SwissFEL CATHODE LOAD-LOCK SYSTEM

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Abstract

The SwissFEL electron source is an RF photo-injector in which the photo-cathode plug can be exchanged. Without load-lock, the cathode exchange takes about one week and cathode surface gets contaminated in the atmosphere during installation, leading to unpredictable quantum efficiency (QE) fluctuations. This motivated the construction of a load lock system to prepare and insert cathodes in the photo-injector. This load-lock system gives the possibility to prepare the cathode surface with methods like annealing. The QE can be checked and the plug can be inserted in the gun without breaking vacuum. This system will eventually give the possibility to use semiconductor cathodes like Cs_2Te. The system is described and first experience with its use is reported. A preparation procedure is proposed to obtain QE above 5.10^{-5} over 6 months

LOAD-LOCK SYSTEM DESCRIPTION

The SwissFEL injector Test Facility [1] is currently operated with an RF photoinjector from CERN (CTF3 Gun – 10 Hz repetition rate [2]). The backplane of this gun, has a hole where a cathode plug can be inserted (Fig. 1 Top). The future SwissFEL gun, allowing 100 Hz operation rate, will also be compatible with such cathode. A cathode plug can be exchanged without breaking the vacuum thanks to a load lock system. Such load-lock system has been recently developed together with Ferrovac [3] and commissioned at the SwissFEL injector test facility (Fig. 2 and 3). With a load-lock chamber the cathode exchange becomes much faster since no venting of the gun is necessary. Only half a day, including RF conditioning of the new cathode, is required per exchange (tested on Cu_17).

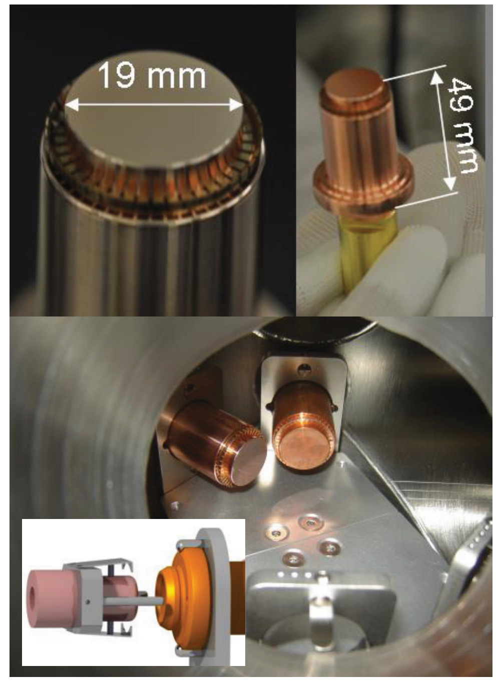

Figure 1: SwissFEL gun cathode plug with RF contact (Top). Grabbing system and storage carrousel (bottom)

The load-lock system consists in fact of three chambers (Fig. 2):

- the preparation chamber where cathodes can be cleaned, annealed and where the quantum efficiency (QE) can be checked.
- the vacuum suitcase where cathode plugs can be loaded from preparation chamber and transported to the gun.

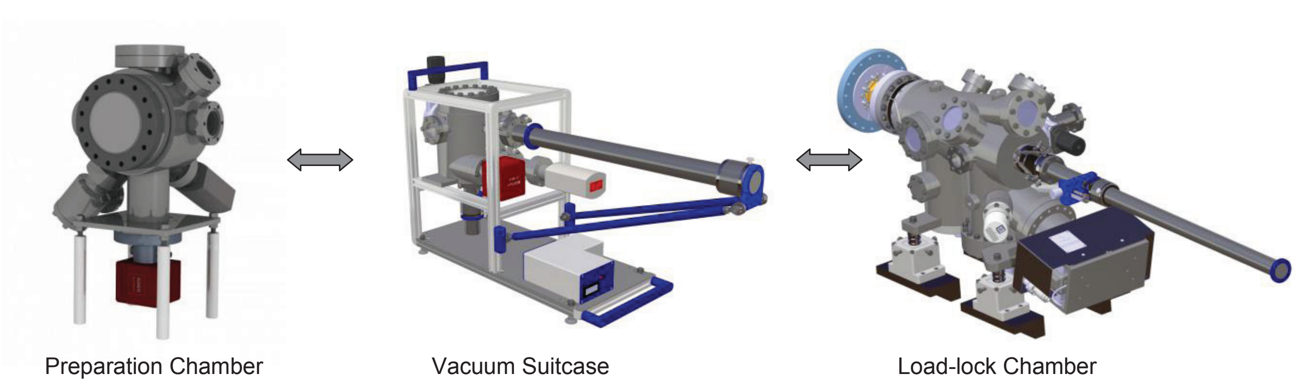

Figure 2 : Cathode plugs go first through the preparation chamber (left), are then transported via the vacuum suitcase (center) into the Load-lock chamber (right).

ISBN 978-3-95450-126-7

- the load-lock chamber which is permanently attached to the gun and in which cathodes can be transferred from vacuum suitcase to the gun backplane.

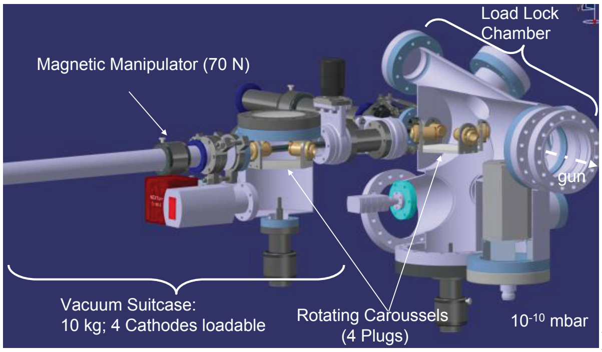

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Figure 3: Vacuum suitcase connected to load-lock showing the cathode transfer principle and the storage carrousels.

The cathode plug design has been slightly modified (additional side groove) such that a magnetically coupled manipulator arm can grab the plug out of a parking holder (Fig. 1) and safely transfer it linearly over half a meter distance, this all, in ultra high vacuum [3]. In each of the 3 chambers, a rotatable carrousel can hold up to 4 cathode plugs. Fig. 3 shows how the vacuum suitcase is connected to the gun load-lock. The manipulator maintains the cathode pushed into the gun during operation. These three chambers have been recently commissioned (Fig. 4) at the SwissFEL Injector Test Facility (SITF). The preparation chamber is not in the tunnel but in a separate laboratory equipped with a laser to check QE. One goal with this 3 chambers system is to find out a preparation procedure for the cathodes so that a predictable and reproducible QE can be obtained. In addition, it reduces shutdown time for cathode exchange and gives the possibility to install semi-conductor cathodes with high QE like Cs_2Te.

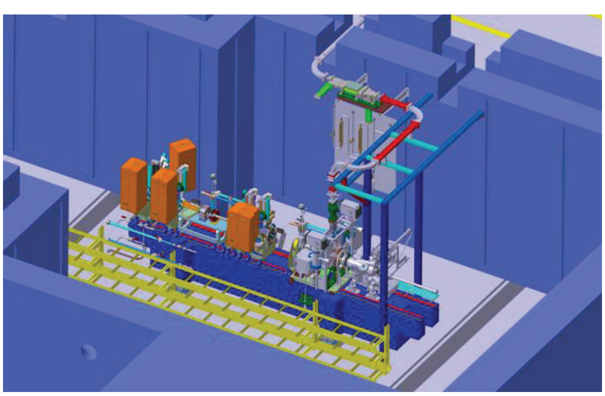

Figure 4: View of the load-lock chamber permanently connected to the RF photogun. The vacuum suitcase is removable.

QE HISTORY AT SWISSFEL INJECTOR TEST FACILITY

Experience at SITF in the past few years has shown that the QE time evolution is not the same for every cathode. Some of them had a very fast QE drop below the desired value of 5.10^{-5} (Fig. 5). Since October 2009, only one cathode (Cu_3 on Fig. 5) could hold a QE value well above this limit for more than 1.5 year.

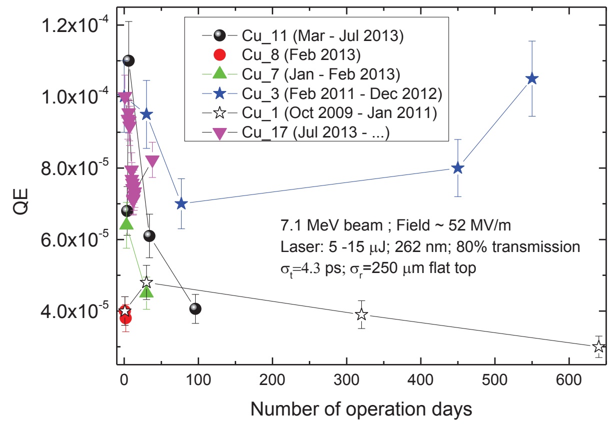

Figure 5: Evolution of the QE versus time for the different copper cathodes used in SITF.

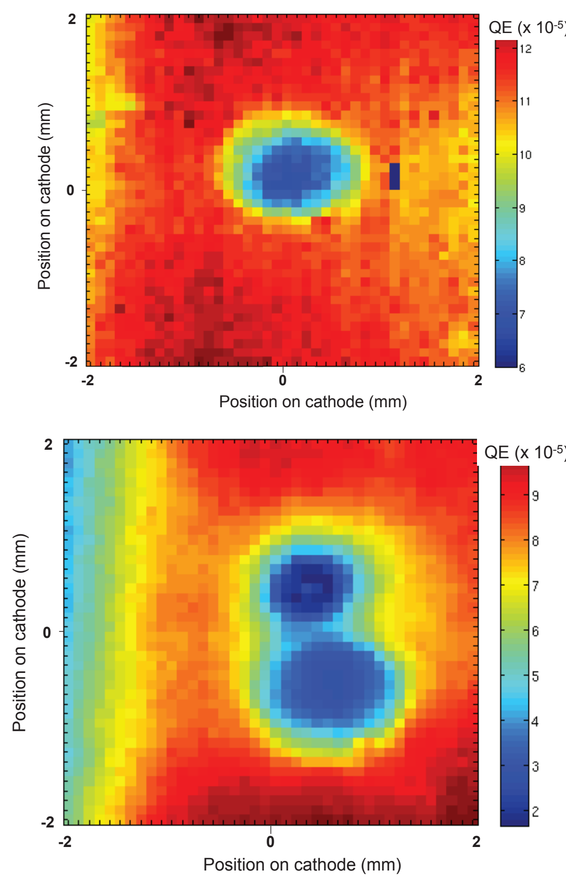

Figure 6: QE maps of Cu_11 after 10 days (top) and after three months of operation (bottom).

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A common behaviour to all the cathodes is a lower QE region at the laser illumination spot, about a factor 2 lower than the rest of the cathode (Fig. 6). This "hole" in the QE map appears already after a few days of operation (surface photochemistry). On top of this fast hole development, a general decrease of the QE can be observed in the first few weeks all over the cathode surface due to adsorption of carbon, oxygen, nitrogen or hydrogen based molecules (Fig. 6) [4, 5] . Although surface coverage by residual gas contaminants cannot be avoided (it takes less than one hour for one monolayer coverage at 10^{-9} mbar), the composition of this adsorbed layers is different when cathode was exposed to air or not. Especially surface water and hydrocarbons which covers copper exposed to air can be efficiently removed by annealing of cathode [6]. Assuming that molecules which will be adsorbed again in vacuum are less detrimental for QE, a careful cleaning of the cathode plug before installation should help to maintain a high QE over long period.

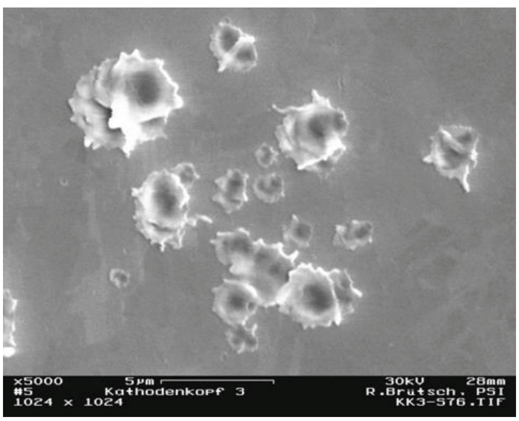

Figure 7: SEM picture of the cathode surface showing the craters resulting from RF breakdowns during conditioning.

Besides residual gas contamination, there are other sources of contamination in vacuum, like during RF conditioning of the gun where each breakdowns released contaminants which can redeposit on the cathode surface (Fig. 7) [7]. A good pre-cleaning of cathode surface should however minimize the RF conditioning duration and the number of breakdowns near cathode axis which eventually damages and contaminates the surface.

CATHODE PREPARATION RECIPE

QE depends on three theoretical parameters: the work function, the surface reflectivity and the local electric field (for a given laser wavelength). Contamination and roughness affect directly these parameters. Table 1 lists the main actions which influences (third column) these parameters and then indirectly the QE. Based on this list, we established a preparation procedure trying to optimizing each preparation actions (see Table 2). The cleaning of the cathode surface is done in the preparation chamber (Fig. 8).

Table 1: Parameters Controlling QE

Theoretical parameters controlling copper QE	Practical parameters controlling copper QE	Main actions controlling copper QE
Laser Reflection R (%) Work function $\Phi_{surface}$ (eV) Surface electric field F (MV/m)	Gas contents in the bulk (inclusion, type of copper)	Copper purity (< 3 ppm O_2) Forged > Cast Copper Cathode Firing (> 400 C)
	Surface contamination (adsorbed gases, oxide layer …)	Annealing (250 C) Exposition to air Ultrasound Cleaning Diamond turning Breakdown Conditioning
	Microstructure defects (local field enhancement)	Diamond milling Polishing

First tests with He / H plasma cleaning where not successful and finally the most effective way to remove surface contaminants was to heat up the cathode plug over several hours at 250 degrees C.

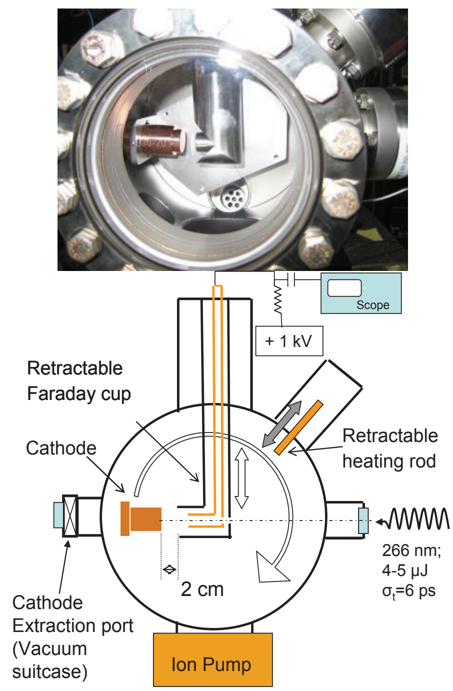

Figure 8: Cathode preparation chamber compatible with the vacuum suitcase for cathode transfer under vacuum.

The preparation chamber is equipped with a heating rod which can be directly inserted in the back of the cathode plug. Fig. 9 illustrates in relative units (QE=1 at t=0), the improvement of QE after heating cycles of more than 10 hours at 250 degrees C. An overall improvement (after some QE drop) by a factor 5 could be reproduced for three different cathodes with simple annealing at 250 degree C.

Different temperatures (but always below 400 degrees C to avoid grain size modifications) have been tested and it came out that 250 degrees C are enough and also the minimum to reach this significant QE improvement. A mass spectrometer attached to the pumping system indicated that mainly water was desorbed during the

ISBN 978-3-95450-126-7

heating procedure. Even if surface coverage will also happen in vacuum, the composition of this layer should be different than after air exposure.

As can be seen on Fig. 9, Cu-17 was removed from the preparation chamber before its QE decreases to 5 (relative unit). Indeed, this cathode has then been installed in the RF photogun for operation. Cu_17 is then the first cathode for which the procedure of Table 2 has been carefully applied.

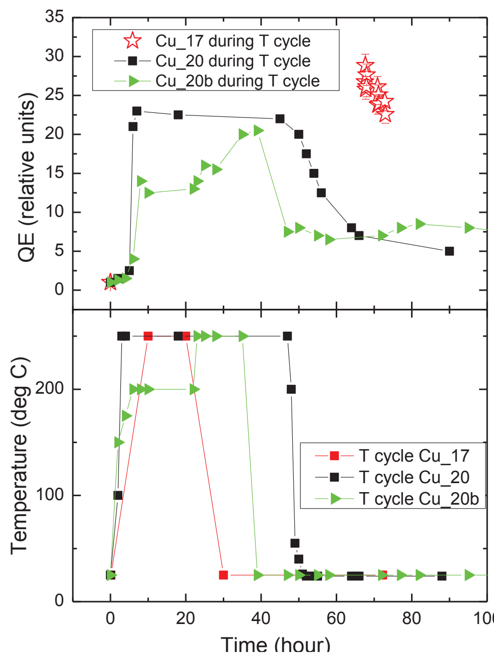

Figure 9: Evolution of the QE (top) during heat treatment of the cathode (bottom). After cool down there is a net gain of QE.

The first measured QE in the gun with Cu_17 was equal to 10^{-4} for a gradient of 52 MV/m (at nominal phase and RF power). After a rapid drop of the QE in the first 2 weeks the QE drop saturated around 7.10^{-5} before to rise again. Long term behaviour and reproducibility is still required to qualify the recepy of table 2 but already now the cathode Cu_17 could hold a higher QE than cathodes Cu_7, Cu_8 and Cu_11 (see Fig. 5 for comparisons).

The load-lock chamber gives the possibility to anneal the cathode and avoid exposure to air afterwards. A receipt for cathode preparation is proposed. Long term behaviour of the cathode, after such procedure, is still missing. In general, the load-lock allows a cathode exchange within 5 hours (RF conditioning included) making a regular cathode exchange possible (every six months for example).

Table 2: Preparation Procedure for Copper Cathodes at SwissFEL Tested on Cu_17

1. Cast Copper Cu – OFE; Grain Size ~ 70 μm; purity:[O_2]=4 ppm; 99.99%
2. Machining at PSI -> Ultra-sound cleaning
3. Sent to Polishing Company in conflat sealed transport tube filled with N_2 (> 1bar)
4. Diamond milling at external company (Ra < 3 nm); surface might be polluted
5. Return to PSI in transport tube (stored in this tube until needed; P> 1bar of N_2)
6. Extract from tube – via air – ultra sound bath acetone (15’); alcohol (10’)
7. Installation in Preparation Chamber (10^{-9} mbar) within 5’
8. QE_0 measurements (around ~ 10^{-5})
9. Cathode heating 250 deg C for 10 hours (ramp 25 deg/h)
10. QE measurements (should be ~ 10^{-4})
11. Extraction via Vacuum Suitcase (10^{-9} mbar)
12. Installation in Load-lock chamber (in tunnel) via Vacuum Suitcase (10^{-9} mbar)
13. Installation in Gun with Load-lock (20’)
14. RF conditioning -> Operation at 10^{-9} mbar; only a few RF breakdown events
15. QE in Gun at t_0 ~ 9.10^{-5}

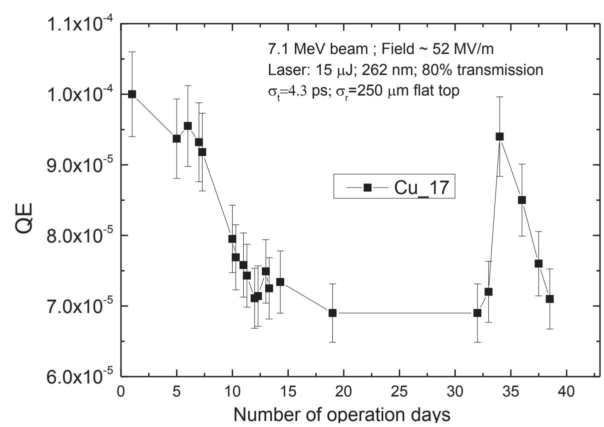

Figure 10: QE evolution with Cu_17 which was prepared using procedure depicted in table 2.

Finally the load-lock offers the possibility to also install semi-conductor photocathodes (e.g. Cs_2Te) with a much higher QE.

REFERENCES

[1] M. Pedrozzi, et al., PSI - Switzerland, Report: FEL-PM06-089-18-Injector_conceptual_report.doc
[2] R. Bossart, et al., in EPAC 1996, Barcelona, Spain, 1996.
[3] http://www.ferrovac.com/
[4] C. M. Quinn, et al., Transactions of the Faraday Society (1964).
[5] D. H. Dowell, et al., Phys. Rev. ST Accel. Beams **9**, 063502 (2006).
[6] D. T. Palmer, et al., SLAC, Report: SLAC-PUB-11355
[7] M. Schaer, et al., in IPAC'13, Shanghai, China, 2013.

ISBN 978-3-95450-126-7