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TEST OF Cs_2Te THICKNESS ON CATHODE PERFORMANCE AT PITZ

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Abstract

Cesium telluride is a widely used cathode in photo injectors, and its performance is one of the keys for not only emittance but also reliable operation. Over the years lots of experiences with Cs_2Te photocathodes produced with the same recipe and thickness were gained at the DESY photo injectors, but cathode performance dependence on the cathode layer thickness were not investigated. In this paper, we test fresh Cs_2Te cathodes with different thickness at the Photo Injector Test Facility at DESY in Zeuthen (PITZ). The dark current, quantum efficiency (QE) and thermal emittance of these cathodes inside the high gradient RF gun will be compared.

INTRODUCTION

The photocathode is one of the key components of photoinjectors. The performances of the photocathode, including quantum efficiency (QE), thermal emittance, response time, dark current and life time, are closely related to the photoinjector performance and its subsystems, such as the photocathode laser, gun gradient, vacuum, and injector emittance [1]. Even for the same cathode material, different cathode recipes may lead to different cathode performances [2]. Several studies have shown that the thickness of cathodes is one of the parameters to optimize the cathode performance. For transmission mode photocathodes, which are illuminated by laser from the back side, greater thickness would increase electrons possibility to scatter with phonons and reduce thermal emittance [3]. Besides, a fine control of cathode film thickness and substrate can optimize the photon absorption and lead to a higher QE [4]. For K_2CsSb cathodes, a thicker Sb layer has shown improvement in both QE and life time [5]. Among all these studies, a performance dependence test of cathode film thickness in high gradient RF guns is missing.

Cs_2Te cathodes are one of the most widely used cathodes in photoinjectors, especially for applications requiring an average current from 1 μA to 1 mA. It has a typical high QE of around 10 % in UV and a long life time (months to years [6]), compatible with a gun vacuum of 10^{-9} mbar. DESY has been collaborating with INFN-LASA, Milano, on testing and optimizing Cs_2Te cathodes for decades, and Cs_2Te cathodes are reliably used for the user facilities, FLASH and European XFEL, and the Photo Injector Test Facility at DESY in Zeuthen (PITZ). In 2010, INFN-LASA reported the Tellurium thickness effects for Cs_2Te measured in a cathode preparation system [7]. The cathode thickness is specified with the tellurium thickness. They are 5 nm, 10 nm and 15 nm, respectively. The corresponding cesium thickness is determined during the deposition process, where the QE is optimized and the final peak of the QE determines the Cs thickness [7]. At this stage, the cathode is believed to be a complete Cs_2Te film [8]. The three cathodes were maintained in a UHV cathode box after fabrication at Milano and sent to PITZ for testing in the high gradient RF gun [9]. The three fresh Cs_2Te cathodes were tested continuously at PITZ for two weeks in the sequence of 5 nm, 15 nm and 10 nm Te thickness. The testing items include dark current, QE and thermal emittance against electric field, QE and thermal emittance maps. The testing results are reported in this paper.

EXPERIMENTAL SETUP

The experiments were carried out on the PITZ beam line. The simplified layout for the measurements in this paper is shown in Fig. 1. Currently Gun4.2 is installed at PITZ, a 1.5 cell L-band RF-gun operated at high gradient and long pulse train [10]. There are two solenoids around the gun. The main solenoid locates at the gun exit. The other one is the bucking solenoid and it is for compensating the residual magnetic field at the cathode. The dark current is measured with a Faraday cup located at the exit of the gun and the solenoid current is tuned to achieve the strongest signal. The QE is measured by the same Faraday cup and a laser energy meter. For thermal emittance measurement, we use the cathode transverse momentum imaging and the details of this method can be found in [11]. The wavelength of the cathode driving laser is 257 nm. The laser profile is transversely uniform and longitudinally gaussian (6 ~ 7 ps FWHM).

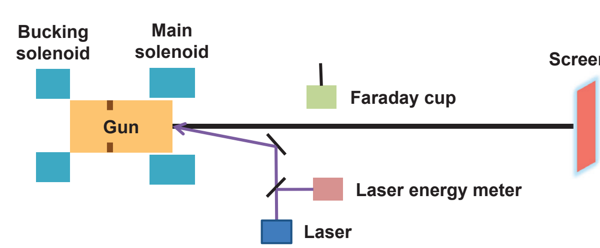

Figure 1: The beam line layout for the experiments. Only the elements related to the experiments are shown.

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DARK CURRENT

Dark current was measured for every cathode, both at the beginning of their insertion and after some days of operation. The results are presented in Fig. 2. Most of the dark current comes from the gun body, but the differences of the dark current among cathodes are caused by the cathode plug. The dark current results of the 5 nm Te cathode and the 15 nm Te cathode are similar, while the 10 nm Te cathode has more than 40% larger dark current at high gun power. It might be attributed to some imperfections on the cathode plug, which needs further study after the cathode extraction. Several vacuum trip events happened during the conditioning of the 10 nm Te cathode. No significant change of the dark current is found after several days of operation.

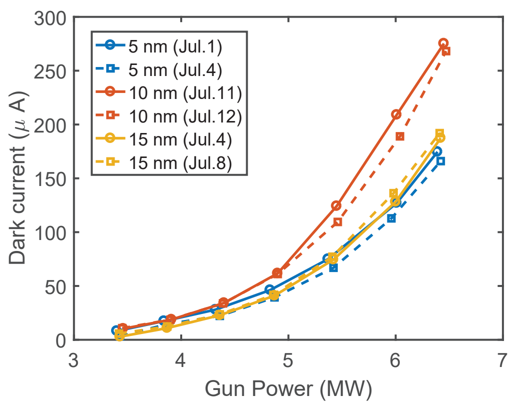

Figure 2: Dark current measurements for different gun power. As a reference, the gun power is 5.65 MW at the working condition of XFEL injector, corresponding to the peak field of 58 MV/m. The solid line is measured with the newly inserted cathode. The corresponding dash line is measured after several days of operation.

QUANTUM EFFICIENCY

The QE is dependent on the laser wavelength and applied electric field. At PITZ, the laser wavelength is 257 nm, corresponding to the photon energy of 4.83 eV. The QE is measured at different emission electric fields by scanning the gun phase. In principle, the QE will increase with the electric field due to the Schottky effect. The results of the QE versus electric field at the cathode center are shown in Fig. 3. All three cathodes show very high QE from 19% to 26%, which is much higher than the typical QE of Cs_2Te [7], and the reasons are still under investigation. Among the three cathodes, the 15 nm Te cathode has the lowest QE, and the QE of the 10 nm Te cathode is the most sensitive to electric field. At the XFEL injector working condition, the emission electric field is 40 MV/m. At this case, the 10 nm Te cathode has the highest QE, around 23.4%.

The QE map was also measured to evaluate the uniformity of the electron emission over the cathode area. The map scan was done with 0.25 mm laser diameter and 0.2 mm step size on the whole surface. Three QE maps are shown

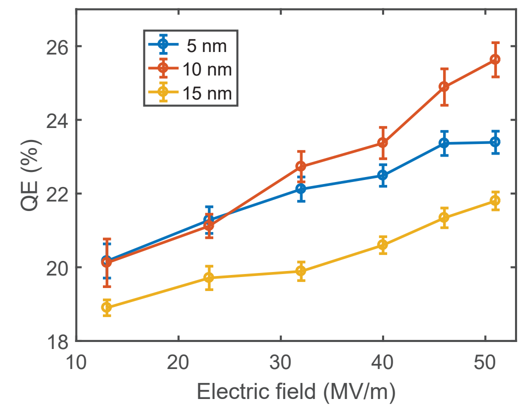

Figure 3: The plot of QE at the center of the cathode against electric field during emission for three cathodes. The error bars are the statistical error.

in Fig. 4 (a)-(c). The rms QE variation over the cathode area are 0.75%, 1.09% and 1.37% for the Te thickness of 5 nm, 10 nm and 15 nm, respectively. Hence, the 5 nm Te cathode has the most homogeneous QE map except for two hot spots. For the other two cathodes, a gradient exists along the horizontal axis and the QE decreases from right to left.

THERMAL EMITTANCE

The thermal emittance determines the lower limit of the beam emittance. Since thermal emittance depends on electric field due to Schottky effect and surface roughness, we took the measurement against electric field during emission. As shown in Fig. 5, although these cathodes have similar thermal emittance at low electric field, the difference becomes larger at high electric field. The thermal emittance of the 5 nm Te cathode is more sensitive to the electric field than the other two cathodes. which may indicate a rougher surface. At XFEL working point, corresponding to the emission field 40 MV/m, the 10 nm Te cathode has the smallest thermal emittance, around 0.97 mm mrad/mm. The transverse momentum profiles of photoelectrons from the three cathodes at 40 MV/m are presented in Fig. 6. From the plot, it is straightforward to find that the 5 nm Te cathode has a broader momentum profile, leading to a higher thermal emittance.

The thermal emittance map was measured for every cathode. The map scan was done with 0.5 mm laser diameter and 0.5 mm step size on the whole surface. Three thermal emittance maps are shown in Fig. 4 (d)-(f). There is a negative correlation between QE map and thermal emittance map, but the discussion is out of the scope of this paper. It should be noted that for all the thermal emittance results, the dominating systematic error comes from the image processing, and we believe the relative changes among all the data points tend to maintain.

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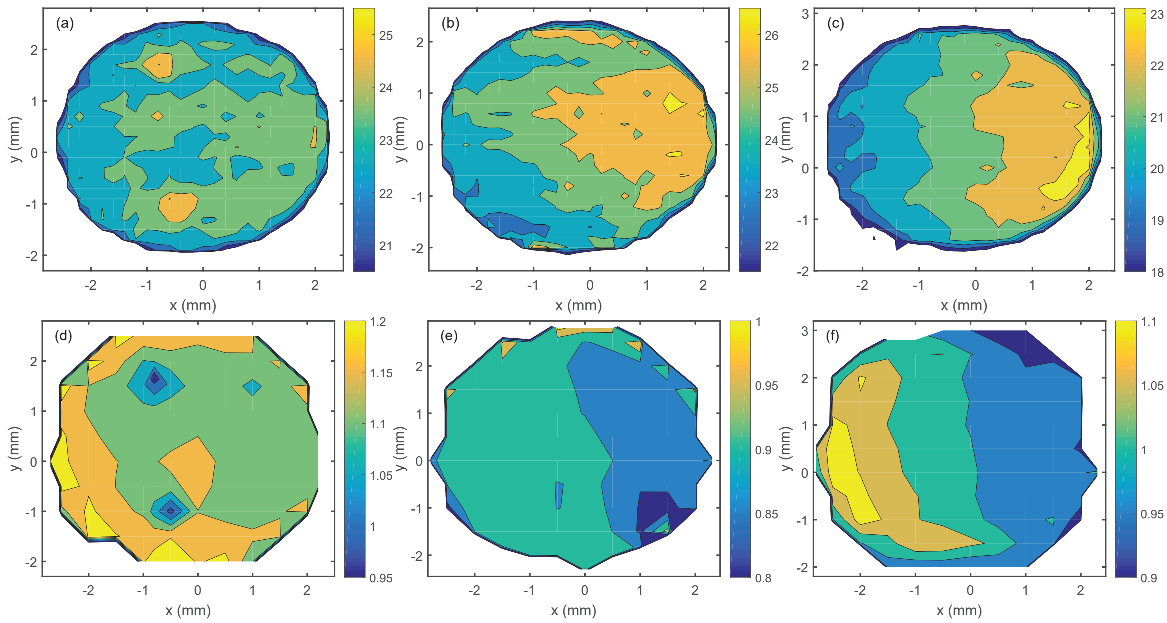

Figure 4: The QE maps (a)-(c) and thermal emittance maps (d)-(f) of three cathodes. The three columns from left to right present the results for 5 nm, 10 nm, and 15 nm Te thickness cathodes, respectively. The number aside the colorbar on the upper row is the corresponding QE with the unit of %. Each color region refers to 1% width of QE within one map. The number aside the colorbar on the lower row is the corresponding thermal emittance with unit mm mrad/mm. Each color region refers to 0.05 mm mrad/mm width of thermal emittance within one map.

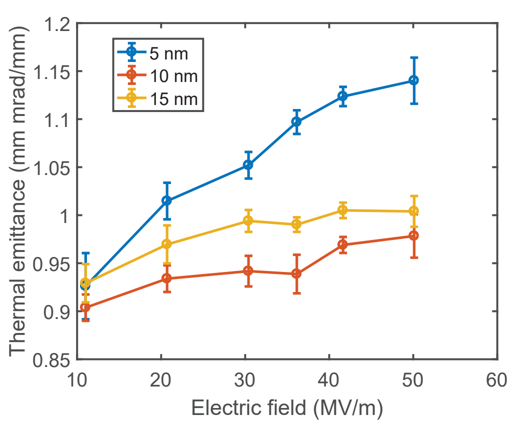

Figure 5: The plot of thermal emittance against electric field for three cathodes. The error bars are the statistical error.

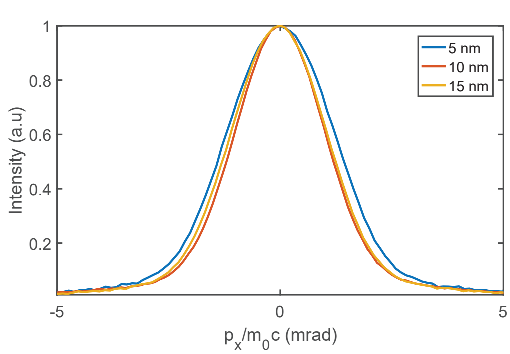

Figure 6: Transverse momentum profile of electrons emitted from different cathodes at 40 MV/m.

CONCLUSION

Three Cs_2Te cathodes from INFN-LASA were tested in the high gradient PITZ gun to study the thickness dependence of cathode performance. The dark current, quantum efficiency and thermal emittance of each cathode have been reported in this paper. More experiments and theoretical analysis are required for a thorough understanding of the thickness effect on the cathode performance.

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