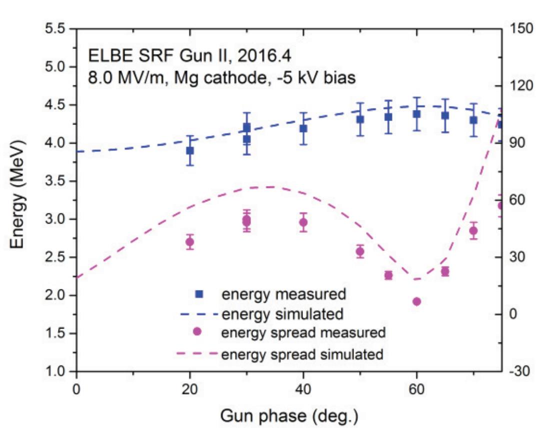

Figure 4: Energy as the function of the SRF gun phase.

MG CATHODE IN SRF GUN

The photoemission of Mg cathode in the SRF gun is dominated by space charge effect and Schottky effect. Fig. 3 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. The energy and energy spread measurement shown in Fig. 4 matches very well to the ASTRA simulation [9].

Besides the enhanced photoemission, the decrease of cathode work function can cause the field emission easier. At the same time, an obvious roughness increase at the cleaning area can also raise the field enhancement factor β. Fig 5 plots the dark current measurement in SRF gun with various metallic photocathode materials. However, it cannot demonstrate laser cleaned Mg has lower field emission although SRF gun with cleaned Mg cathode did produce lower dark current than it with uncleaned Mg cathode. This difference could be explained with another possibility, that the field emission from the cavity itself reduced due to the rf training between the two measurements. More measurements are needed to clear the field emission issue led by the laser cleaning.

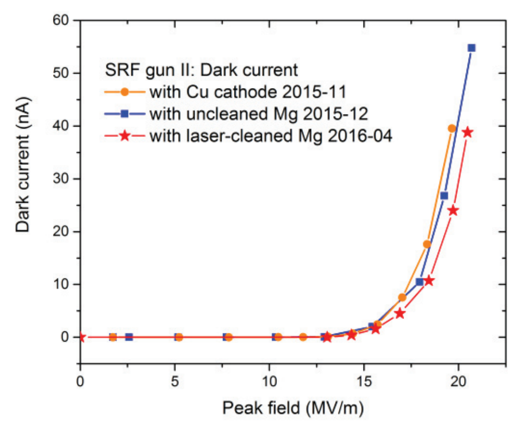

Figure 5: Dark current from the ELBE SRF gun.

Photoemission of Mg photocathode in the rf field belongs to the surface photoemission, thus the laser cleaning reduces the work function and then improve the QE, but the change of work function and surface roughness can also increase the thermal emittance $\varepsilon_{thermal}$, which is the limit of the electron beam emittance of the photoinjector. As reported before, the thermal emittance of Mg cathode is 0.4 - 0.5 mm mrad /r(mm) [7], similar to the theoretical thermal emittance of Cs_2Te of 0.43 mm mrad /r(mm) [10]. As known, for metal cathode, the rf field will affect the $\varepsilon_{thermal}$ through Schottky effect [11]:

$$\frac{\varepsilon_{thermal}}{\sigma_x} = \sqrt{\frac{h\nu - \emptyset_{eff}}{3m_e c^2}}. \quad (1)$$

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$$\emptyset_{eff} = \emptyset_0 - \sqrt{\frac{e^3 \beta E_{cath}}{4\pi\epsilon_0}} \quad (2)$$

where σ_x is the rms laser spot size, hν is the photo energy 4.8eV, ϕ_{eff} and ϕ_0 is the effective and the virgin work function, β is the field enhancement factor and E_{cath} is the e-field on surface. Eq. (1) shows us that the thermal emittance will grow with reduced work function ϕ_{eff}, and Eq. (2) presents the relationship between the effective work function and the effective e-field βE_{cath} on surface.

We plan to carry out thermal emittance measurement in the SRF gun with slit scan method. It is quite challenging, because the measured electron beam emittance was composed of various sources. Besides the thermal emittance of the cathode, the emittance leading from space charge effect, rf field and measurement error has to been considered. For the experiment, we will reduce the bunch charge so low that no obvious divergence change appeared on the screen by slightly increasing the bunch charge. The gradient of SRF gun in the experiment is 8 MV/m, which will lead less rf field effect to emittance compared with that in normal conducting guns with much higher gradient [7]. The measurement is going on and the result will be reported soon.

CONCLUSION

The metallic photocathodes provide us another alternative to semiconductor photocathodes, 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, which is suitable for the applications in the ELBE radiation centre.

The use of high QE semiconductor photocathode for ELBE SRF gun is promising but very challenging because of the compatibility. However, semiconductor photocathodes in the SRF gun-I gave out very positive result. For high bunch charge and high current application with SRF gun-II, Cs_2Te photocathode will be applied in 2016 instead of Mg. Also the other semiconductor materials like Cs_2KSb and GaN(Cs) are also considered as candidates in the future development.

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