ON THE PHOTOCATHODES USED AT THE TTF PHOTOINJECTOR

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Abstract

Since the start-up of the laser driven rf gun based photoinjector at the TESLA Test Facility (TTF) late 1998, several cathodes have been used. We report on the properties of Cs_2Te and KCsTe cathodes under operating conditions, their quantum efficiency and lifetime. Darkcurrent emitted by the RF gun or the cathodes have been a major concern in the first year of operation. Meanwhile, new cathode production techniques and a conditioning effect of the RF gun has reduced the darkcurrent significantly.

INTRODUCTION

Since December 1998, the TESLA Test Facility (TTF) at DESY operates a laser-driven RF gun based photoinjector. It has been used for TESLA related experiments and to drive the TTF-FEL free electron laser[1]. The TTF accelerating structures are based on superconducting technology, which allows acceleration of long pulse trains. At TTF, trains of up to 800 μs length with four different bunch frequencies have been generated: 100 kHz, 1 MHz, 2.25 MHz, and 54 MHz. Beam parameters used in different experiments or running conditions are summarized listed in Table 1.

Table 1: Electron beam parameters as produced by the TTF RF gun during the last runs.

Parameter		TESLA (CDR)	TESLA FEL (TDR)	HOM
RF frequency	GHz	1.3		
Repetition rate	Hz	1		
Pulse train length	μs	1 to 800		
gradient on the cathode	MV/m	40 MV/m		
Pulse train current	mA	8	9	2
Bunch frequency	MHz	1	2.25	54
Bunch charge	nC	1 to 8	1 to 4	0.04
Nb bunches per train		1 to 30	1 to 1800	20000
Bunch length (rms)	mm	≈ 4	≈ 3	
Laser spot diameter	mm	10	3	6

Producing a large number of bunches per train is only possible with a high quantum efficiency cathode. Cesium telluride photocathodes have been chosen, since a quantum efficiency above 1 % has been first achieved at CERN[3]. The required laser energy in the UV reduces to be only a few μJ for a bunch charge in the nC range. This makes a laser system producing thousands of laser pulses per pulse train feasible. The quantum efficiency of metals like copper are three orders of magnitude smaller and thus would require a large kW-scale laser system. In the following, we report our experience with the various cathodes used at TTF.

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CATHODE SYSTEM AND PREPARATION

A sketch of the the cathode system attached to the RF gun is shown in Fig. 1. The RF gun built by FNAL is an

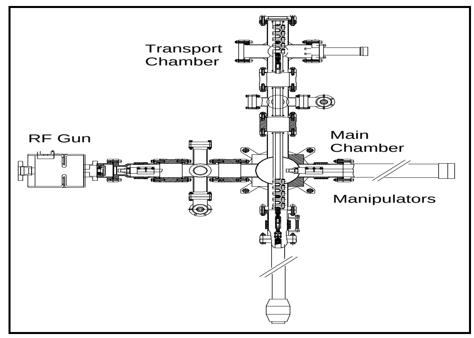

Figure 1: Schematic overview of the cathode system attached to the TTF RF gun.

L-band 1 1/2-cell RF gun operated with a 5 MW 1.3 GHz klystron. The RF pulse length is up to 900 μs with a forward RF power of 3 MW, corresponding to a gradient of 40 MV/m on the cathode, and a repetition rate of 1 Hz. A Cs_2Te or KCsTe cathode is illuminated by a train of UV (262 nm) laser pulses. The laser, a mode-locked solid-state laser system based on Nd:YLF, is synchronized with the gun RF.[4] The laser pulse length measured with a streak camera is 7 ± 1 ps.

To maintain their quantum efficiency, Cesium telluride cathodes have to stay allways in ultra-high vacuum. Therefore, a load lock system has been developed.[5] It is a split function system, where the cathodes are not prepared in the system attached to the gun, but off-site. Cathodes are first prepared at INFN-LASA in Milano. A stack of up to four cathodes is transported in a transportation chamber to DESY. During the transport, an ion pump powered by a battery keeps the vacuum level stable around $1 \cdot 10^{-10}$ mbar. The transport chamber is then attached to the load lock system of the RF gun. Two vacuum manipulators are used to pick a cathode from the stack and to insert it into the gun. Figure 2 shows the cathode plug inserted into the backplane of the gun. The RF contact is assured by a Cu-Be spring.

The cathode plug is made out of pure Molybdenum. The surface is cleaned and polished with optical quality. Thin layers of Tellurium and Cesium are then deposited in UHV onto the polished plug surface. Tellurium and Cesium react to produce Cs_2Te. It has an energy gap of 3.2 eV and an electron affinity of 0.5 eV [6]. It is blind to visible radi-

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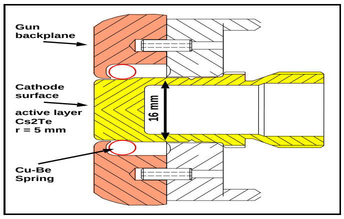

Figure 2: Detail of the cathode plug inserted to the RF gun backplane. The Cu-Be spring asuring RF contact is indicated.

ation, UV light is required for photoemission.

Cathodes have been operated in the RF gun from December 1998 to November 2002. During this four years of running, 12 different cathodes have been used, 10 Cs_2Te and 2 KCsTe cathodes (Tab. 2). In total for 1192 days, cathodes have been operated in the gun. The reason to remove a cathode has never been a low quantum efficiency. Only during the period of strong dark current, cathode have been changed frequently.

Table 2: Cathodes used during TTF phase. Cathodes not otherwise indicated are Cs_2Te.

cathode	days in use	
1	89	
13	234	
12	92	
22	9	
23	29	
21	27	
33	26	
36	145	
50	139	KCsTe
11	317	
51	85	
54	0.1	KCsTe
sum	1192	

QUANTUM EFFICIENCY MEASUREMENTS AND LIFETIME

The quantum efficiency (QE) measured with a Hg lamp after growing of the emissive film is usually very high, up to 10% for Cs_2Te and 20% for CsKTe. The spectral response shows a plateau which is reached at a wavelength of 260 nm. The measured uniformity of the QE is a few percent with respect to the maximum.[5]

Transportation

To evaluate the effect of the 24 hour long transportation, we measured the QE just before leaving Milano and just after arrival at DESY. To keep ultra-high vacuum conditions, the pumping system of the transportation chamber is powered by a battery through a DC/DC converter. This keeps the vacuum pressure in the $1{\cdot}10^{-10}$ mbar range. In Table 3, measurements performed for the first set of cathodes are reported. The measurement shows no QE degradation during the transportation.

Operation in the RF gun

The quantum efficiency of the cathodes has been measured several times during their operation in the gun. The laser energy is measured with a calibrated ($\pm$ 5%) joulemeter (Molectron). The charge is measured at the exit of the gun with an integrated current transformer (Bergoz). Figure 3 shows an example for cathode 13. From the slope of a straight line fit to the data we obtain a quantum efficiency of 0.6 %. The estimated measurement error is 10 %. The QE after the production of cathode 13 was 10 % with uniformity near to 5 %. It remained three months in the transport system before it was installed into the gun. Immedeately after its installation, we measured a QE of 5.6 %. After 5 months of usage in the RF gun, the QE decreased by a factor of 10 to 0.6 %. During this period, the pressure at the pump near the gun was stable at $3.5{\cdot}10^{-11}$ mbar. Since the gun has never been baked, we expect a water partial pressure of some $1{\cdot}10^{-10}$ mbar. In other words, the cathode has been exposed to some $1{\cdot}10^{-3}$ mbar s of water. The harmful effect of water is at least comparable to oxygen. This explains the rather low, but stable QE in our case.

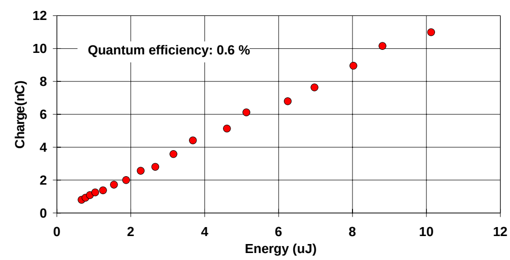

Figure 3: Measured charge output of the RF gun as a function of laser energy on cathode 13. The laser spot diamter was 10 mm.

Table 3: Quantum efficiency (QE) measured before and after transportation from Milano to DESY, after 3 month of storage, and after operating in the RF Gun for 5 months.

QE (%)	Milano	DESY	3 month storage	5 month operation
stack 1	6.1 ± 0.2	6.0 ± 0.3		
cathode nb 13	10		5.6	0.6

DARKCURRENT

During operation in the RF gun, the cathode is exposed to a very high electric field of 40 mV/m. Field emission from the cathode and the gun backplane form dark current emitted by the RF gun. To understand the origin of the darkcurrent and to find ways how to suppress it has been one of the major concerns at the beginning of the RF gun operation.

Darkcurrent values quoted here are measurd with a Faraday cup at the RF gun exit, with nominal solenoid fields which are used for beam, and for a field of 35 MV/m on the cathode surface.

In the first two years of operation, we observed frequently a sudden on-set of strong field emission. Fig. 4 shows the history of the darkcurrent measured for all cathodes operated in the RF gun. After an initial 'eruptive' period of one year, we observed suddenly a very strong emitter on the gun backplane close to cathode 21, which leads to a darkcurrent of several mA. Once this emitter has been conditioned, the darkcurrent decreased slowly, until – after another year – the darcurrent almost vanished. During

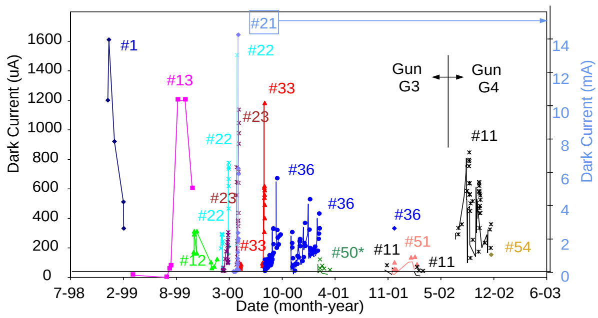

Figure 4: History of the darkcurrent of all cathodes used during TTF phase 1.

the 'hot' period, we studied the dependance of the darkcurrent on the finishing of the cathodes. The coated substrate shows always a higher dark current then uncoated Mo substrates. At the beginning, all substrate surfaces have been finished with a tooling machine, they were not mirror-like and an inspection with an optical microscope revealed deep scratches at the surface. For these reasons, the next sets of cathodes have been prepared with a better surface polishing. We used diamond grinding powder with size down to 50 nm to obtain a mirror like surface. The first Cs_2Te cathode with this new surface finishing was tested in March 1999. A significant reduction of darkcurrent has been achieved: from 300 μA to 16 μA. However, also with this cathode a sudden increase in darkcurrent after 3 month of usage has been observed.

Only after two years of operation, the darkcurrent stablized with cathode nb. 11 to a very low and for us acceptable value of 20 to 25 μA. For this reason, cathode 11 has been left in the gun from July 2001 – with some interruptions – up to the end of TTF1 mid November 2002.

Since the darkcurrent has now been low and stable, checks with a former high darkcurrent cathode could be made. We reinserted cathode 36 with which 200 μA of darkcurrent have been measured earlier. Indeed, after reinsertion to the gun, the darkcurrent increased again to 200 μA. After putting cathode 11 back, the current fell back down to the 25 μA level. At least in this case, the cathode is responsible for the darkcurrent, not the gun, nor the RF contact spring, since both have not been changed.

However, later-on we made a different observation. In May 2002 we replaced the RF gun G3 with gun G4 from FNAL. Now the darkcurrent with cathode 11 inserted 200 μA again and even increasing. This gun has been operated at the NICAAD photoinjektor test facility in FNAL with short RF pulses of only 30 μsat 1 Hz. Gun G3 has been operated at TTF most of the time with long RF pulses of 500 to 900 μs, with 1 Hz and around the clock.

The darkcurrent measured at TTF with G4 is very similar to the values obtained FNAL.[7] On the other hand, the small value of darkcurrent has now moved with G3 to FNAL. This is a strong indication, that a conditioning effect of the gun during operation significantly reduced the darkcurrent.

To summarize, both, gun and cathode contribute to the dark current phenomena and have to be attact both. This explains also partly the confusing picture we got from the data for different cathodes. Only with a clean gun, effects of the cathode induced darcurrent can be evaluated correctly.

DISCUSSION AND CONCLUSION

At TTF we have been operating various cathodes from December 1998 to November 2002. The quantum efficiency drops during gun operation presumably due to residual water in the vacuum down to a stable 0.5 % level. This is sufficient to allow to produce bunchs trains of 9 mA as required.

We have been suffering by strong darkcurrent emission in the order of mA during the first two years, until its level stabilized at a reduced and acceptable level of 25 μA. This is on the one hand due to a conditioning effect of the RF gun itself, and on the other due to improved finishing techniques of the cathode surface. From our understanding, the RF contact spring does not contribute significantly to the dark current.

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