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STUDY ON QE EVOLUTION OF Cs_2Te PHOTOCATHODES IN ELBE SRF GUN-II

R. Xiang†, A. Arnold, S. Ma[1], P. Michel, P. Murcek, J. Schaber[2], J. Teichert, A. Ryzhov, P. Zwartek,
Helmholtz-Zentrum Dresden Rossendorf, 01328 Dresden, Germany
[1] also at Univ. Hamburg, 20148 Hamburg, Germany
[2] also at TU Dresden, 01069 Dresden, Germany

Abstract

The quality of the photocathodes is critical for the stability and reliability of the photoinjector's operation. Thanks to the robust magnesium and Cs_2Te photocathodes, SRF gun-II at HZDR has been proven to be a successful example in CW mode for high current user operation.

In this contribution, we will present our observation of the QE evolution of Cs_2Te photocathodes during SRF gun operation. The variables including substrate surface, film thickness, Cs/Te stoichiometric, multipacting, RF loading and charge extract are considered in the analysis.

INTRODUCTION

As well known, the quality of photocathodes is a key factor to improve the stability and reliability of the photoinjectors [1]. For SRF guns developed at HZDR, metal cathodes (copper, magnesium) and semiconductor photocathode Cs_2Te are chosen as photocathode materials. Copper was used as commissioning cathode in SRF gun. But the work function of Cu (4.6 eV) is rather high and its quantum efficiency (QE) of 1×10^{-5} at 260 nm is too low for the regular beam production. For medium bunch charge mode, magnesium is a good photocathode candidate. Mg is a metal with low work function of 3.6 eV, and its QE can reach 0.5% after ps UV laser cleaning [2]. Although it has lower QE than Cs_2Te, Mg has the advantages of long life time, reliable compatibility and little risk of contamination to the niobium cavity.

Driven with UV laser the photocathode Cs_2Te (with band gap 3.3 eV + electron affinity 0.2 eV) has shown good QE and long life time in the ELBE SRF gun-I [3]. In 2017 we suffered the strong field emission and also thermal contact problem during SRF gun-II operation with three Cs_2Te cathodes (on molybdenum plug). An intensive study has been performed to understand the problem of overheating of those cathodes in SRF gun cavity. Then we decided to give up the Mo plug and apply OFHC as the plug material, though copper is not the friendliest substratum for the active Cs_2Te. Since then Cs_2Te on Cu plug has be prepared at HZDR and operated successfully in SRF gun-II for the THz user beam time.

CS_2TE CATHODES IN SRF GUN II

Since May 2020, seven Cs_2Te photocathodes have been used in the SRF gun-II. The average operation duration in gun is three months, providing 7-17 coulomb charge depending on the current request of the beam users. Cathodes would be exchanged when the gun warmed up during shutdown season and/or QE of the cathode in gun was not sufficient for the next beam time.

Preparation Process

The Cs_2Te photocathodes are prepared in the HZDR cathode lab and transported to the SRF gun in vacuum. The cathode plug is made of copper to ensure a high thermal conductivity for LN_2 cooling. The Cu plug is mirror polished or finished with diamond turning to a roughness in level of 10 nm. In our experiments, the Cs_2Te cathodes on the mechanical polished plugs and those on the diamond turning finished plugs show almost the same photoemission quality and also the same dark current in gun. The plugs are carefully treated in the clean room. The chemical cleaning, dry ice cleaning and 350°C baking in vacuum are applied to keep the surface free of any pollution.

During the preparation process, the plug is kept at 120°C with a halogen light. At first the tellurium and then cesium are deposited subsequently through a ϕ 4 mm mask onto the plug surface. Meanwhile, 260 nm and 340 nm LEDs are used to illuminate the cathode as the diagnostic light and the plug is -200 V biased. The cesium evaporation is stopped when the photocurrent at 260 nm reaches maximum, which actually leads to the Cs/Te ratio fluctuation from one cathode to another one.

The prepared cathodes are stored in the transport chamber with a vacuum around 5×10^{-11} mbar. Up to six photocathodes can be transported together from the photocathode lab to the SRF gun.

QE Dropping Due to RF Loading

During the cathode transport and insertion into gun, the QE can be very well preserved. However, a strong QE dropping did happen when the radio frequency power was started.

The QE tracking of the latest photocathode is shown in Fig. 1. This cathode was deposited with 6 nm Te and 37 nm Cs. From the photograph of the cathode, the coating was homogeneous with a narrow shadow of mask on the border. Note that QE measured in the transport chamber (red points) and the first QE value in SRF gun (first blue point) were almost the same, which means there was no QE lost during both transport and insertion activities. But soon after the pulsed RF was loaded, especially when the CW power was started, a strong QE degradation was observed.

† email address: r.xiang@hzdr.de

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Later during the beam operation the cathode QE could keep relatively constant.

Before the RF field was built in cavity, we applied a DC bias of -5 kV on the cathode for QE measurement, and the photocurrent about 200 nA landed on the cavity wall. We believe that the lower QE in the cathode centre is due to the ions back to cathode. In order to reduce the influence of multipacting (MP) to vacuum, a dedicated RF starting up process was developed [4]. At first only low power pulsed RF was loaded with variable DC voltage in order to process the possible MP in the cathode and choke area. There happened some pressure rising up to 10^{-9} mbar (vacuum read by the gauge at the gun exit), which led a slight QE dropping. After the pulsed RF reached 8 MV/m, the duty factor was increased till CW mode. But this process might induce new MP cases and thus vacuum issues, so new QE falling and also the distribution changing could be observed.

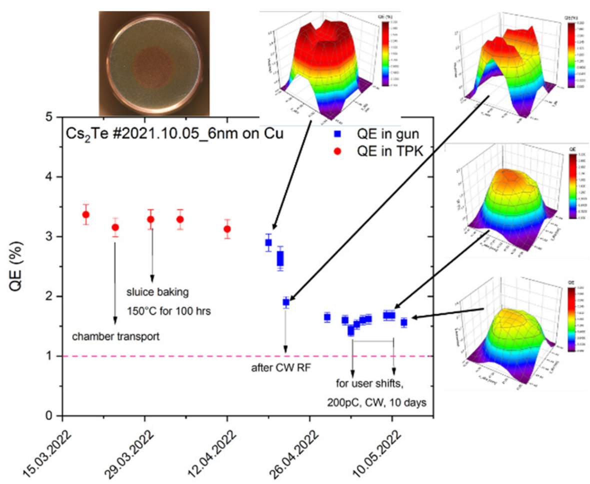

Figure 1: QE tracking of Cs_2Te #2021.10.05 before and after inserting into SRF gun. The red points are the QE measured in the transport chamber and the blue ones are those during SRF gun operation. The photograph of the cathode and the QE mappings in different stages are shown here as additional information.

QE Evolution Due to Beam Extraction

However, there were several Cs_2Te cathodes shown very inhomogeneous QE mapping during the operation. For example Cs_2Te #2021.06.07 shown in Fig. 2. This cathode was coated with 8 nm Te and 40 nm Cs, but the film was 0.4 mm off centre (in Fig. 3).

In the first week in gun we used only DC bias to study the cathode itself, which led a QE dropping together with 'hole' in the cathode plug centre (not film centre). But soon after the RF field of 8 MV/m in CW mode was loaded, an obvious QE changing happened. The whole cathode degraded 'equally' with a 'hole' in cathode plug centre. We believe that the photoelectrons and dark current hit the cavity wall and release the absorbed gases, which contaminate the Cs_2Te surface.

When the operation went on, right side of the film showed faster degradation trend than the left side. The vacuum measured at the gun exit showed 4 - 5 × 10^{-10} mbar without visible accidents. Clearly the vacuum was not the reason leading this phenomenon. But if the rest gas molecules were ionized by accelerated photoelectrons & dark current, those ions could be accelerated by the RF field as well as the cathode DC field and fly back to the cathode surface.

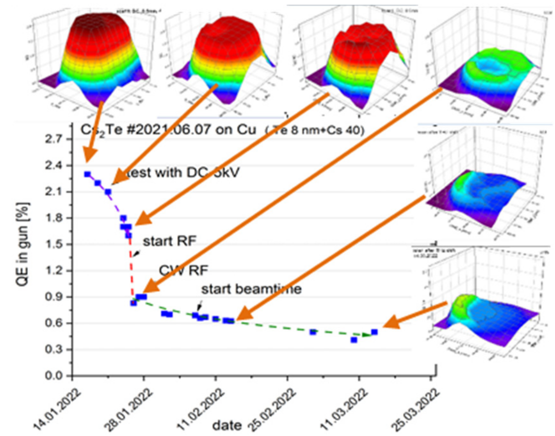

Figure 2: QE tracking of Cs_2Te #2021.06.07 with the QE mappings in different stages during operation in SRF gun.

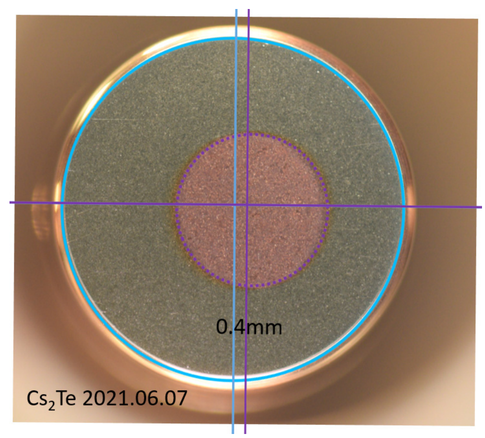

Figure 3: Photograph of the Cs_2Te cathode #2021.06.07 with 8 nm Te and 40 nm Cs, but 0.4 mm off centre.

IMPROVE OPERATION LIFETIME

We have paid great effort to improve the cathode life time during operation in gun. On the one hand is to enhance the cathode robustness and to preserve the QE during cathode transport, on the other hand is to find out a dedicated RF starting up process to avoid MP and vacuum issue.

A study has been done to investigate the relationship between the cathode robustness and the film Cs/Te stoichiometric ratio. The film border of Cs_2Te #2020.03.04 showed different operation life time from the rest of the film (left in Fig.4). Contrasted with the centre part with low QE, the border had a circled QE valley and a narrow corner with a QE 'peak'. After the cathode plug was taken out from vacuum, we observed the colour changing of the whole film,

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and the border showed some ring-like structure, which was confirmed under the microscope (right in Fig.4).

Because the cathode showed homogenous distribution as it was freshly inserted into gun, what was the reason resulting this QE valley and peak? It might be due to the thickness gradual change or the Cs/Te ratio gradient in the mask shadow.

In order to measure the local Cs/Te ratio, scanning electron microscopy (SEM) and energy dispersive X-Ray analysis (EDX) were applied to study the film. The SEM image was taken with a Zeiss NVision SEM microscope and the EDX measurements were done with a Bruker® 129 QUANTAX EDS spectrometer. The measurement showed the top and bottom border (middle of Fig. 4) had the same gradient structure, and the right and left border had a sharp edge. This could be explained by the linear Te and Cs sources, which produced a one-direction shadow.

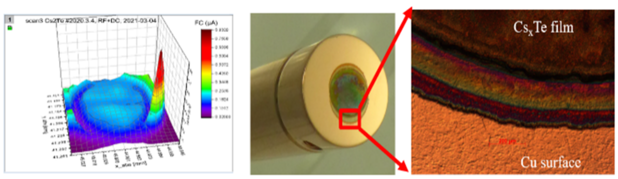

Figure 4: QE mapping of Cs_2Te #2020.03.04 after three months operation (left). The photograph of this used cathode already exposed in air (middle). The film border under microscope (right).

The results of SEM and EDX are shown in Fig. 5. During preparation there were 10 nm Te and 50 nm Cs deposited on the surface. In the centre part, Cs/Te was measured as homogeneously 1.6. After a ratio valley, there appeared a narrow circle with higher Cs/Te ratio of 1.8, followed by the dropping ratio outer rings.

If one compares the QE mapping with the local Cs/Te ratio changing, it seems that there is some relationship between the lifetime and stoichiometric. A Cs/Te ratio of 1.8 could result in better life time during operation than the lower ratio. But this good life time only presented on one side of the cathode, which looks similar to the cathode #2021.06.07 in Fig.2.

However, this experiment was done with a cathode already exposed in air, which was different to the "real" situation. And we cannot measure the local thickness difference of the film, so we cannot exclude the thickness influence to the life time, which needs other methods.

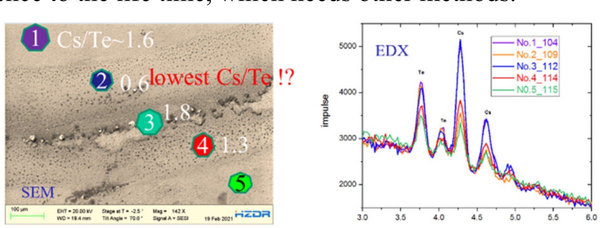

Figure 5: The SEM photograph of the film border of Cs_2Te #2020.03.04 with the local Cs/Te ratio (left). The EDX spectra taken at the different location for Cs/Te ratio calculation (right).

CONCLUSION

Cs_2Te photocathodes on copper plugs have been successfully applied in the SRF gun-II for user operation for two years. We observed the QE evolution during operation and tried to understand the influence of the variables to the cathode lifetime, including Cs/Te stoichiometric, film thickness, multipacting, RF loading and charge extracting.

Additional to the study in this paper, in order to clarify the QE inhomogeneous changing during operation in gun, we still need to simulate the movement of dark current and charged gas molecules in gun as well as the ion bombardment process on cathode.

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