ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-THPMF039

STUDY OF MAGNESIUM PHOTOCATHODES FOR SUPERCONDUCTING RF PHOTOINJECTORS

R. Xiang*, A. Arnold, P. Lu[1,†], P. Murcek, J. Teichert, H. Vennekate[1,‡], Helmholtz-Zentrum Dresden-Rossendorf, 01314 Dresden, Germany
[1]also at Technische Universität Dresden, 01069 Dresden, Germany

Abstract

The superconducting RF photoinjector (SRF Gun II) has successfully served for the ELBE user facility at HZDR. The quality of photocathodes is one of the most critical issues in improving the stability and reliability for its application. Mg has a comparably low work function and shows quantum efficiency up to 0.3% after laser cleaning. But the present cleaning with a high intensity laser beam is time consuming and produces unwanted surface roughness. Thermal treatment and excimer laser cleaning are being investigated as alternative methods.

INTRODUCTION

Since 2016 the superconducting (SC) RF photoinjector (SRF Gun II) at the ELBE radiation facility has been operated with Mg photocathodes (PC). After a commission phase of the gun which followed installation at ELBE in 2014 with a copper PC [1,2], the decision was taken to develop and apply Mg PCs. Magnesium has a low work function of 3.6 eV and is the metal with the highest quantum efficiency (QE) ever used as a PC in accelerator electron sources [3,4,5,6]. For irradiation with ultraviolet laser light at 260 nm, the expected QE of Mg is over 0.1 %. This value is much lower than e.g. the QE of semiconductor material Cs_2Te with values between 1 and 10 % which is the preferred material for use in normal-conducting RF photoinjectors. In the first version of the SRF gun at ELBE, in operation until 2014 (SRF Gun I), the main problem caused by Cs_2Te PCs was multipacting, but PC lifetime was no issue [7]. In SRF Gun II, a life time of only two weeks for Cs_2Te PCs was found. It turned out that overheating of the PCs could have degraded the Cs_2Te layers. Further detailed studies and technical modifications are needed to eliminate this effect. Beside this acute reason, Mg PCs have the advantages of easy fabrication, high vacuum robustness, long lifetime, and little risk for contamination of the niobium cavity. In the SRF gun the Mg PCs can be used with the existing UV drive laser system designed for Cs_2Te PCs. The laser can deliver pulses with up to 3 µJ at 100 kHz repetition rate which is enough to produce bunches with charge of >100 pC with a Mg PC.

MAGNESIUM PHOTOCATHODES

Mg Plug Production

The PC consists of a bulk plug with 10 mm diameter of pure poly-crystalline Mg. The plug is mirror-like polished with diamond compound of different sizes. Care must be taken to assure the plug length is 8 mm with an error less than 0.3 mm. The polished cathodes with a mean roughness of ca. 10 nm are de-oxidized and cleaned, then stored in filtered dry N2 till installed in the cathode transport chamber. Before closing the transport chamber an extensive dry-ice cleaning procedure is carried out to remove all particles which could potentially pollute the SC cavity of the gun.

Cathode Cleaning

Even with the chemical de-oxide process, the QE of the Mg PCs is only about $2x10^{-5}$. In order to reach a clean Mg surface and to reduce the surface work function, a treatment in vacuum is necessary. There are a number of alternative ways to remove the surface oxide layer:

- Laser cleaning with UV gun drive laser.
- Laser cleaning with nanosecond KrF excimer laser.
- Heat treatment.
- Ion beam sputter cleaning.

Laser cleaning with the drive laser is a well-known method to increase the QE of Cu or Mg PCs in normal-conducting RF photoinjectors [8,9]. For our laser system a specific set-up was developed because the low pulse energy of this CW laser required a very strong focusing with a 200 mm focus length lens at the end. Beside the pollution issue for the SC cavity, this requires to perform the cleaning outside the cavity. Figure 1 shows a photograph of the optical set-up for the laser cleaning. It is attached to the transport chamber of the PC transfer system of the gun.

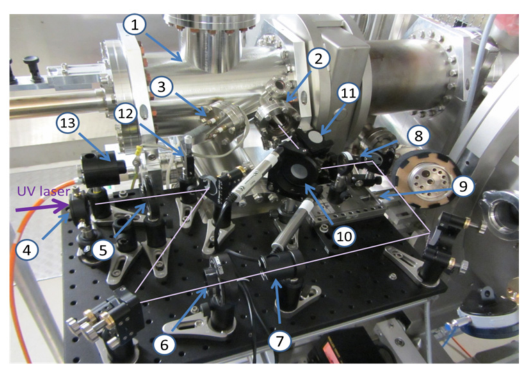

Figure 1: Optical set-up for laser cleaning, (1) transport chamber, (2) vacuum viewport for laser, (3) anode voltage feedthrough, (4) lens, (5) aperture, (6) wave plate, (7) polarizer, (8) final focus lens, (9) linear stage for final focus lens, (10) motorized scanning mirror, (11) flip mirror, (12) knife-edge aperture, (13) power meter.

Recently, the transport chambers have been upgraded, as can be seen in Figure 2. With the anode and a Keithley

*r.xiang@hzdr.de
†KLA-Tencor, Shanghai
‡RI Research Instruments GmbH, Bergisch Gladbach

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-THPMF039

2410 SourceMeter the photo current can be measured during the laser cleaning. The accurate measurement of the QE is not carried out with the ps laser drive laser due space charge saturation effects, but with a UV laser diode emitting in DC. The power density window of the laser beam for successful cleaning is rather narrow around 2 W/mm^2 and requires an accurate adjustment. Therefore the optical set-up has the opportunity to measure and set the laser power and to determine the laser spot size with the knife-edge method.

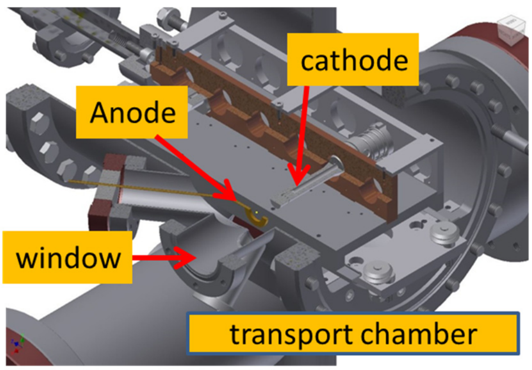

Figure 2: Transport chamber design with window for laser cleaning and optical inspection, electrical feedthrough for anode, and QE measurement.

Up to now, several cathodes in a first testing set-up and five Mg PCs in the transport chamber have been cleaned by means of the laser achieving up to 0.3 % QE. Other groups utilize the increase in vacuum pressure to find the laser working point for cleaning. We also observed an increase from 10-^{10} to 10-^{9} mbar, but use the photoemission current as a more accurate indicator. A disadvantage of this UV laser cleaning consists in the increase of surface roughness, since a slight surface melting cannot be avoided.

QUALITY MANAGEMENT

For superconducting RF photoinjectors like the SRF gun at ELBE, the quality of PCs has two important issues: i) the PCs must fulfil the requirements coming from the production of high-quality electron beams. The properties are QE, thermal emittance, surface roughness, charge lifetime, and further parameters. ii) The SC cavity performance must be sustained during PC exchange and during operation with the PC. Thereby particle pollution, surface quality, field emitters, and layer quality are important. For that reason, a quality management system has been established starting with the fabrication of the PC plugs, and consists of a number of quality checks and corresponding documentation.

In Preparation Lab

- Dry-ice cleaning of plugs and PCs.
- Visual inspection relating to scratches and particles.
- Repeat dry-ice cleaning and inspection, if needed.

In Transport Chamber

- Visual inspection relating to scratches and particles.
- Laser cleaning.
- QE measurement and QE mapping (regularly).

In SRF Gun

- DC voltage QE measurement and QE mapping.
- RF test, cavity quality factor, multipacting.
- PC temperature rise caused by RF losses.
- Dark current, total and energy spectrum.
- QE measurement and QE mapping with RF field.

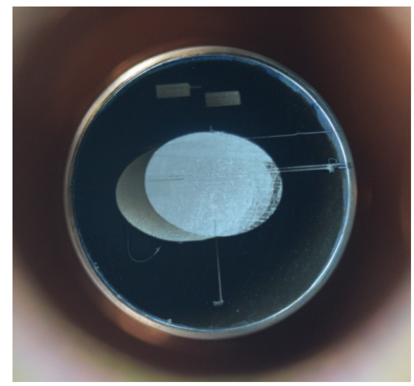

Figure 3: Photograph of Mg photocathode Mg#214 after second laser cleaning.

CATHODES IN SRF GUN

Since March 2016 the SRF Gun II has been operated with magnesium PCs. An overview of the used cathodes and their parameters are given in Table 1. The latest PC (Mg#214) is used in the gun since August 2017. At the end of the ELBE winter shut-down in January 2018, this cathode was laser cleaned for a second time and reaches again an excellent QE of 0.3 %. Fig. 3 presents a photograph of the cathode after the laser cleaning.

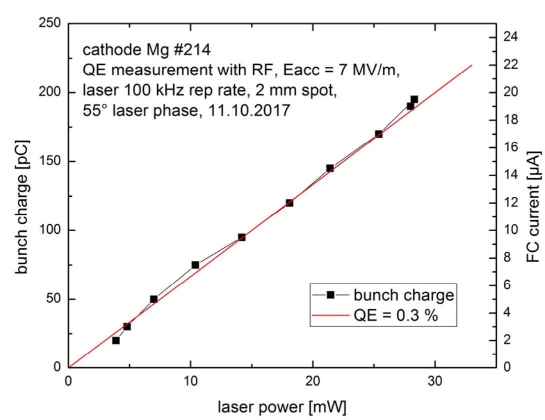

Figure 4: Measurement of photoemission current vs. laser power for QE determination.

The result of the QE measurement using the RF field and the UV drive laser is shown in Fig. 4. The photoemission in the SRF gun is influenced by the Schottky effect and by the space charge effect. Fig. 5 plots the emitted electron current measured in the Faraday cup downstream the gun as a function of the bunch launch phase (laser phase). In

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-THPMF039

the case of low laser power, the Schottky effect is visible leading to a small current increase with laser phase due to the reduction of the effective work function with increasing RF field. But for larger bunch charges the space charge effect is dominant and limits the bunch charge at lower laser phases because of the low acceleration field at launching time.

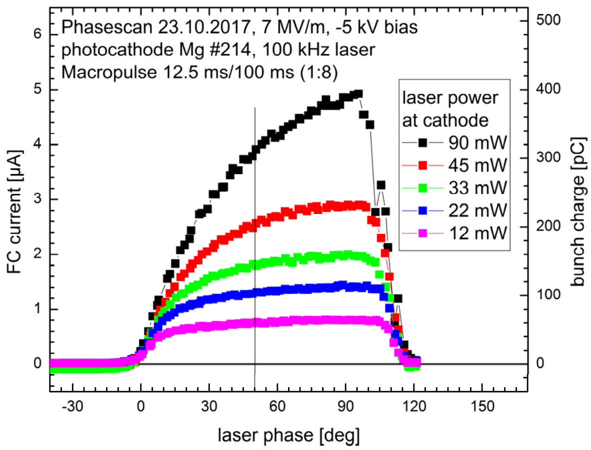

Figure 5: Measured Faraday cup current (bunch charge) vs. drive laser phase for different laser power. The phase working point of the SRF gun is indicated by the vertical line at 50°.

Table 1: Mg Photo Cathodes in SRF Gun II

Name	**Use in SRF Gun**	**QE** [%]	**Bunch Charge [pC]**	**CW Current [µA]**
Mg#201	Mar. 16 - Aug. 16	0.2	200	20
Mg#207	Nov. 16 - Dec. 16	0.1	80	8
	Mar. 17 - May 17	0.2	150	15
Mg#214	Aug. 17- now	0.3	300	30

CONCLUSION

Mg PCs made of bulk magnesium and laser beam cleaned are the working horses for characterization and optimization of gun at higher bunch charge as well as for the regular user operation of ELBE with the SRF gun. The combination of the present UV laser and the Mg cathode allows for production of beam with up to about 300 pC, which the space charge limit for the gun with an acceleration gradient of 8 MV/m (20.5 MV/m peak field on axis). Electron beams with 200 pC at 100 kHz (20 µA in CW) are being applied for user experiments and improving the performance of the ELBE THz radiation facility [10].

REFERENCES

[1] A. Arnold *et al.*, “Commissioning results of the 2nd 3.5 cell SRF gun for ELBE”, in *Proc. IPAC’14*, Geneva, Switzerland, Aug. – Sept. 2014, p. 578.

[2] J. Teichert *et al.*, “Commissioning of an improved super-conducting RF photo injector at ELBE”, in *Proc. FEL’14*, Basel, Switzerland, Aug. 2014, p. 881.

[3] T. Srinivasan-Rao *et al.*, “Performance of magnesium cathode in the s-band rf gun”, in *Proc. PAC’97*, Vancouver, Canada, May 1997, p. 2790.

[4] X.J. Wang *et al.*, “S-band high duty photo-injection system”, in *Proc. EPAC’02*, Paris, France, June 2002, p. 1822.

[5] H. Iijima *et al.*, “High charge Mg photocathode RF gun in s-band linac at university of Tokyo”, in *Proc. EPAC’02*, Paris, France, June 2002, p. 1771.

[6] T. Vinatier *et al.*, “Performances of the Alpha-X RF gun on the PHIL accelerator at LAL”, Nucl. Instrum. And Meth. A 797, 222 (2015).

[7] R. Xiang *et al.*, “Recent Improvements of Cs2Te Photocathodes at HZDR”, in *Proc. IPAC’14*, Dresden, Germany, June 2014, p. 642.

[8] F. Zhou *et al.*, “Establishing reliable good initial quantum efficiency and in-situ laser cleaning for the copper cathodes in the RF gun”, Nucl. Instrum. and Meth. A 783, 51 (2015).

[9] R. Xiang *et al.*, “Improvement of photoemission efficiency of magnesium photocathodes in *Proc. 8th Int. Particle Accelerator Conf. (IPAC’17)*, Copenhagen, Denmark, May 2017, p. 500.

[10] J. Teichert *et al.*, “Experiences with the SRF Gun II for user operation at the ELBE radiation facility”, presented at IPAC’18, Vancouver, Canada, Apr.-May 2018, paper THPMF039 this conference.