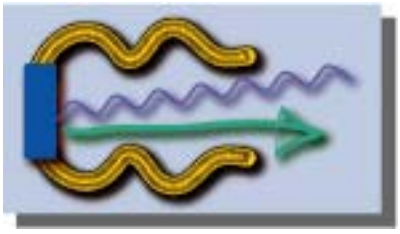

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REPORT ON PHOTOCATHODES

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1) Visiting Scientist from Peking University, Beijing

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Introduction

Advanced electron injectors are based on photocathode electron guns. These guns can produces electron beams with short pulses and high brightness. At the beginning the progress in photo-injector development has been mainly driven by FEL applications. But now photo-injectors are the electron source of choice for future linear colliders, high-power FELs, linear accelerators with energy recovery, fourth generation light sources, injectors for laser-driven plasma wake field accelerators, or low-energy electron linacs for applied research.

For all the different photo-injector systems the photo cathodes play a key role. In strong connection with the laser system the choice of the optimum cathode type and its further improvement is a main issue for the progress in photo-injectors. in the following an overview of the existing knowledge in the field of photo cathodes for rf photoelectron injectors is given and the status of research and development of the laboratories collaborating in the CARE/JRA2 and working in this field is presented.

Photocathode material and their properties

In the following the information about some types of photocathodes: semiconductor cathodes, metallic cathodes, thermionic cathodes, ferroelectric photocathodes, ion-implanted photocathodes and ceramic superconducting cathodes. Among these materials, semiconductor cathodes have higher quantum efficient (QE), but shorter life time than metallic cathodes. Thermionic cathodes are investigated as cathode for RF injector using heating temperature below the usual operating temperature for thermionic emission. Ferroelectric photocathodes and ceramic superconducting cathodes are not very wellknown in the photoelectric performance. From ion-implanted photocathodes not enough information is available to describe them well.

Cs_2Te is a p-type semiconductor, and has been chosen as the best candidate in several FEL laboratories. It has good QE in hundred of hours, and it can stand a field as high as 100MV/m, but it needs ultra high vacuum and be sensitive to oxygen. And its physics performance in low temperature (2~4K) is unknown.

For semiconductor, photons must deliver enough energy to raise the electron from the valence to the conduction band (E_g) and from conduction band to vacuum level (E_a), so the energy of photons must be: $E_{photons} > E_g + E_a$ for a single photon process. For metallic cathode, the excitation energy must be larger than their work function.

		E_a+E_g (eV)	(nm)	Advantages	Disadvantages	Ref
Alkali-halide	CsI	6.4	209	Air transportable	209nm is impractical satellite bunches and saturation in RF gun	[1]
	CsI-Ge	5.0	248			
Alkali-antimonide	Cs_3Sb	2.0	620	Work in visible range	Very sensitive to contamination, short lifetime	[1]
	K_3Sb	2.3	539			[1]
	Na_2KSb	2.0	620			[1]
	K_2CsSb					[2]
Alkali-telluride	Cs_2Te	3.5	354	a reliable photocathode material		[1]
				Good QE and life time. Stand high field up to 120MV/m	Need UHV	[4]
				Ä Resistance to laser damage: at least 6 W/cm^2 @ 262 nm		[7]
				Rejuvenation partially The dark current@20MV/m is negligible	Need uv laser	[11][13] [2]
	Rb_2Te	4.1	302	Rejuvenated partly, by heating and ion bombardment etching		[1][6]
	RbCsTe	-				
	K_2Te	-				
Negative Electron Affinity	GaAs (Cs)			polarized electron source	response time is as long as ns	
	(111) Diamond		<210nm	Long life time and fast response	A poor response because of NEA	[2]

Table1: Properties of semi-conductor photocathodes.

	No.	Work function (eV)	□nm)	Advantages	Disadvantages	
Nb		4.0	310	Nb cavity itself, direct and simple, and no contamination, robust cathode	QE is too low because of their high reflectivity and the shallow escape depth, even with special treatment (etching, laser conditioning)	[20]
Ca	20	2.9	427	The most robust cathode, Air transportable		[8]
Ba	56	2.5	496			[2]
Y	39	2.9	427			[2]
Sm	62	2.7	459			[2]
Mg	12	3.66	339			[2]
Cu	29	4.3	288			[2]

Table 2: Properties of metallic photocathodes.

	QE @λ	Advantages	Disadvantages	
Trioxide cathode	0.1%@355nm	Air transportable Can be rejuvenated by heating to700^{o}C, the work function of Scandate dispenser is on the order of 2 eV	Long response time. Need slight heating to keep the QE from degrading too quickly	[2][21]
B-type thermionic dispenser	3.5×10^{-4}@266nm		Need slight heating to keep the QE from degrading too quickly,	
LaB_6	0.1%@355nm ~ one day			

Table 3: Properties of thermionic electron emitters.

For ferroelectric photocathodes [2] a quantum efficiency of QE~6×10^{-4} at 355nm wave length was found. The other performance is unknown. Ceramic superconducting cathode were investigsted in [24] but their photoelectric performance is still unknown. Ion-implanted photocathodes [18] were produced by implanting Cs ions to 30 nm of metal, which is about the mean-free path of visible light in metal. Implantations into Ag, Au, W, and Mg were carried out. The quantum efficiency can increase by one order of magnitude. The lifetime is longer than that of semiconductor photocathodes. Another significant result is that photoelectrons can be generated with ion-implanted photocathodes by green laser light.

Photocathode Operation

The relevant properties for a Photocathode are: spectral response, operational lifetime, temporal response, saturation level, damage threshold, voltage hold-off, the transverse energy spread of the emitted electron beam [2] and the dark current, average current density.

Material	sub	QE @λ	Life time	Field (MV/m)	working vacuum (mbar)	Dark current	average current density	Response time	damage by Laser	Laboratory	Ref.
CsI-Ge		0.73 %@213nm 0.13%@266nm	$T_{1/\tau}$ > One year	70						CERN	[1]
		2%@209nm	$T_{1/\tau}$ > 150 h		10^{-10}~10^{-9}			(>ps)			[2]
Cs_3Sb		2.0%@266nm 0.38%@532nm	very short (from 1 to few hours)							CERN	[1]
		4%@527nm	$T_{½}$ <4 hours	>20	10^{-10}~10^{-9}			~ps			[2]
K_3Sb		1.6%@266nm 0.023%@532nm								CERN	[1]
		1~3%@262nm	robust								[6]
K_2CsSb		8%@527nm	$T_{½}$ <4 hours	>20	10^{-10}~10^{-9}			~ps			[2]
		1.2%@541nm	daily							Netherland FEL	[19]
Cs_2Te		13%@266nm									[1]
	Cu,Au	0.2-0.5 %		22		Very small				ELBE	
		16%@262nm	~450 hrs QE>1.5%	100						CTF2-2002	[2]
	Cu-Au	2~8%@262nm	Few week QE>1.5%	120	$1~5\times10^{-9}$					CERN-PHIN	[4]
	Cu		>300 hrs	100	7×10^{-9}	Several mA					[5]
		10% at 262nm	drops during the first 50 hours with a τ~40 hours, followed by a slower decrease with a τ~350 hours.	127	10^{-9}			<2ps		CERN	[6]

		> 1.5 %	QE > 1.5 % during 460 h @ 750 μA		1.4x10-9		21 mA/cm^2		6 W/cm^2 @ 262 nm	CERN	[7]
	Mo	5.6%@262nm		35~40	10^{-10}	16μA				DESY	[10] [21]
		0.2-0.5 %		22		Very small				ELBE	
		8%@263nm	More than one month QE>1%		5×10^{-8}					Fermi lab	[11]
	Mo	16~18% @ 251nm 8~12% @ 263nm	over 1% for 100h	20~25	10^{-10}	<0.4mA/cm^2				LANL	[13]
		13%@266nm	$T_{1/\tau}$ >100 hrs	>20	10^{-10}~10^{-9}			<3ps			[2]
KCsTe	Same as Cs_2Te									CERN	[21]
GaAs (Cs)		3~5%@ HeNe		30		Larger than PEA carhodes				BINP, Russia	[9]
			20 hours of CW beam with an average current of 3.1mA, $T_{1/\tau}$ ~58 hrs	3.9 DC gun							[12]
		1.5~6%@750nm	short		10^{-11}			<ns			[2]
Material		QE @λ	Life time	Field (MV/m)	working vacuum (mbar)	Dark current	average current density	Response time	damage by Laser	Laboratory	Ref.

Cu	4×10^{-5}@248nm		75						ARGONNE	[8]
	1.4×10^{-4}@266nm	Almost indefinite	>100	10^{-7}			<ps			[2]
									BNL	
Mg	1.3×10^{-4}@248nm		75							[8]
	6×10^{-4}@266nm	>5000hours		10^{-7}			<ps			[2]
	0.2 ~ 0.3% @266nm.		100	10^{-9}	thermal emittance is 0.4 mm-mrad/mm				BNL	[22]
	1.3×10^{-4}@265nm			10^{-10}					Univ. of Tokyo, Japan	[23]
Y	1×10^{-5}@248nm		75							[8]
	5×10^{-4}@266nm	long	~100	$<10^{-7}$			<ps			[2]
Ca	4×10^{-5}@248nm		75							[8]
Sm	7×10^{-4}@266nm	long	~100	$<10^{-7}$			<ps			[2]
Ba	0.1%@337nm			$<10^{-7}$			<ps			[2]
Nb	10^{-4}@266nm							0.3 mJ/mm^2 for 15ps, 266nm 3.5 mJ/mm^2 for 20ns, 248nm	BNL	[20]

Photocathode preparation (Cs_2Te preparation process)

1. Cs_2Te cathode plug

Mo, Mg, Cu can be as the substrate. Mo is the best, and Mg has high dark current [6]. The Cs_2Te cathodes on gold film have higher QE at the beginning in use, but the QE deceases more rapidly [3]. In CERN, cathode plug was cleaned by Ar+ bombardement, QE > 1.5 % during 460 h @ 750 μA, $1.4x10^{-9}$ mbar [7]. In Milano, the Mo or Cu substrate is polished with diamond grinding powder of 50nm size [10]. In Milano and CEA-BIII, the Mo substrates were mechanically polished with 1 mm diamond powder, and then rinsed with acetone and ethanol. Once UHV conditions were obtained, the substrates were heated at 500 °C for about 30 min to improve the surface cleaning. During this phase, the total pressure never exceeded 2×10^{-9} mbar [15].

In Fermi lab, the molybdenum cathode is heated with a halogen lamp to encourage the evaporation of surface contaminants: the temperature is ramped up to 350°C and held at 350°C for 30 to 60 minutes. The cathode is then allowed to cool to 120°C and held at that temperature for the duration of the coating [11].

2. The standard evaporation process:

That is evaporation of alkaline layer over the Tellurium layer on substratum [4]. The Cs_2Te formation goes on through several steps (analyzed by Auger and XPS spectroscopy) [15]:
i) a two-phases system Te + $Cs_{1.2}$ Te is observed at the beginning of the reaction of the Te film with the Cs vapour;
ii) as the Cs deposition is carried on a new $Cs_{x>2}Te$ phase has been detected ~0.5 nm below the surface;
iii) finally, a homogeneous, single phase Cs_2Te film results.

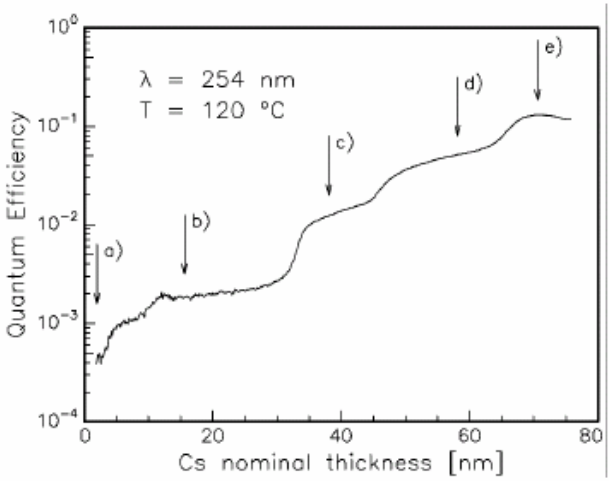

Fig. 1: Increase of QE versus Cs deposition.

In Milano and CEA-BIII [15], during the fabrication process, the substrate was held at 120 °C by resistive indirect heating. First, 10 nm of Te was deposited at a rate of 1 nm/min. Then, the film was illuminated by the 253.7 nm radiation and Cs was deposited at a rate of 1 nm/min. The photocurrent gave a real time control of the growth process (fig1). At the end of the fabrication, the Cs source and the substrate heater were simultaneously switched off. The cooling rate was 6 °C/min.

In the Fermi Lab [11], the sources are degassed by flowing a small amount of current through them at the beginning. In the mean time, the molybdenum cathode is heated with a halogen lamp to encourage the evaporation of surface contaminants: the temperature is ramped up to 350°C and held at 350°C for 30 to 60 minutes. The cathode is then allowed to cool to 120°C and held at that temperature for the duration of the coating. A quartz crystal thickness monitor is inserted momentarily to calibrate the evaporation rates for the Cs and Te sources. Ultra-violet (UV) light from a mercury lamp (λ= 254 nm) is focused onto the cathode and the photocurrent is monitored during the deposition. Te is deposited for 10 minutes at a rate of 1 nm/minute, and then Cs is deposited at the same rate for 60 to 120 minutes. The pressure typically increases to the order of 10^{-9} mbar during evaporation. The color of the photo-emissive film was orange for the first cathode (Cs deposited for 63 minutes) and blue for the second cathode (Cs deposited for 110 minutes).

3. With co-evaporation: [5]

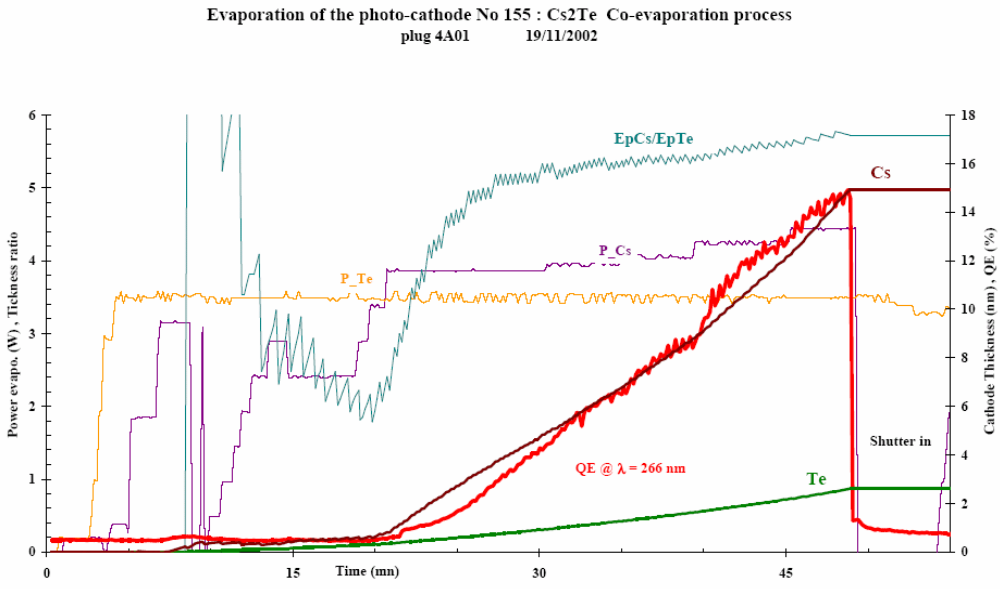

Fig. 2: Time curves of the co-evaporation at CERN.

In standard evaporation process, the Cs-Te cathode experiences some stages [15], and not only Cs_2Te forms in the process, but Cs_2Te_5 is also a stable component [16] among them. They have different photoelectric property, so may make the quality of the cathode un-anticipative.

Another thing is that maybe the Te film cannot be activated uniformed. The deeper layer is short of Cs atoms and the surface is rich of Cs. These layers are different in quality.

If we control the ratio of Cs/Te exactly, we can use the Chemical Vapour Deposition to get more proportioned Cs_2Te film. But the control of the two sources needs many experiments and much time to test.

4. Rejuvenation

The main contamination comes from oxygen [6]. The oxidation damage can be partially recovered by simultaneously heating the substrate to ~230 °C and illuminating it with the 4.9 eV ultraviolet radiation. No recovering has been observed under the effect of the temperature or the radiation alone [15].

Preparation Chambers

In the Fermi lab [11] all components of the cathode preparation chamber are compatible with UHV. The chamber is baked at 150 to 200^{o}C after exposure to ambient air. The vacuum is maintained by two ion-getter pumps and a titanium sublimation pump. Ionization gauges and a residual gas analyser (RGA) are used to monitor the pressure. The chamber can accommodate up to 5 cathodes, which could in principle all be used in turn without the need to bleed up the chamber. A cathode is moved from the coating chamber to the RF gun via one mechanical actuator and two magnetically coupled actuators. The electrical contact between the cathode and the wall of the gun is made with a toroidal Be/Cu spring.

In Milano and CEA-BIII [15] Te and Cs sources are Ni boats from SAES-Getters, filled with 99.999% Te powder and a mixture of Cs_2CrO_4 and 84%Zr–16%Al (ST 101) non-evaporable getter alloy, respectively. They are resistively heated by a current flow. The evaporation rate has been monitored by a quartz crystal microbalance. The photocurrent was produced by an Oriel 100 W high pressure Hg arc lamp, equipped with a condenser lens, a diaphragm, a dichroic mirror, a series of interference band pass filters (253.7, 270, 297, 334, and 355 nm, with 10 nm band pass) and a fused silica lens. The light intensity at the substrate position was measured by a calibrated Si photodiode. The photo-emitted electrons were collected by a circular anode, polarized at 1100 V with respect to the Photocathode (grounded).

Photocathodes for SRF photoinjectors

Requirements

1. Enough QE (>1%) in needed lifetime (several months).

2. Robust against strong laser shots
3. The least contamination to Nb cavity
4. Plug without C or H element on surface.
5. The least heat load to SC cavity
6. Tolerance to high RF field
7. Lowest reflection
8. The good vacuum in the SC cavity does benefit to the operation lifetime of the photocathode

Future questions for photocathodes in SRF

1. How to get enough QE (>1%) in needed lifetime (several months).
2. For a Photocathode used in CW mode, it is necessary to get the best thermal conduction and electric conduction of both the emitter layer and the stem.
3. Study the physics performance of the cathode material in high rf field and in the low temperature condition (77K or 4.2K), such as the thermal emittance, response time and the interaction between the substrate and emitter.
4. If the curve (spherical, concave, plane) of the plug surface affects the performance of the cathode.
5. To produce the uniform emitter, the holder of the cathode plug can be designed to rotate slowly.
6. To minimize the cathode sputtering onto the cavity due to the laser shot, we can use a small chamber with Ultra High Vacuum before the SC cavity, where cathodes can be cleaned (and ossified?) with the same density laser as the drive laser.
7. Try to look into the other material as the potential one, especially the superconducting materials, such as MgB_2, Nb_3Sn, NbN or some ceramics superconducting cathode [24].

Photocathode preparation and investigation at CERN

CERN has longstanding experience in the preparation, investigation and application of Cs_2Te photocathodes, but also other photo emissive materials have been studied. At CERN a photocathode preparation lab exists with a DC photo gun for measurements. The co-evaporation process has been developed.

A dramatic improvement of Q.E. and lifetime of photocathodes produced by the co-evaporation process has been found. But photocathodes produced by co-evaporation seem to be more sensitive to the vacuum quality. Fig. 3 shows a comparison of test results obtained in the DC gun of two photocathodes, one produced with the conventional subsequent deposition of Te and Cs and the other produced by co-evaporation. In Fig. 4 the change in the Q.E. for different operation conditions (DC gun operation, storage in the transport chamber, RF gun operations) is shown.

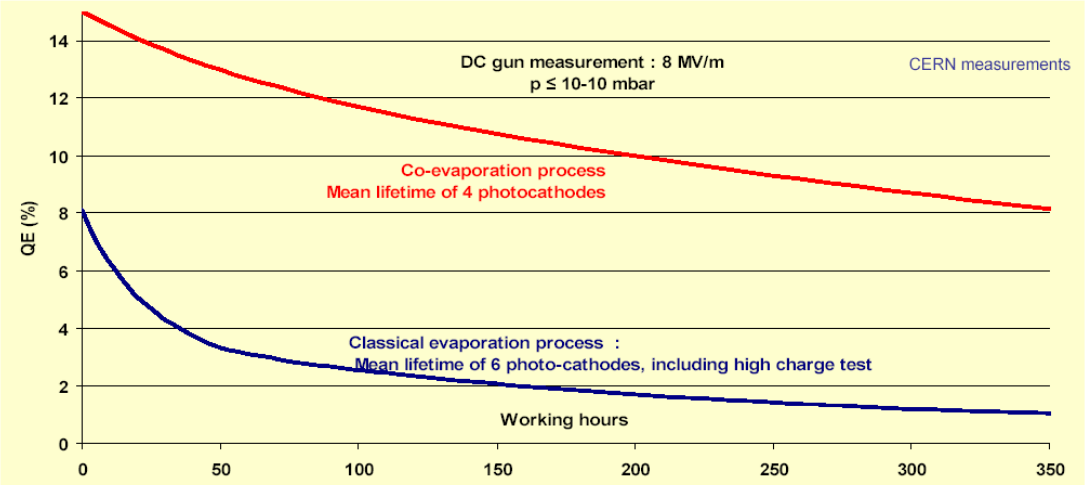

Fig. 3: Comparison of quantum efficiency as a function of operation time for Cs_2Te photocathodes produced by classical evaporation and by co-evaporation.

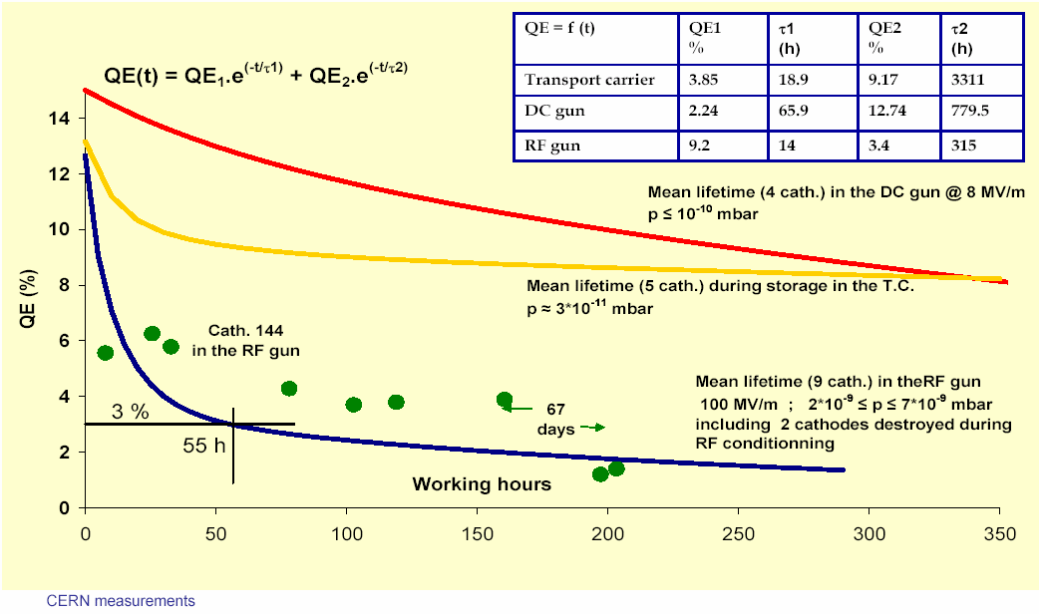

Fig. 4: Comparison of quantum efficiency as a function of life time for Cs_2Te photocathodes under different conditions.

Photographs of the main components of the CERN photocathode preparation equipment for co-evaporation are presented in the Figures 5 and 6.

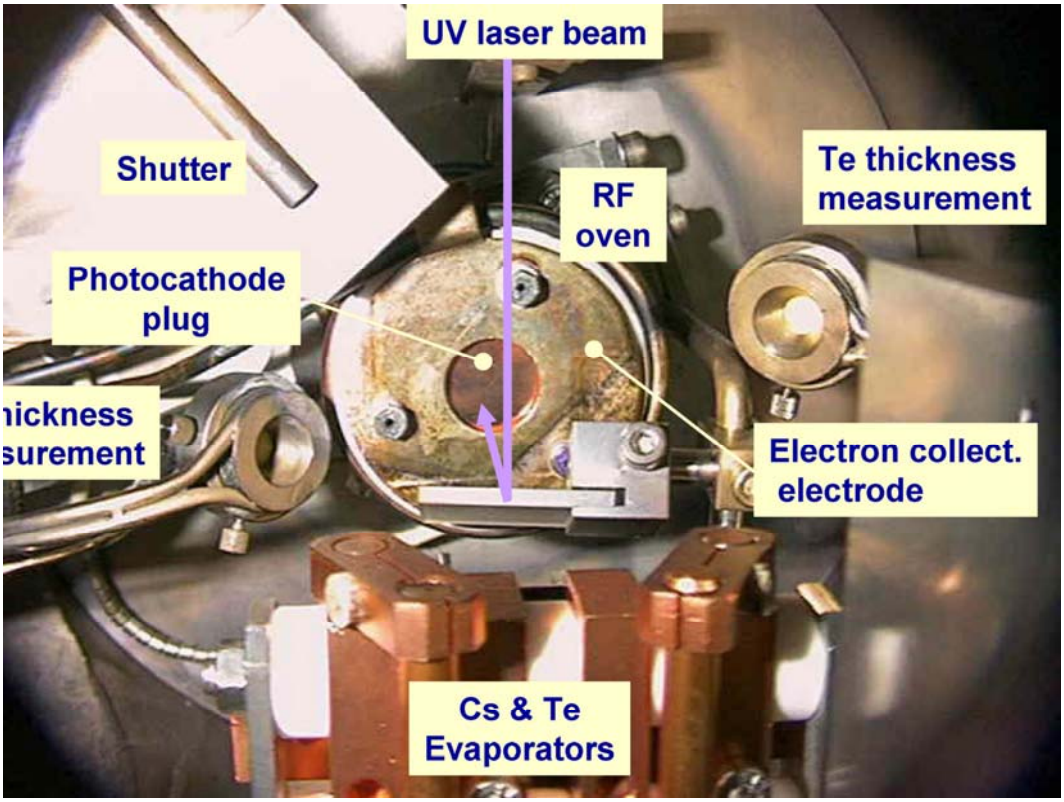

Fig. 5: Photograph of the co-evaporation equipment in the cathode preparation chamber at CERN.

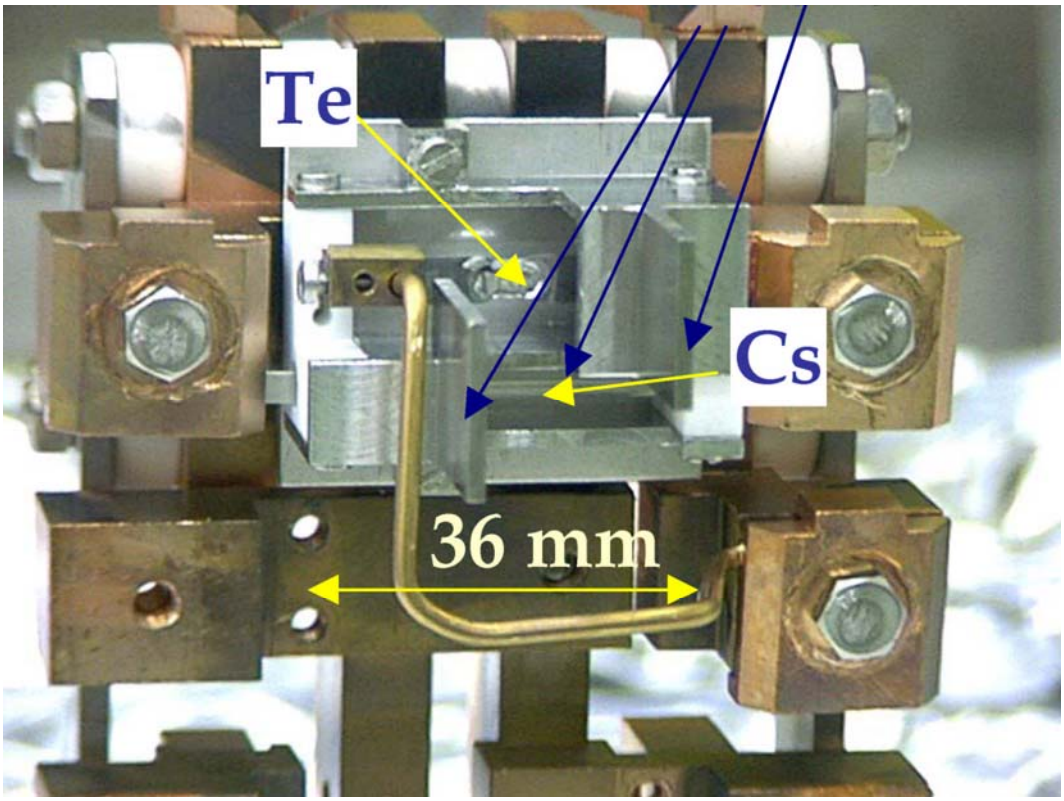

Fig. 6: Details of the evaporators.

Further photocathode investigations will be concentrated on the reproducibility of alkali-telluride photocathodes produced by co-evaporation, the study of alkali-antimonide photocathodes produced by co-evaporation. A comparison between telluride and antimonide cathodes for the CTF3 specifications and substratum studies will be carried out. The preparation chamber will be improved with respect to stoichiometric rate measurement, deposition rate control, and evaporator design for co-evaporation.

Photocathode preparation at FZR

At the FZR photocathodes are prepared and investigated for the application in a superconducting rf photo gun (SRF photo-injector). The work is concentrated on Cs_2Te photocathodes. The previous preparation chamber was directly connected with the photo gun as it is shown in the schematic picture Fig. 7 and the photograph in Fig. 8.

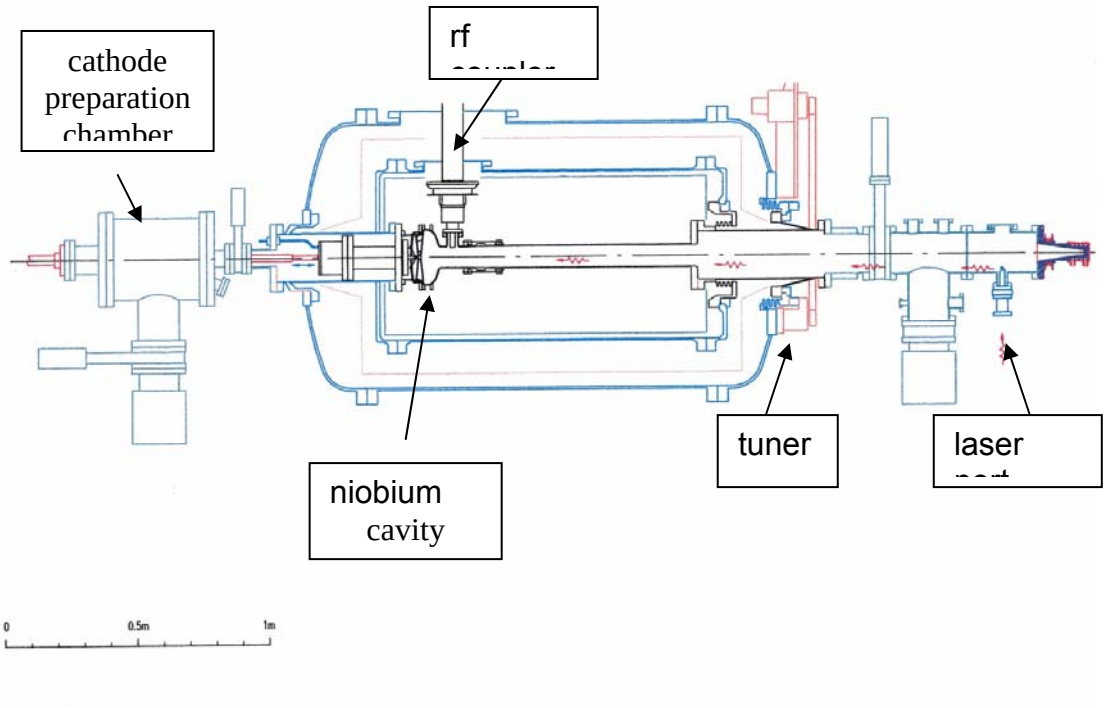

Fig. 7: Schematic drawing of the first Rossendorf SRF photo-injector.

The preparation of the cathodes was performed with the standard evaporation process. Thicknesses of the Te and Cs layers and the deposition rates were measured with a crystal sensor and during Cs evaporation the Q.E. was measured. The preparation procedure yielded in quantum efficiencies of 0.25% approximately. This result could be reproduced with less than 10% deviations for the preparation of 5 cathodes. The spatial emission patterns was found to be non-uniform, both when measured inside the preparation chamber as well as when inserted in the resonator. The achieved Q.E. was sufficient for the performed experiments. However, it was not satisfactory compared to the values reported in the literature for Cs_2Te. Also, the

homogeneity of the Q.E. distribution over the cathode surface was not sufficient. The low Q.E. is mainly to be blamed to the poor vacuum conditions during the deposition process. A photograph of a photocathode with Cs_2Te layer is shown in Fig. 9. Due to insufficient mechanical stability and reproducibility the cathode surface was only partly covered with Cs.
Prepared photocathodes have been investigated by electron

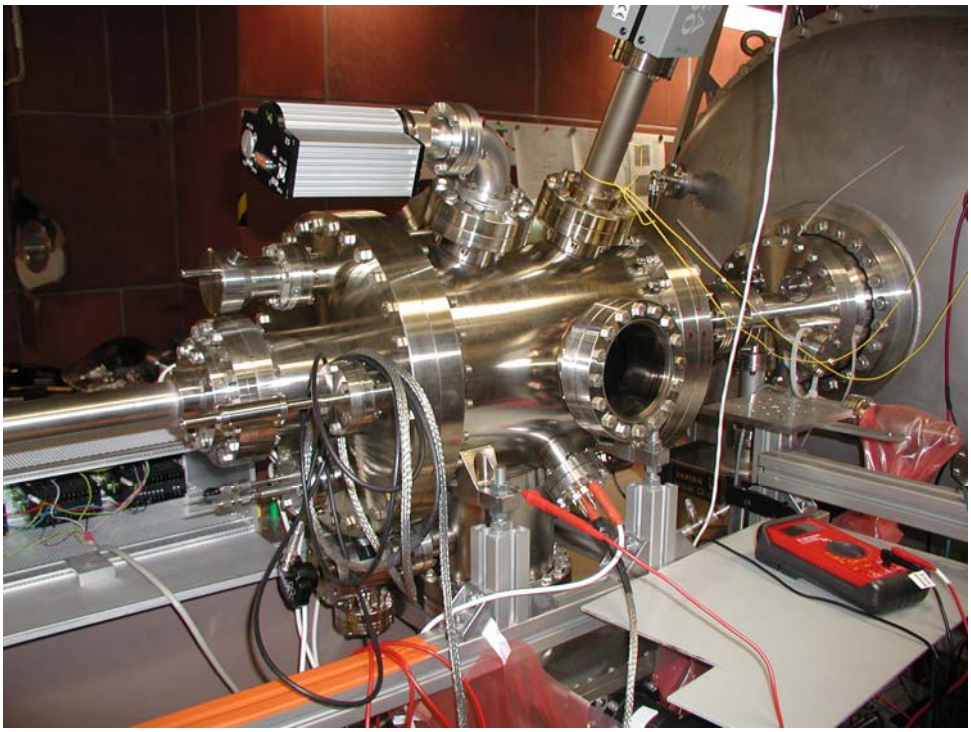

Fig. 8: Photograph of the previous FZR cathode preparation equipment.

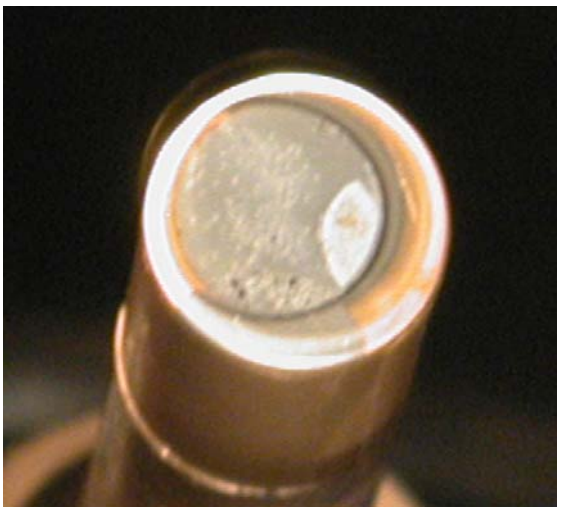

Fig. 9: Photograph of a Cs_2Te photo cathode.

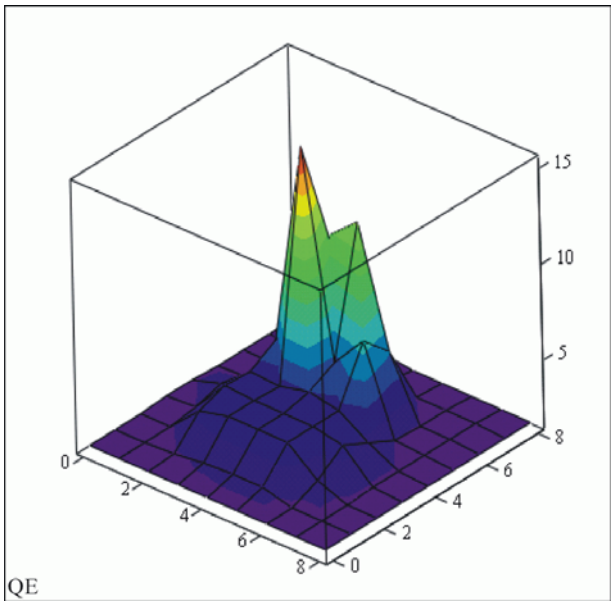

Fig. 10: Q.E. distribution over the cathode surface (arbitrary units).

Studies with scanning electron microscopy (SEM) and EDX reveal inhomogeneous distribution of the Cs on the Te layer (see Fig. 11).

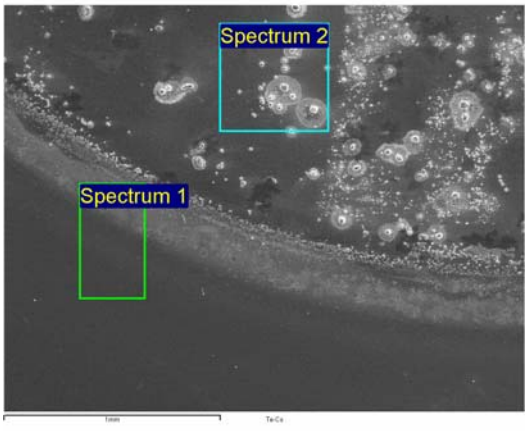

Fig. 11: SEM image of a photocathode which shows inhomogeneous distributed Cs grains.

For the new SRF photo-injector project at the FZR a new photocathode preparation chamber has been designed. It will be installed in a new preparation laboratory. For the preparation of new cathodes the co-evaporation process developed by CERN will be adopted. The design of the new photocathodes for the SRF photo-injector is presented in Fig. 12.

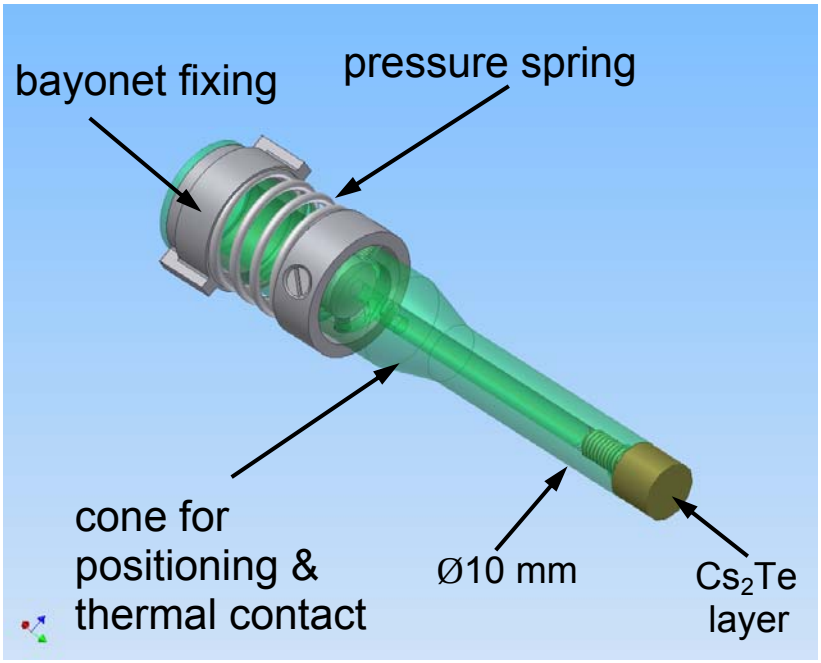

Fig. 12: Design of the photocathodes for the SRF photo-injector.

Twente University

Twente University operates a linear accelerator with a photo gun driven by a UV laser system (fourth harmonics of a Nd:YLF laser). The layout of the accelerator facility (TEUFEL project) is shown in Fig. 13. The photocathode preparation chamber is directly connected with the vacuum system of the photo gun. The exchange of cathodes from the chamber into the gun can be performed with a transfer rot. The principal design of the cathode preparation chamber is presented in Fig. 14.

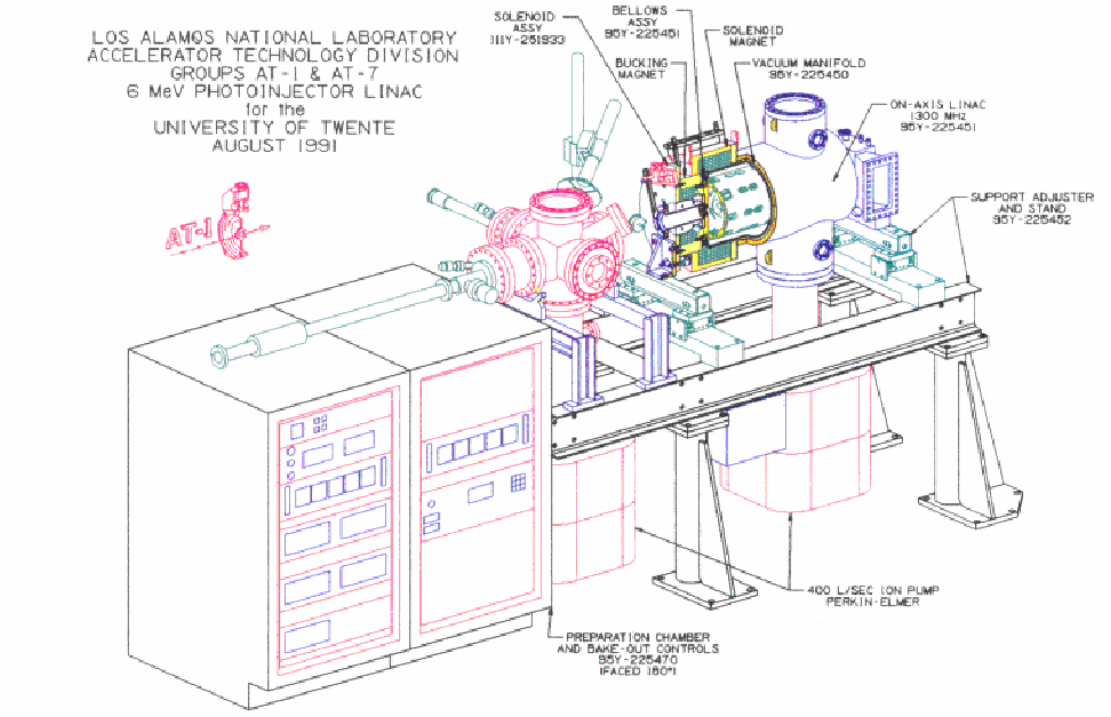

Fig. 13: View of the 6 MeV linac with photo gun and preparation chamber.

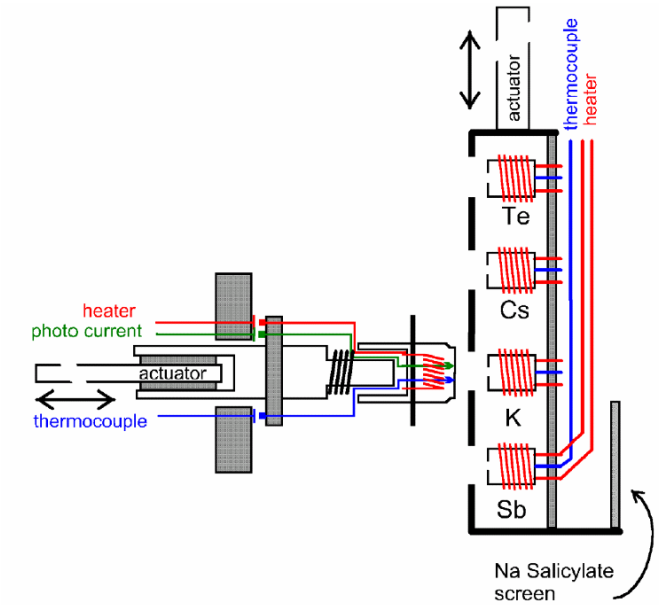

Fig. 14: Schematic picture of the photocathode preparation chamber.

Twente University has studied the preparation of Cs_2Te, KTe, and CsKTe photocathodes. The are produced by subsequent evaporation of Te and Cs, Te and K, and Te, K and Cs, respectively. Typical curves, showing the Q.E. versus time during the preparation process are presented in the Figures 15 and 16.

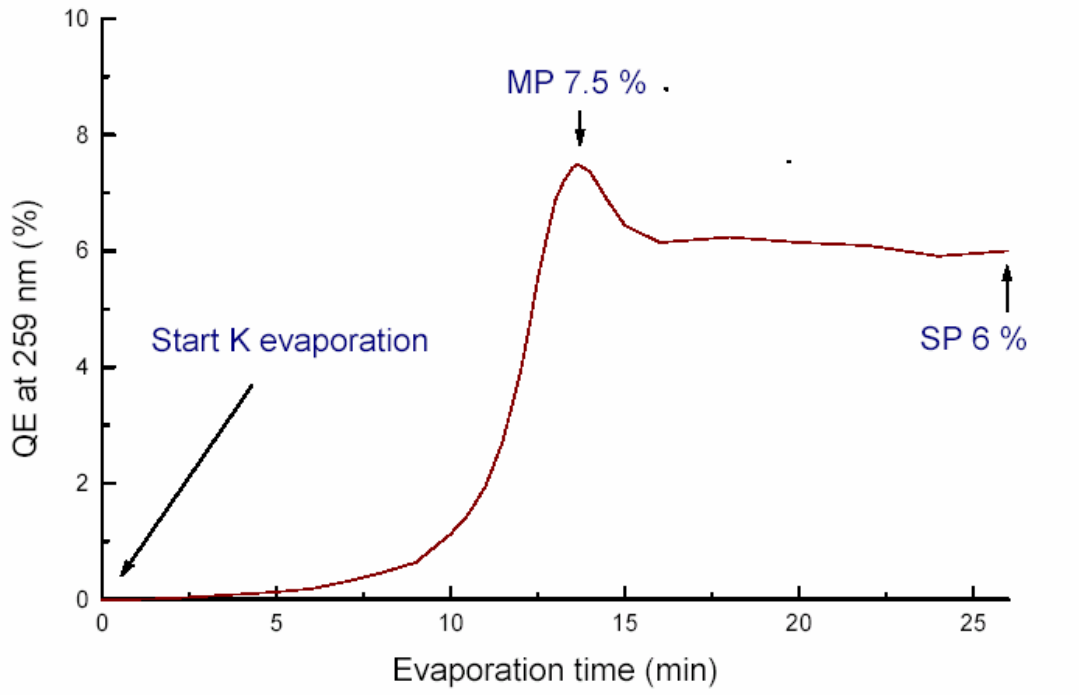

Fig. 15: K-Te preparation process.

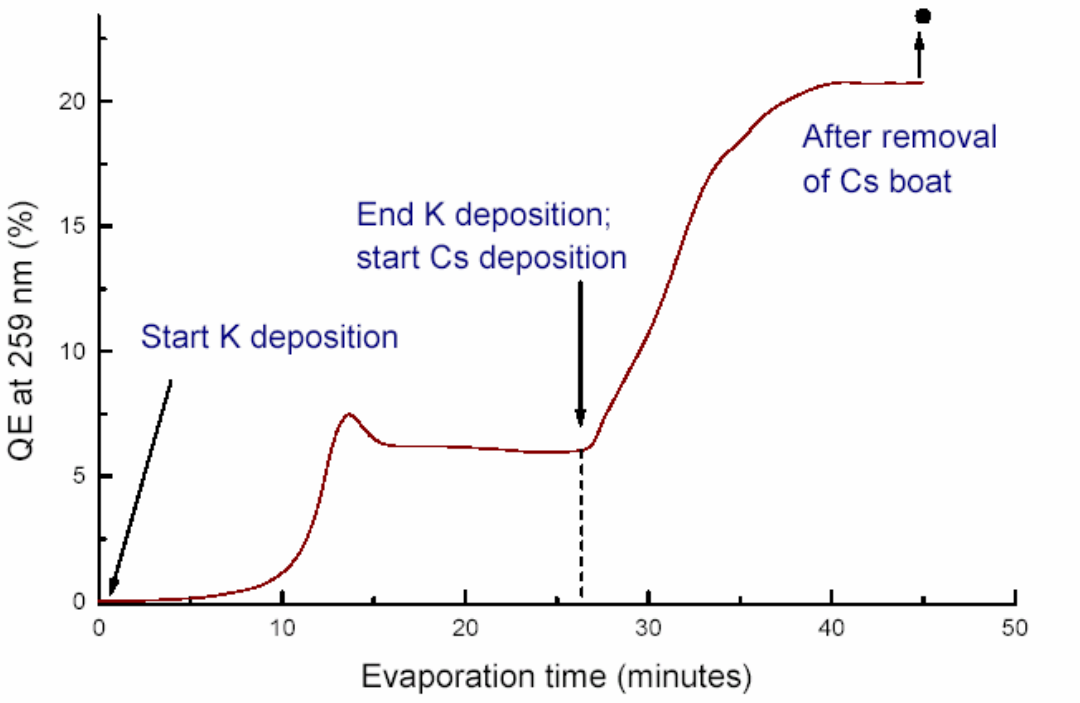

Fig. 16: Cs-K-Te preparation process.

The results of comparative studies of the three different types of photocathodes with respect to the photon energy of light and the life time are presented in the Figures 17 and 18.

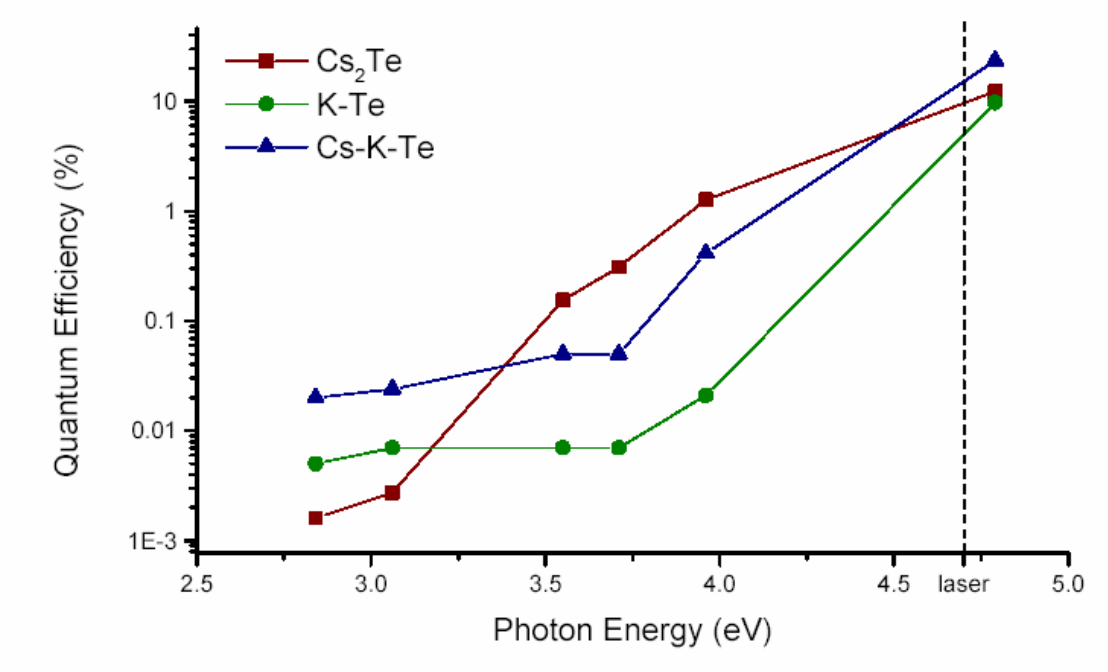

Fig. 17: Measured Q.E. versus photon energy for the three cathode types.

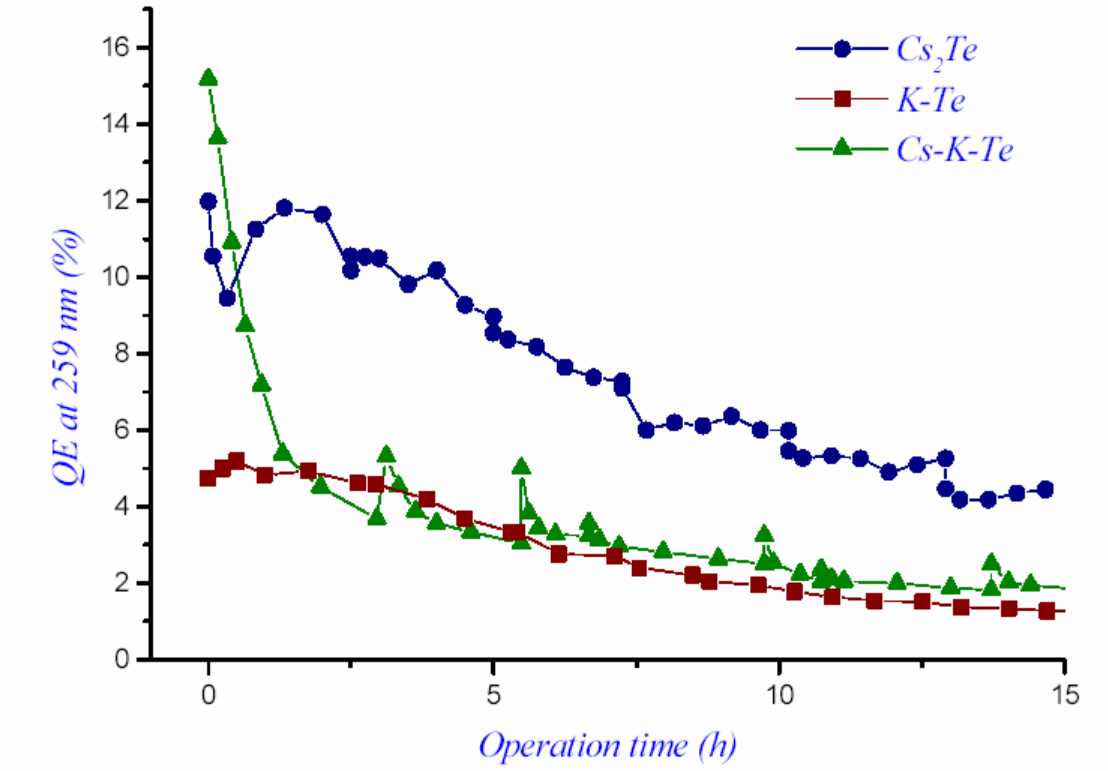

Fig. 18: Measured Q.E. versus operation time in the photo gun.

The layers on the molybdenum photocathodes were prepared at 120 °C starting with 25 – 30 min Te deposition. Then Cs was deposited until the maximum photo current was obtained. Typical Q.E. were between 4 and 8 % and the life times between 8 and 25 h. Rejuvenation of the cathodes was done by further Cs deposition at 120 °C for 7 – 8 times. Cleaning was performed (7 – 8 cycles are possible) by heating above 600 °C. The operation time of the photocathodes in the rf gun depends strongly on the emission current. For currents below 150 A, the life time is moderate. For higher currents above 150 A, the life time is insufficient (few ten minutes) and a rejuvenation is not possible. The photocathode surfaces show ablations or structure changes. The degradation is only significant at the illumination spot. Further studies will be concentrated to life time improvement for high current operation. A first attempt is, to produce cathodes with thinner Cs layers. Other materials will be taken into consideration and usage of protective layers will be studied.

References

1. *http://ucq.home.cern.ch/ucq/cathodes_alcalines.htm#telluride*
2. *S.H. Kong, J.Kinross-Wright, D.C. Nguyen, R.L. Sheffield,* Photocathode for free electron lasers, NIM A 358 (1995) 272
3. *Eric Chevallay, Guy Suberlucq, Heiko Trautner,* Production of a high average current electron beam with Cs-Te photocathodes, CTF3 note 020 (tech.)
4. CERN Lab activities related to PHIN. http://ucq.home.cern.ch/ucq/EU-PI/Presentation.pdf
5. Photocathode performance – design requirements, http://ucq.home.cern.ch/ucq/Coferences/CTF3_col-meet-2003/CTF3_col_meet_Photocat.pdf
6. *E. Chevallay, J. Durand, S. Hutchins, G. Suberlucq,* PHOTO-CATHODES FOR THE CERN CLIC TEST FACILITY
7. Cathodes for CTF3/CLIC, From 1st Photoinjector Workshop in CERN
8. *P.Schoessow, E.Chojnacki, G.Cox, et al.,* THE ARGONNE WAKEFIELD ACCELERATOR HIGH CURRENT PHOTOCATHODE GUN AND DRIVE LINAC, http://epaper.kek.jp/p95/ARTICLES/WPB/WPB11.PDF
9. *A.V.Aleksandrov, E.S.Konstantinov, P.V.Logatchov, et al.,* HIGH POWER TEST OF GaAs PHOTOCATHODE IN RF GUN, http://accelconf.web.cern.ch/accelconf/e98/PAPERS/TUP02J.PDF
10. *D. Sertore, S. Schreiber,K. Floettmann, et al.* First operation of cesium telluride photocathodes in the TTF injector RF gun, NIM A 445 (2000) 422~426
11. *A. Fry, E. Hahn,W. Hartung,y M. Kuchnir,* EXPERIENCE AT FERMILAB WITH HIGH QUANTUM EFFICIENCY PHOTO-CATHODES FOR RF ELECTRON GUNS
12. *T.Siggins, C.Sinclair, D.Bullard, et al.,* Performance of the Photocathode Gun for the TJNAF FEL, http://www.fel.duke.edu/fel2000/program/book/node64.html
13. *S.H. Kong, D.C. Nguyen*, Fabrication and characterization of cesium telluride photocathodes: A promising electron source for the Los Alamos Advanced FEL, NIM A 358 (1995) 276.
    S.H. Kong, Performance of Cesium telluride photocathodes as an electron source for the Los Alamos Advanced FEL, NIM A 358 (1995) 284S
14. http://ucq.home.cern.ch/ucq/ctf2_cath_.htm
15. *A. di Bona, S. Valeri, P. Michelato,* FORMATION OF THE Cs_2Te PHOTOCATHODE: AUGER AND PHOTOEMISSION SPECTROSCOPY STUDY,
    A. Di Bona, F. Sabary, S.Valeri, P.Michelato, D.Sertore, G. Suberlucq, Auger and x-ray photoemission spectroscopy study on Cs_2Te photocathodes", J. Appl. Phys., Vol. 80, No.5, (1996), 3024-3030

16. *E. Chevallay, S. Hutchins, P.Legros, G. Suberlucq, H.Trautner*, Production And Studies Of Photocathodes For High Intensity Electron Beams, CLIC Note 449, CERN/PS 2000-046 (PP)
17. *J. Gubeli, R. Evans, A. Grippo, et al.,* Jefferson Lab IR demo FEL photocathode quantum efficiency scanner, NIM A 475 (2001) 554–558
18. *K. Zhao et al.,* Researches on new photocathode for RF electron gun, NIM A 445 (2000) 394~398
19. *Bart M. van Oerle, Gerard J, Ernst,* On the use of CsK_2Sb photocathodes in RF linacs, NIM A 358(1995)287-290
20. *Qiang Zhao, Triveni Srinivasan-Rao et al*., TESTS OF NIOBIUM CATHODE FOR THE SUPERCONDUCTING RADIO FREQUENCY GUN, PAC2003
21. *D. W. Feldman, P. G. O.Shea, M. Virgo, IREAP, et al.,* DEVELOPMENT OF DISPENSER PHOTOCATHODES FOR RF PHOTOINJECTORS, PAC 2003
22. *X.J. Wang, M. Babzien, R. Malone and Z. Wu,* Mg CATHODE AND ITS THERMAL EMITTANCE, LINAC 2002
23. *H. Iijima, M. Uesaka, T. Ueda,et al.,* HIGH CHARGE MG PHOTOCATHODE RF GUN IN S-BAND LINAC AT UNIVERSITY OF TOKYO, EPAC 2002
24. *Evgeny Podkletnov, Giovanni Modanese,* Investigation of high voltage discharges in low pressure gases through large ceramic superconducting electrodes, http://arxiv.org/abs/physics/0209051, J. Low Temp. Phys. 132 (2003) 239-259