EU contract number RII-CT-2003-506395 CARE-Report-2008-029-PHIN

PHIN
A Joint Research Activity for Photoinjector

Deliverables n° 2007-27

PHOTOCATHODE TESTS IN SUPERCONDUCTING CAVITY

Rong Xiang, Jochen Teichert, André Arnold, Petr Murcek

FZ Dresden-Rossendorf, Dresden, Germany

Abstract

The Rossendorf superconducting radio frequency (SRF) gun has been installed in the ELBE accelerator hall. The first cool-down was successfully carried out in August 2007. After that the first accelerated beam was produced from a copper photocathode on November 12, 2007 [1]. In March 2008 the cathode transfer system was mounted and the first set of cesium telluride photo cathodes for the gun was produced. Since May 2008 two Cs2Te photocathodes Cathode (#090508Mo and #070708Mo) have served in the gun. Cathode #090508Mo worked in SRF gun for one month, and emission time was more than 44 hours. It was damaged because of the pressure increase during the cavity warming. Cathode #070708Mo worked in gun for two months and was pulled out because of the cavity development. In this report, the cathode preparation, transportation and operation in the gun will be presented in detail.

CS_2TE PHOTOCATHODE TESTS IN SUPERCONDUCTING CAVITY

R. Xiang, J. Teichert, A. Arnold, P. Murcek
FZD, Dresden, Germany

INTRODUCTION

The Rossendorf superconducting radio frequency (SRF) gun has been installed in the ELBE accelerator hall. The first cool-down was successfully carried out in August 2007. After that the first accelerated beam was produced from a copper photocathode on November 12, 2007 [1]. In March 2008 the cathode transfer system was mounted and the first set of cesium telluride photo cathodes for the gun was produced. Since May 2008 two Cs_2Te photocathodes Cathode (#090508Mo and #070708Mo) have served in the gun. Cathode #090508Mo worked in SRF gun for one month, and emission time was more than 44 hours. It was damaged because of the pressure increase during the cavity warming. Cathode #070708Mo worked in gun for two months and was pulled out because of the cavity development. In this report, the cathode preparation, transportation and operation in the gun will be presented in detail.

CATHODE PREPARATION

Figure 1 is the cathode preparation chamber in the clean room. This system combines the cathode surface cleaning, film deposition and cathode diagnostic functions. The chamber is an accumbent stainless-steel cylinder sealed by flanges in both sides, one of which includes the laser windows and the other is cathode-holder-side connected to the cathode transfer system. The vacuum in the chamber is kept to 10^{-9} mbar level to ensure the Q.E. and reproducibility of the cathodes. The cathode is fixed in the cathode-holder-side of the chamber with the same holder as that in the SRF-gun. A Halogen light is used to keep the temperature of cathode plug $120 \pm 1^{o}C$ during preparation. There are three UV laser windows, which are used for the laser beams of diagnostic and evaluation (Q.E. distribution scanning and the reflection rate test). There is a diagnostic laser beam installed in the clean room. This small laser system provides 1mW 262nm UV laser, and the laser beam can be steered to normal incidence with small spot size (about 0.3mm diameter) for evaluation or to oblique incidence with big spot size (about 2mm diameter) for diagnostic during the evaporation.

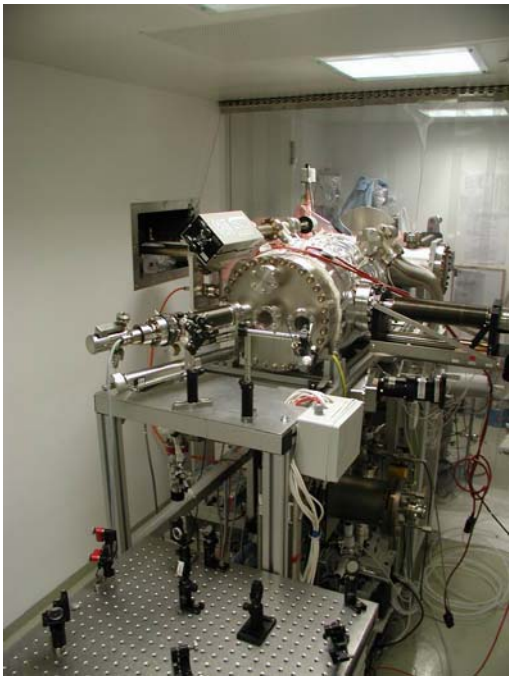

Fig. 1: the cathode preparation chamber at Rossendorf

The cathode plugs are made of molybdenum or copper. For the cathodes tested in the gun (#090508Mo and #070708Mo) the substratum is molybdenum. The plug surface is mechanical polished by machine, and then washed in the ultrasonic tank in turn with acetone, deionized water and isopropanol. After blowing with the dry N_2, the plug was installed on the top of cathode body, which is made of copper. Figure 2 shows the copper cathode body with polished plug. Totally 6 cathode bodies with plugs can be fixed with springs on the small movable carrier in the transport chamber.

Fig. 2: the cathode body with plug

The transport chamber is connected with the preparation chamber through buffer chamber (sluice) and transfer chamber. After the chambers are pumped to vacuum better than 10^{-8} mbar, the valves between the chambers can be opened, and then the cathode can be transferred from movable carrier to preparation chamber by the manipulators.

The vacuum in the preparation chamber is in the 10^{-9} mbar level before evaporation, and after the heaters begin to work, the vacuum increases to 10^{-8} mbar. During the whole production process, the vacuum is kept in this level. The cathode plug is degassed at 130^{o}C by a Halogen light for at least one hour, and cooled down to 120^{o}C for cathode production.

The cathodes #090508Mo and #070708Mo were produced with "sandwich" method—after the standard Te deposition and Cs activity, a thin layer Te was deposited again. This step enhanced Q.E. obviously in our experiments.

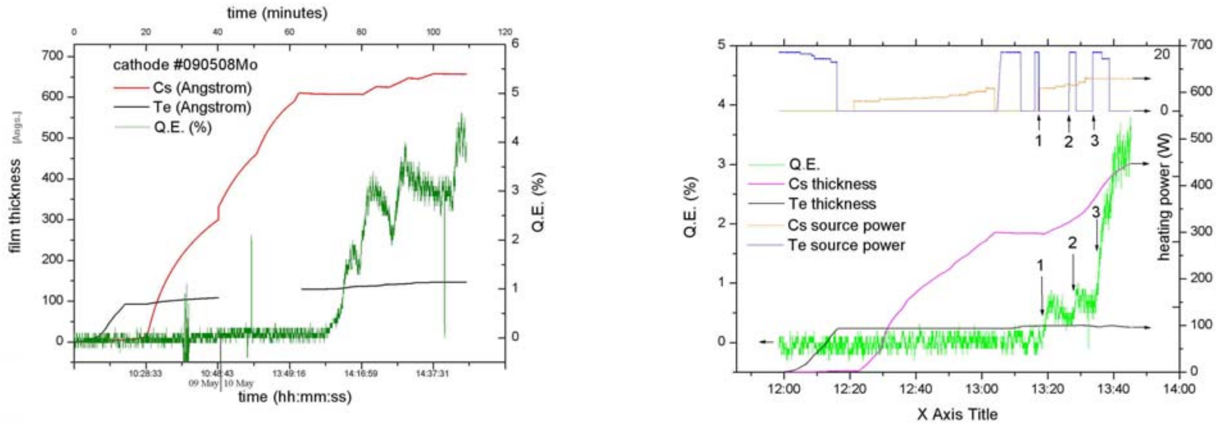

Fig 3: The experiment process of cathode production

Figure 3 gives the deposition process of Te and Cs and the Q.E. increase during the preparation process of cathode #090508Mo and #070708Mo. We take the cathode #090508Mo (left) as example. The film thickness is measured by the Sycon thickness and rate monitor, and then calibrated by a factor defined from a series film thickness measurement result with Rutherford backscattering spectroscopy (RBS). At first, the Te film is deposited to 100nm in a rate of 1nm/min, and then the Cs activity starts, but in this step the Q.E. increases very slowly. A layer of thin Te film (about 1nm) is deposited on the surface again, followed by another thin Cs film, and the Q.E. increases quickly up to more than 3%. This is a different phenomenon with the normal cathode production trend, and we believe this relates to the forming and changing of semiconductor surface structure in the process, not only the contents of film and their stoichiometric change. Similar phenomenon happened in other cathodes preparation processes. For example, figure 4 is the preparation process of the cathode #140508Mo, which is produced with co-evaporation method, but during the deposition process the Q.E. increases slowly. After the re-evaporation of a layer of thin Te film (1.5nm) the Cs activity restarts, the Q.E. jumps from 0.5% to 6.5% in short time. Detailed research must be done to explain these phenomena in the near future.

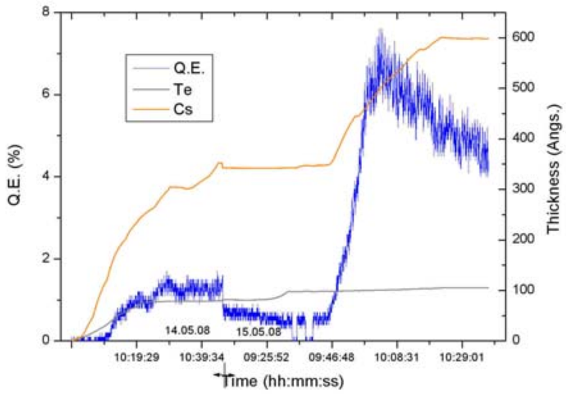

Fig 4: The experiment process of co-operation cathode #140508Mo

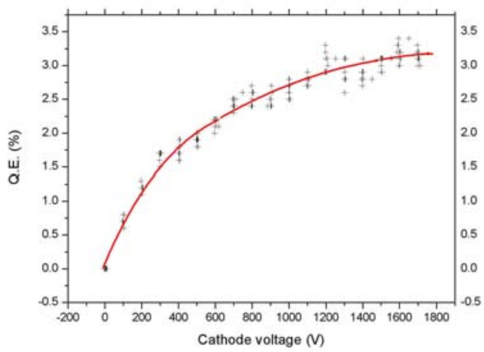

Fig. 5 the Q.E. measurement after 3 days for cathode #090508Mo

After the evaporation is stopped, the cathode is kept to 120^{o}C for half an hour to get more stable emission film. The Q.E.-HV curve has been measured after 3 days (Figure 5), from which the Q.E. 3.2% is found reasonable compared with the fresh Q.E. of 4%.

The prepared cathode is transferred back to the movable carrier by manipulators and stored in the transport chamber, at last transported to ELBE accelerator hall and installed into the SRF gun.

CATHODE TRANSPORTATION

The semiconductor photo cathode like Cs_2Te is sensitive to the oxygen and the other contaminators, and requires a cathode transfer system, in which the cathodes can be manipulated and stored in ultra-high vacuum. Its design is presented in Figure 6. The system consists of three vacuum chambers: the transfer chamber (left), the buffer chamber (middle), and the transport chamber (right). In the system a movable carrier for 6 photo cathodes is located. One of the two manipulators is for the movement of the carrier, and the second serves for the exchange of the photo cathodes in the the gun. A second similar transfer system exists in the photo cathode preparation lab, and the transport chamber can be dismounted, the cathodes are brought from the preparation lab to the SRF gun cathode position (figure 7).

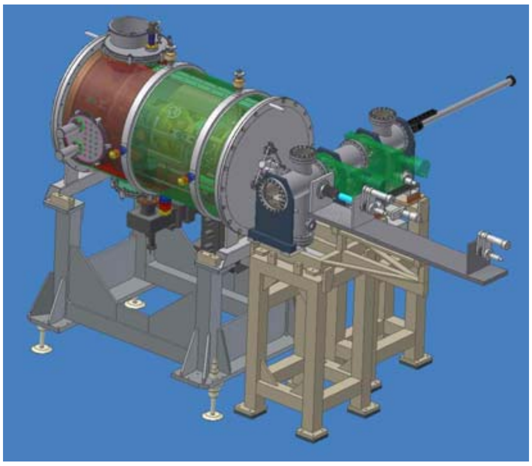

Fig. 6: Design of the photo cathode transfer system.

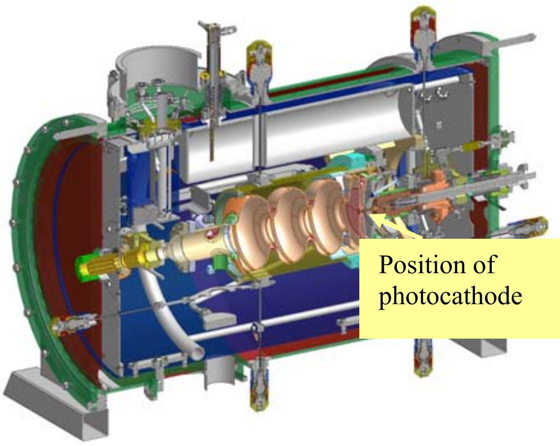

Fig 7 photocathode position in SRF gun

In the cathode storage and transportation, the vacuum is most important. In Figure 8, the red curve presents the vacuum fluctuating in the transport chamber during the cathode #070708Mo transport. Because of the valve opening, the manipulator operation and the carrier movement, the vacuum can reach $2*10^{-8}$ mbar for several seconds. Although this was a short time contamination, this hurt Cs_2Te film and reduced the Q.E. from 3% to 0.04%.

To improve the vacuum, a NEG pump from SAES has been installed in the transport system between the chamber body and the ion getter pump. This NEG pump doesn't need electrical power after activity, so it is suitable to keep UHV on the way. At the same time, better baking is needed to degas the chamber wall.

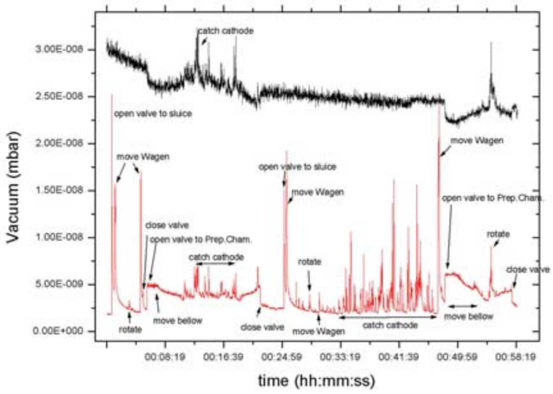

Fig.8: the vacuum fluctuating during the cathode transport
(red curve: vacuum in the transport chamber)

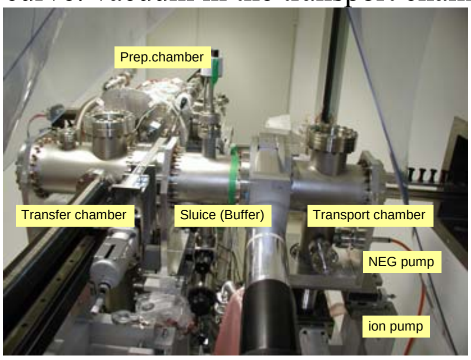

Fig 9: the cathode transport system for SRF gun

CATHODE TEST IN SRF GUN

In order to fulfill the requirements of the SRF gun specifications, a UV laser system has been developed by MBI. The laser system can provide 500 kHz, 125 kHz, 2 kHz and 1 kHz for the experiments. The laser pulse has a Gaussian temporal beam shape with a width of 15 ps FWHM, and the beam is cut with an aperture to obtain a circular flat top profile. A picture of the laser spot (virtual cathode) is shown in Figure 10. The diameter of the spot is 2.7 mm.

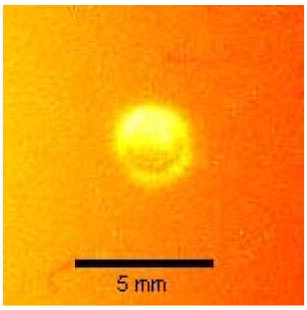

Fig. 10: CCD camera image of the laser spot at the virtual cathode.

After installation of the cathode transfer system, two sets of Cs_2Te photo cathodes were produced in the preparation lab at FZD (see the table 1). Cathode #090508Mo and #070708Mo are used in the SRF gun for the beam loading tests. Here we will report on the test results about the quality of cathodes.

Table 1: the cathode arrangement in the transport chambers

Cathode arrangement in transport chamber 1 (Max) (preparation lab, 14.05.2008)				16.05.2008 to Elbe hall 12.07.2008 to Prep.lab	
position	body No.	plug No.	cathode No.	fresh QE	status
1		Mo	#010508Mo	0.1%	In Max
2		Cu	#010508Cu	0.3%	In Max
3		Mo	#090508Mo	4%	23May to gun, 23Jun.out
4		Mo	#140508Mo	5%	damaged, in Paul
5		holder	fluorescence		
6		-	-		

Cathode arrangement in transport chamber 2 (Paul) (preparation lab, 11.07.2008)				12.07.2008 to Elbe hall 23.09.2008 to Prep. Lab	
position	plug No.	plug length	cathode No.	fresh QE	status
1	-	-	#140508Mo		damaged
2	Mo14	7.88mm	#070708Mo	3%	21.Jul.to gun, 19.Sep.out
3	Mo15	7.87mm	#080708Mo	0.1%	Paul
4	Mo16	7.99mm	#100708Mo	1%	Paul
5	Mo20	7.99mm	#110708Mo	3%	Paul
6	Mo21	7.89mm			in gun

Cathode #090508Mo

After preparation the cathode #090508Mo had fresh quantum efficiencies of 4%. It was transported to SRF gun on 23 May 2008 and then the first beam from it was produced. On 23.June, the cathode #090508Mo was damaged because of the accidentally exposure to bad vacuum of 10^{-5} mbar range during the cavity warming process.

Figure 11 shows the measured Q.E. distribution measured in SRF gun. The laser power was 50 mW repetition rate 100 kHz, and the bias cathode voltage -4.5 kV. Whereas the local fluctuation of about 20 % was rather good, the overall Q.E. of the photo cathode was dropped down to about 0.05%. We assume that the reason is the bad vacuum of 10^{-8} mbar in the transfer system during the transport and insertion into the gun. The QE measurement was repeated every weak without any further significant changes. As we know, the good vacuum environment in the SRF cavity ensures the cathode life time.

The Q.E. via cathode voltage curves were measured in different position and with different laser power (Figure 12). From the left graph, the points for black and red curves located in the centre of cathode, and the other points in the relative edge of emission film. Obviously, the centre of cathode had higher efficiency than the other area, which was the same as Q.E. map in Figure11. For the centre point, -5 kV cathode bias voltage seemes not enough for the eduction of all electrons. This can be found in the right graph too, the curves have not reached the maximum photocurrent in the given voltage range. In the test of the second cathode, RF field is used to measure cathode quality with higher surface field.

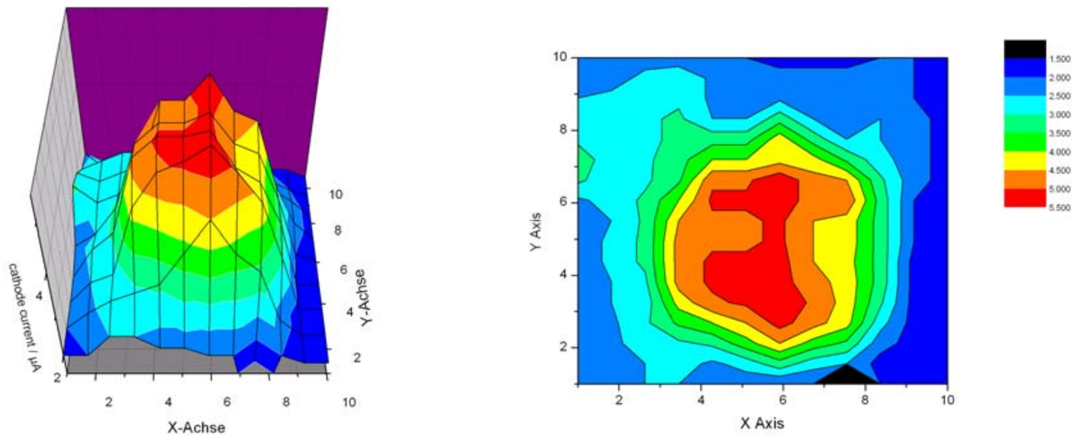

Fig.11: Q.E. map of cathode #090508Mo measured in SRF gun

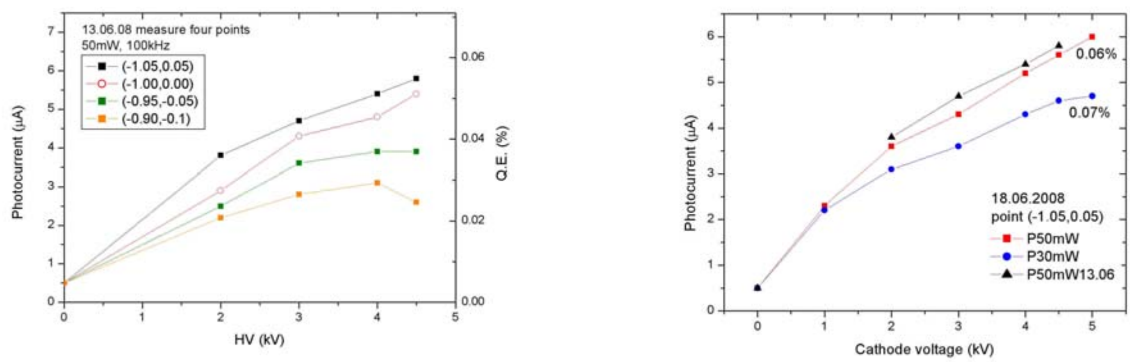

Fig. 12: the Q.E. measured in different position and with various laser power

cathode #070708Mo

The cathode #070708Mo was produced soon after the vacuum accident in the gun and the transfer system. The fresh Q.E. was 3%, and kept to 3% after one day stored in the preparation chamber. It was inserted to SRF gun on 21.July and worked in the gun for two months. A large number of experiments in the beam physics have been done with this cathode, for example, emittance, energy and energy spread measurement, Schottky scan, and so on [2].

Immediately after the cathode installation the Q.E. was measured, but it was pitifully reduced to 0.04%. And periodic measurement has been done and there was no distinct decrease found in the next two months. Figure 13 is the last measurement result. From the linear fit for the low laser power range, the Q.E. can be calculated to 0.04%. The history of Q.E. is presented in the figure 14. After the test, cathode #070708Mo was sent into the preparation chamber again and the rejuvenation has been done on it. After it was heated to 120oC, the Q.E. increased to 0.7% and kept in this level. Then, the Cesium reactivation was performed and the Q.E. continued to increase till 1.4% and then stopped.

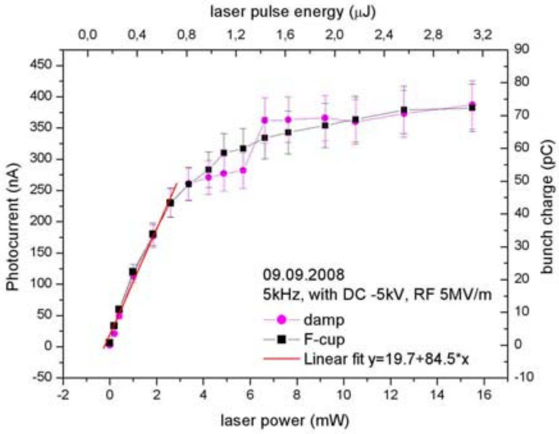

Fig 13: cathode #070708Mo Q.E. measurement in SRF gun

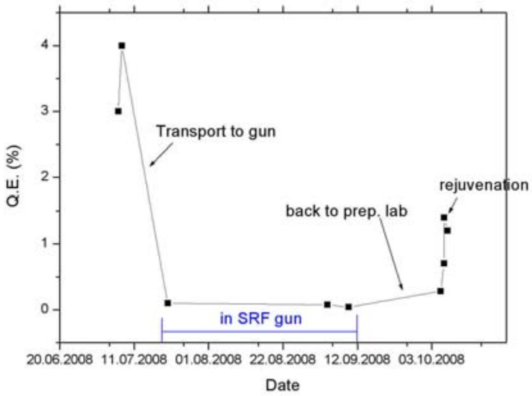

Fig 14: the Q.E. history of cathode #070708Mo

The Q.E. maps were measured with and without RF filed in the gun (see figure 15). The left graph was measured only with cathode bias voltage 4.5kV, and the photocurrent was read from the high voltage generator. The right graph was measured with DC voltage and RF gradient 5MV/m, and the photocurrent was read from Faraday cup. The efficiency distributions from the two maps are similar. The edge of emission area is not so sharp, because the laser spot on the cathode is as big as ф2.7mm, but the emission area is only ф 8mm. A smaller diagnostic laser beam will be built in the next step.

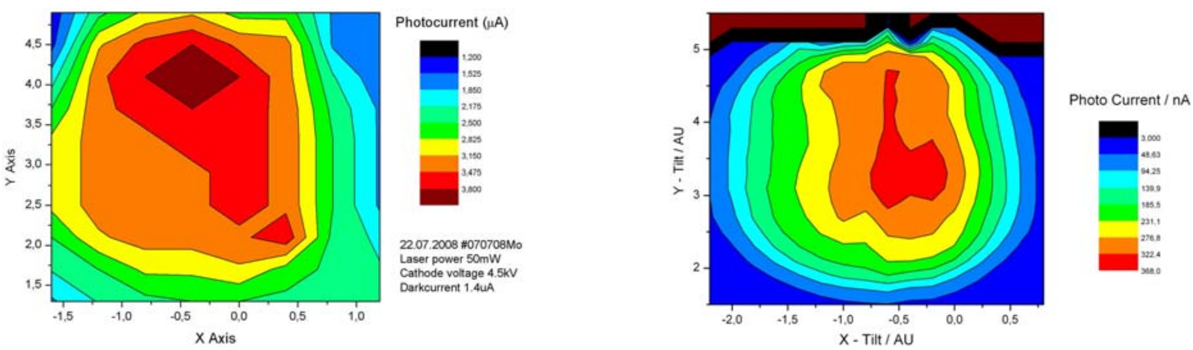

Fig. 15: Q.E. maps of the Cs_2Te photo cathode in the SRF gun

Field emission has been found in the SRF gun cathode area. A series of photos was taken from the fluorescence screen as figure 16. The first photo is the field emission only with RF field 5MV/m. A ring in position of cathode edge or the gap to cavity can be seen obviously. It doesn't come from the Cs_2Te but from the cathode itself film because of the ring shape. The cathode sharp edge from the polishing may cause the local high field. From the second photo on, the field emission increases with the RF field gradient, this can be found clearly from figure 17. The dark current measured in the Faraday cup increased quickly when the RF field was more than 4MV/m, correspond 1.6 MV/m on cathode surface. This dark current may come from the Cs_2Te film or the cathode plug itself.

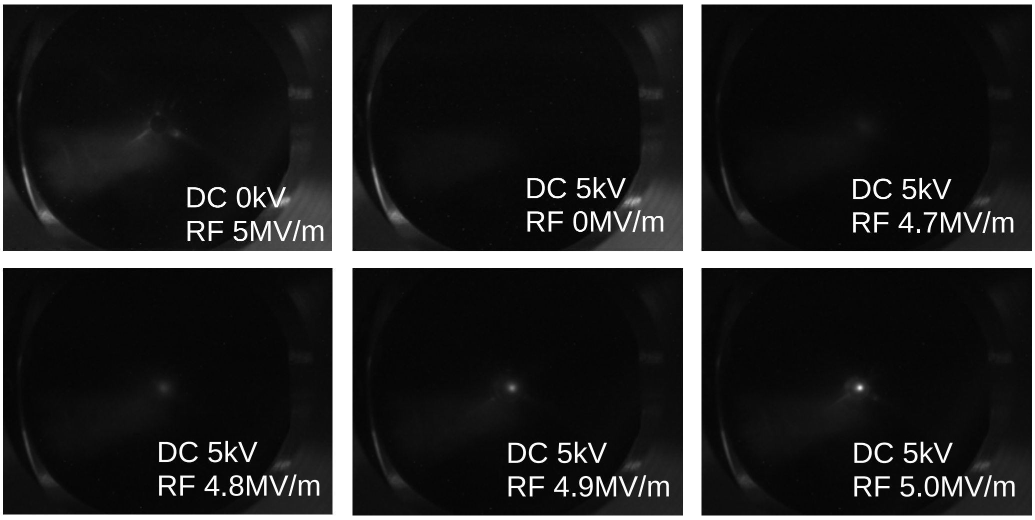

Fig.16: Field emission found in the SRF gun

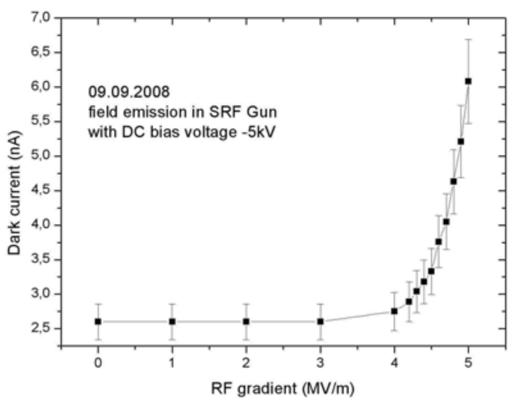

Fig.17: dark current in the SRF gun increasing with RF gradient.

SUMMARY AND OUTLOOK

A SRF photoinjector has been installed at the ELBE linac in summer 2007. The commissioning phase is finished before October 2008. Two Cs_2Te photo cathodes #090508Mo and #070708Mo are used successfully in SRF gun for beam loading tests. There is no contamination found from the Cs_2Te cathode to the SRF cavity in our tests up to now (from the result of cavity quality measurement), and there is no further reduce of Q.E. during the cathode running in the gun. The next step is to improve the vacuum in the transport chamber, and realize the automatic cathode exchange in the ELBE accelerator hall.

REFERENCES

[1] J. Teichert, et al.,"A Superconducting RF Photo-Injector for Operation at the ELBE Linear Accelerator", Proc. FEL 2007, Novosibirsk, Russia.

[2] J. Teichert, et al.," Initial Commissioning Experience with the Superconducting RF Photoinjector at ELBE", 30th International Free Electron Laser Conference, Gyeongju, Korea, 2008

ACKNOWLEDGEMENT

We acknowledge the support of the European Community-Research Infrastructure Activity under the FP6 "Structuring the European Research Area" programme (CARE, contract number RII3-CT-2003-506395) and the support of the German Federal Ministry of Education and Research grant 05 ES4BR1/8.