Cu AND Cs_2Te CATHODES PREPARATION AND QE HISTORY AT THE SwissFEL INJECTOR TEST FACILITY

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Abstract

The installation of a load-lock chamber attached to the RF photoinjector gives the possibility to carefully prepare the metallic cathodes under vacuum and also to use semiconductor cathodes like Cs_2Te cathodes which cannot be transported through air. An annealing procedure of copper cathodes to desorb water guarantees a good reproducibility of the initial quantum efficiency (QE) above 10^{-4}. Cs_2Te cathodes were tested in the same gun and showed that they also fulfill the emittance requirements of SwissFEL but with a much higher QE (1-2%). In order to better understand and improve the deposition procedure at PSI (based on a CERN recipe), surface analysis were performed and are discussed in the paper (SEM, EDX, interferometry, microscopy).

INTRODUCTION

The main advantage of semi-conductor cathodes (like Cs2Te) over metallic cathodes (copper) is the increase in quantum efficiency by several orders of magnitudes (QE). The laser energy required for photoemission can then be reduced and invested elsewhere like in a better shaping (which always consumes laser power) or in multi bunch operation. The main drawbacks of Cs_2Te cathodes is however the increase in slice emittance and the short lifetime (rapid decrease of QE). At SwissFEL we would like to have both cathode options (Cu and Cs2Te) ready for the future operation. In this paper we present the preparation procedures for both cathode materials together with their QE performances.

EXPERIENCE WITH COPPER CATHODES AT THE SITF

The SwissFEL Injector Test Facility (SITF) is a 250 MeV accelerator to test components and beam quality for SwissFEL. SITF produces beam since 2009 using copper cathode plugs installed in a RF photo-injector [1]. Cathodes are illuminated with laser pulses at 262 nm with a duration of σ_t=4 ps rms (Gaussian), a nominal diameter of σ_r=250µm (flat top transverse profile) and a repetition rate of 10 Hz. The electric field at the cathode surface during illumination is about 52 MV/m.

Until 2013, SITF was operated without any load-lock system and the QE directly after cathode installation was not reproducible and sometimes below the specification threshold of QE_{min} ~ 7.e-5, see for example Cu_7 and Cu_8 in Fig. 1. Only cathode Cu_3 has behaved exceptionally well for a very long period. After the installation of the load-lock chamber in july 2013, we have established a cleaning and annealing procedure with temperature as high as 250°C [1] which guarantees a starting QE always above 10^{-4}. This could be demonstrated on more than 5 cathodes. The duration until the QE decreases below $7.0 \cdot 10^{-5}$, is between 50 and 150 days (see Cu_19 and Cu_17 in Fig. 1).

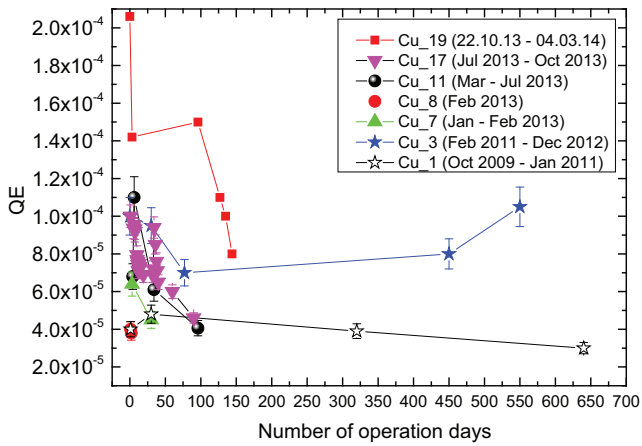

Figure 1: Evolution of the QE of copper cathodes installed in the injector since 2009. The load-lock chamber has been installed in July 2013.

The future laser system of SwissFEL (Yb:CaF_2 crystal) will be more powerful so that the minimum required QE will be as low as 4.10^{-5}. In view of Fig. 1, this would mean that the duration between two consecutive cathode exchanges should exceed 100 days. This would correspond to one shift shutdown every 100 days. Indeed, the exchange of cathodes with the load-lock takes only a few minutes but the RF conditioning of a new cathode still takes several hours.

Cs_2Te PREPARATION AND PERFORMANCES AT THE SITF

Cs2Te Cathode Preparation

The deposition procedure used at PSI is copied from a CERN [2,3] recipe where 15 nm of tellurium and 25 nm of caesium are successively evaporated directly on the copper cathodes [4]. The copper cathodes undergo beforehand the same annealing procedure as for operation with pure copper cathode. An aperture mask limits the deposition area to a disc of 1cm diameter (Fig. 2). The cathodes can then be transferred from the evaporation chamber to the gun load-lock via a vacuum suitcase. The initial pressure in the evaporation chamber is around 3.10^{-10} mbar going up to 1.10^{-8} mbar during evaporation. The base pressure in the gun during operation is around 1.10^{-9} mbar when RF is powered.

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Figure 2: Evaporation chamber with the cathode holder and micro balance on the left and the Cs evaporation source on the right. (Top); Two cathodes with a 1 cm diameter disc of Cs_2Te (Bottom).

Cs2Te Cathode Performances

Five Cs_2Te cathodes were prepared at PSI based on the above mentioned procedure. The two cathodes tested in the SITF gun started with a QE above 1% (Fig. 3). The laser energy had to be attenuated from typically 5 - 15 microjoules (in the case of normal copper cathode) to few tens of nanojoules showing the enormous spare potential in terms of laser energy. This laser energy could then be invested in a better shaping of the transverse and longitudinal profile of the laser pulses.

Two Cs_2Te cathodes were tested in the gun during one week with a few months interval. The first cathode produced and tested in the RF photoinjector (Cu(Cs2Te)_13) had already a drop of the QE after 50 hours operation which might be related to a local surface contamination. For the second cathode (Cu(Cs2Te)_8) the level of vacuum during deposition was improved and the QE stayed above 2 % during the whole week of operation.

The main goal of these tests was to compare the slice emittance obtained with Cs2Te to the one obtained with copper in the same RF photoinjector. In fact, for both Cs_2Te cathodes the measured slice emittance increased only by 20 to 30% in comparison to what is typically obtained with copper cathodes. These results are presented in a companion paper [5].

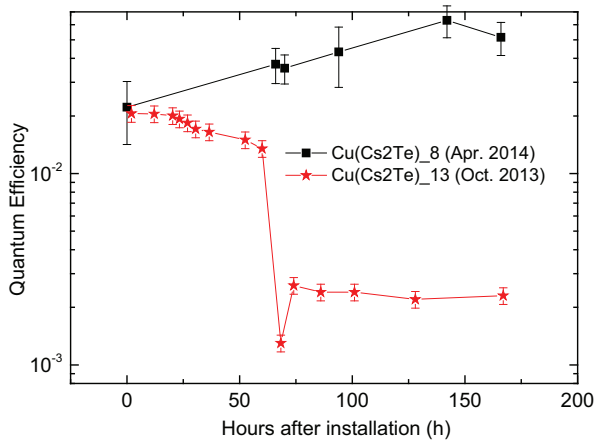

Figure 3: Evolution of the QE of Cs_2Te cathodes installed in the RF photo injector of the SITF in two different periods. (262 nm; 200 pC; $\sigma_{t,laser}$=4 ps rms; 10 Hz).

Cs_2Te SURFACE ANALYSIS

The QE maps taken during the tests of Cu(Cs2Te)_13 and Cu(Cs2Te)_8 present non uniformities as shown in Fig. 4 (bottom). Such non-uniformities are not good for beam quality and might be related to the deposition procedure.

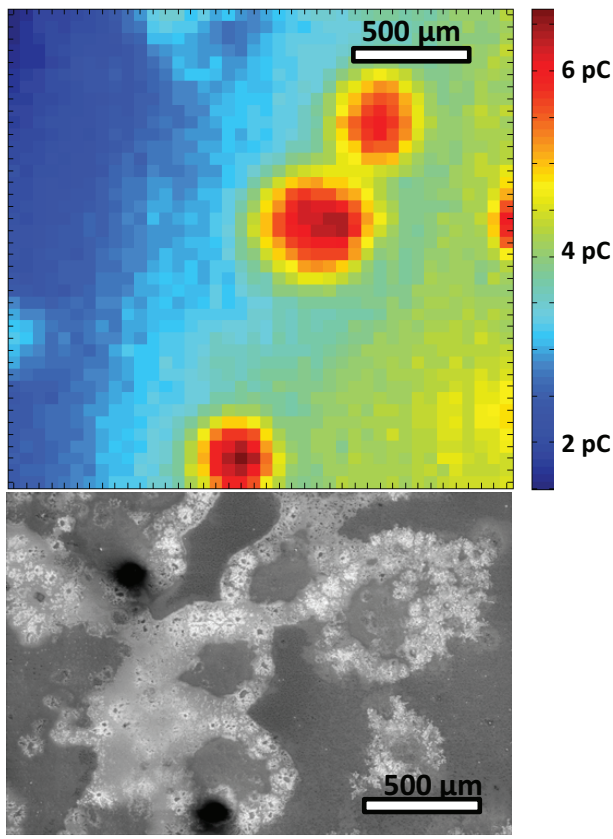

Figure 4: QE map of Cu(Cs2Te)_13 measured in the gun by scanning small laser spots with constant energy (Top). SEM picture (with secondary electrons) of the same cathode after exposure to air (Bottom).

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In order to better understand what causes these non-uniformities a series of surface analysis of the cathode were performed. As soon as the cathode is brought to air for surface analysis the oxidation is changing the surface so that the interpretations given below are only hypothesis. The scanning electron microscope picture of Fig. 4 exhibits many structures present on the surface with about the same size as the non-uniformities seen on the QE map.

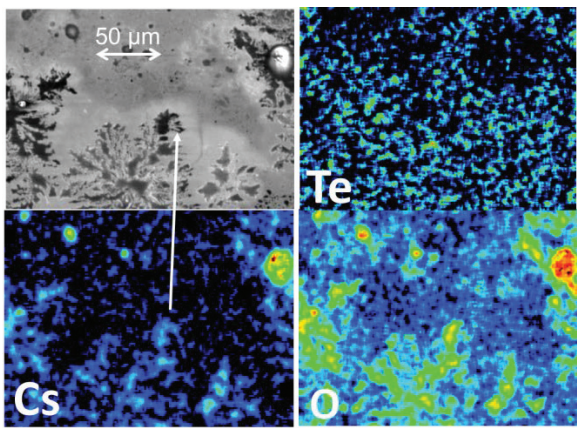

Figure 5: EDX analysis of Cu(Cs2Te)_13 cathode showing the distribution of Cs (caesium), O (oxygen) and Te (Tellurium). The SEM reference picture (with back scattered electrons) is in the upper left corner.

EDX analysis (energy dispersive X-ray spectroscopy) revealed that these bright structures observed in Fig. 4 top picture correspond to high concentration of caesium Cs and oxygen. Indeed the structure indicated by the arrow on Fig. 5 corresponds to Cs and oxygen. Oxygen is just going preferentially to the area with high Cs content when cathode is brought to air. At the difference of Cs the Te is much more spread over the entire area (see upper right picture of Fig. 5). This is consistent with the way Cs_2Te layer grows on copper substrate (island type of formation) [6].

Further SEM analysis of Cs alone deposited on copper and Te alone deposited on copper (Fig. 6) confirm this tendancy that Cs does not spread over copper surface but rather grow by island on specific nucleation sites (see Fig. 6, center). Te is much more uniformly distributed even if some granularity is also visible (Fig. 6, Top). The SEM picture of the Cs_2Te layer is then a combination of the island with granularity (Fig. 6, Bottom).

These SEM pictures were however taken after exposure to air and it is not clear what comes from the air oxidation and what was the Cs non uniformity just after deposition in vacuum.

Finally, interferometry analysis of the Cs_2Te deposited layer where performed to quantify the increase in roughness in comparison to the copper substrate. In fact we observed a rise of the dark current from 1.5 nC to 1.6 nC when going from copper to Cs2Te. This increase can either come from a lowering of the work function or from the increase of the surface roughness.

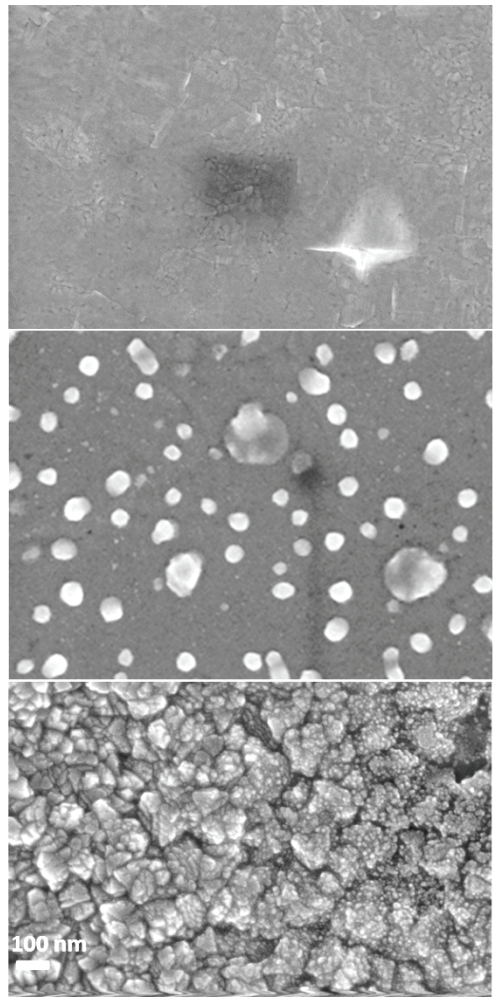

Figure 6: SEM pictures of 15 nm Te deposited on Cu (Top), 25 nm of Cs deposited on Cu (middle) and 40 nm of Cs2Te compound on copper.

The interferometry analysis have shown that the average roughness Ra went from Ra ~ 3 nm for pure copper to Ra ~ 15 nm once Cs2Te was deposited (Fig. 7). It is however not clear which part of the roughness is due to oxidation due to exposure to air and what was already present under vacuum. Nevertheless an increase of the roughness could well explain the observed increase of dark current.

Cs_2Te LIFETIME AND REJUVENATION

In order to be compatible with SwissFEL operation the Cs_2Te cathodes need to maintain a QE above 0.1 % for at least one week and this at a repetition rate of 100 Hz. Exchanging the cathode every week (4 cathodes can be stored in advance) should be possible for standard operation. The measurements done in the SITF gun and shown in Fig. 3 were for 10 Hz repetition rate. Cs_2Te cathodes are much more sensitive to contamination than copper, especially to oxygen contamination [6] [7]. Lifetime measurements were done in a test chamber where the applied electric field was only 1 kV/cm so that

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space charge limited regime was already observed for charges above a few pC.

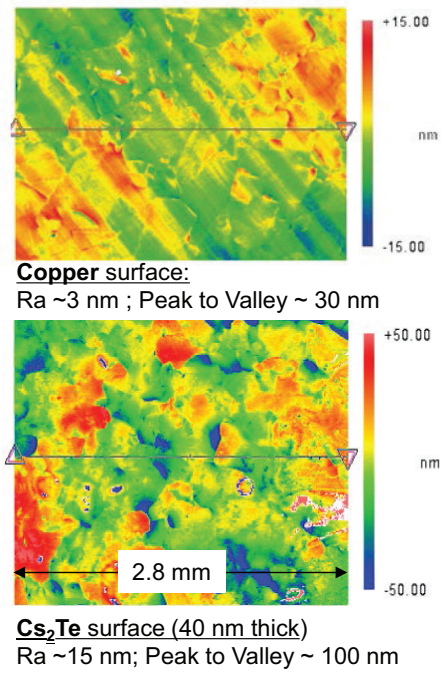

Figure 7: Interferometry measurements of a copper cathode surface (top) and of the Cs_2Te layer surface (bottom).

That is to say for laser energies above 1 nJ, the QE started to decrease due to space charge screening effect (Fig. 8). In addition the Schottky effect which influences the QE by lowering the barrier of potential is much less important for 1 kV/cm than in the RF gun where the extracting field is around 52 MV/m.

Nevertheless Fig. 8 shows that a QE of 0.1% is reached after 200 hours of operation at a pressure of 1.4e-8 mbar (the initial QE was around 1%). After 200 hours, an annealing procedure of 10 hours at 250°C has been applied to the cathode. This had the effect to bring back the QE to its initial value. This treatment was tested on a second cathode with the same result so that such annealing could be a sort of rejuvenation procedure to retrieve QE. It is however not clear what is the effect of annealing on the QE map and also how many times it could be applied. Most probably, the heating of the cathode helps to remove contaminants (oxygen based) present in vacuum and which accumulate on the cathode surface.

CONCLUSION

With the load-lock chamber installed at the RF photo-injector of SITF, one could clean copper cathode under vacuum and get QE above 1.e-4 and prepare Cs_2Te with QE above 1%. Using Cs2Te photocathodes instead of copper improves the QE by a factor 100 at the cost of 20 % emittance increase which is still within the requirements of SwissFEL operation. QE maps of Cs_2Te cathodes showed however non uniformities which might be explained by non-uniform spreading of Cs over the Te layer. Lifetime test at 100 Hz still need to be carried out but Cs_2Te is a valid cathode candidate for SwissFEL operation.

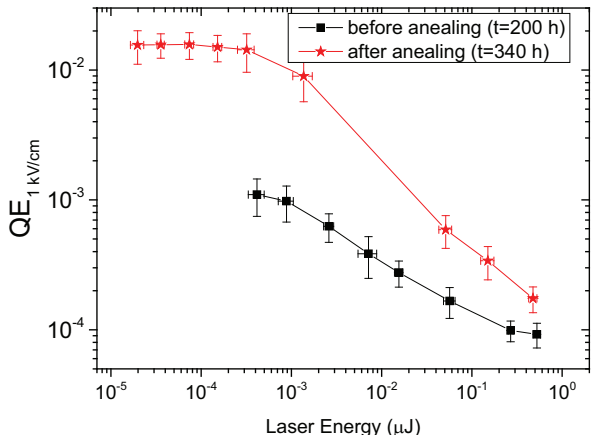

Figure 8: QE versus illuminating laser energy (266 nm, $F_{cathode}$=1 kV/cm DC; annealing temperature = 250 °C, P=1.4e-8 mbar).

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