PROPERTIES OF CATHODES USED IN THE PHOTOINJECTOR RF GUN AT THE DESY VUV-FEL

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Abstract

The new injector of the DESY VUV-FEL is being commissioned in spring 2004. Two cathodes have been tested in the photoinjector RF Gun. We report on quantum efficiency, dark current, and the overall appearance of the cathodes after their use.

INTRODUCTION

The VUV-FEL project at the TESLA Test Facility (TTF) at DESY[1] will be the first user facility for VUV and soft X-ray coherent light experiments with an impressive peak and average brilliance. With the beginning of 2004, the installation has been mostly completed. The photoinjector has been redesigned to meet the demanding beam parameters in terms of transverse emittance, peak current, and energy spread. The successful commissioning of the new injector took place from March to June 2004.[2] Even though major parts of the injector have been redesigned, the cathode system of TTF phase 1 installed in 1997 has been taken over without changes.

For the VUV-FEL long trains of electron bunches have to be generated. The design asks for up to 7200 bunches in a train of 800 μs length at a repetition rate of 10 Hz, with a single bunch charge of 1 nC. In order to keep the laser system within a reasonable size and cost, the quantum efficiency of the cathode has to be in the order of 1 %. We have chosen Cesium Tellurite (Cs_2Te) as the emissive film for our cathodes since their quantum efficiency is as high as 16 % after production. In the past however, the quantum efficiency dropped within days to a low but stable value of 0.5 % during operation at TTF.[3]

During the commissioning of the injector, two new cathodes have been tested.

THE CATHODE SYSTEM

A sketch of the the cathode system attached to the RF gun is shown in Fig. 1. The RF gun is an L-band 1 1/2-cell RF gun operated with a 5 MW 1.3 GHz klystron. The gun has been commissioned at PITZ during the last two years[4] and installed at TTF in January 2004. The gun has been operated with an RF pulse length of up to 900 μs with a forward RF power of 3.2 MW, corresponding to a gradient of 42 MV/m on the cathode. The repetition rate is up to 10 Hz. Most of the time during the commissioning, the gun has been operated with 5 Hz and an RF pulse length of 100 μs to reduce the radiation load due to darkcurrent emission.

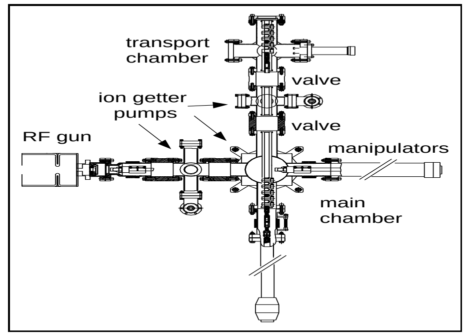

Figure 1: Schematic overview of the cathode system attached to the TTF RF gun.

The cathodes are 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.[5] The laser pulse length measured with a streak camera is $\sigma_L = 4.4 \pm 0.1$ ps.[2]

A crucial issue for the quantum efficiency of Cs_2Te cathodes are the vacuum conditions during their production, transport, loading, and operation in the gun. It has been shown, that the cathode is easily contaminated by residual gases like hydrocarbons and oxygen with a pressure of $1 \cdot 10^{-9}$ mbar even for short term exposures.[6] Great care has been taken to keep the vacuum pressure below $1 \cdot 10^{-10}$ mbar.

The cathodes used for the injector commissioning have been prepared at INFN-LASA in Milano in December 2003. In the transportation chamber, four cathodes can be transported. One cathode plug without emissive film, one plug with a scintillator for the alignment of the laser onto the cathode, and two cathodes with emissive films (internal numbers 37.2 and 42.2). During the transportation to DESY, the cathodes stay under ultra-high vacuum. 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.

The cathode plug is made out of pure Molybdenum with a surface of 16 mm in diameter. The surface is cleaned and polished with optical quality. Thin layers of Tellurium and Cesium are then deposited in UHV onto the polished plug

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surface. Tellurium and Cesium react to produce Cs_2Te. First a thin layer 10 nm of Tellurium is evaporated on the cathode, which is heated at 120°C. Cesium is then evaporated at a rate of 1 nm/min while monitoring the cathode quantum efficiency (QE). When the QE is at maximum, the evaporation is stopped. The final photoemissive layer thickness is some tens of nanometers. A mask is used to restrict the formation of the Cs_2Te film on the center of the cathode with a diameter of 5 mm.

Cs_2Te has an energy gap of 3.2 eV and an electron affinity of 0.5 eV [7]. It is blind to visible radiation, UV light is required for photoemission. The initial QE of cathodes 37.2 and 42.2 is 8.5 and 8 % measured with a Hg-lamp at 254 nm.

Cathode 42.2 has been operated for 80 days at TTF and has accumulated a charge of approximately 0.1 C during the commissioning. Cathode 37.2 has been tested at the end of the run for 30 h.

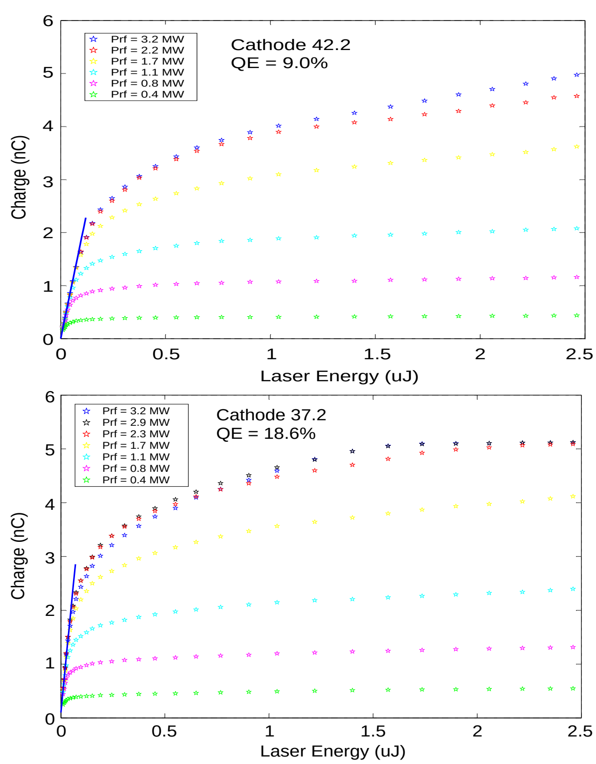

Figure 2: Measured charge output of the RF gun as a function of laser energy on cathode 42.2 after 80 days of running and 37.2 directly after first insertion. The data are plotted for various RF powers in the gun.

QUANTUM EFFICIENCY

The quantum efficiency (QE) has been measured with two methods. A high pressure Hg lamp with suitable wavelength filters is used to shine a small light spot on the cathode. The photocurrent is measured with a sensitive picoampere meter. A small bias voltage of 150 V is applied between the cathode and the pick-up wire to ensure, that all emitted electrons are collected. The second method is an in situ measurement during RF gun operation with beam. The laser pulse energy is measured with a calibrated (±5 %) joulemeter (Molectron). The charged emitted and accelerated by the gun is measured with a calibrated (±3 %) toroid. The measurement is performed for different accelerating fields on the cathode surface to take emission losses due to space charge effects on the cathode surface into account. For example, for an RF power of 3.2 MW, the field on the cathode surface is 42 MV/m. The laser spot diameter is 3 mm, its length 4.4 ps (sigma). Even for a very large laser pulse energy (more than required for 5 nC), the emitted charge is limited to about 5 nC due to the strong space charge forces building up, when the head of the bunch is emitting. The quantum efficiency is determined from the slope of the linear part at low energy densities, where space charge effects are small. Figure 2 shows measurements for cathode 42.2 after 80 days of operation and for the fresh cathode 37.2. From the slope of a straight line fit to the data we obtain a quantum efficiency of 9 % for cathode 42.2 and 18 % for the fresh cathode 37.2. Table 1 summarizes the measurements. There is a large discrepancy between the data obtained with the Hg lamp and the in situ measurement. The QE fit is done with the data for laser energies below 0.1 uJ. It is very difficult to measure with the given joulemeter laser pulse energies below 0.1 μJ. This may explain the from our point of view to high QE data measured with beam. What we definitely can say is, that the laser energy required for a 1 nC bunch is much less than at TTF1. The measurements with the Hg lamp before and after the run are consistent and show, that the QE for the used cathode 42.2 is by a factor of 6 higher than in the past at TTF.

Table 1: Quantum efficiency (QE) measured after preparation in Milano, during the gun operation, after their use in the gun.

nb	after preparation	fresh in the gun	after 80 days	after operation	
	Hg lamp 254 nm	in situ 262 nm		Hg lamp 262 nm	254 nm
42.2	8.0		9.0	2.9	4.2
37.2	8.5	18.6		6.8	8.2

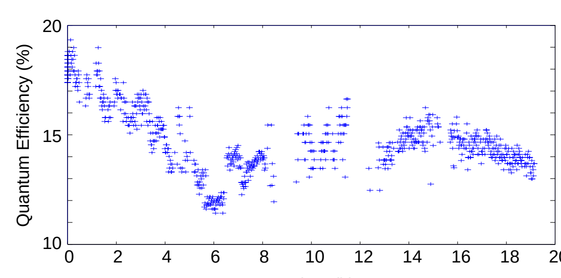

Figure 3: On-line quantum efficiency for the first 20 h after insertion of cathode 37.2 into the gun.

The quantum efficiency of cathode 37.2 has been monitored constantly from the insertion on. Figure 3 shows the on-line QE as a function of time over a period of 20 hours after its insertion into the gun. In the first hours the QE drops as expected, in this case from 18 to about 12 % and stays roughly constant afterwards. The drop is presumably due to the vacuum condition in the gun during operation, which is not as good as in the cathode system itself.

CATHODE SURFACE

After operation of the cathodes at PITZ with their present gun, damage on the emissive film has been observed. Up to now, this has not been observed at TTF. Figure 4 shows a picture from the surface of cathode 42.2 at TTF after 80 days of operation (left). Inspection with the eye does not reveal any damage on its surface. The picture in the middle shows cathode 60.1 taken after 2 month in the present gun at PITZ. The picture on the right is taken after another 2 month. The damage is probably due to the high darkcurrent level in the present PITZ gun. For a closer discussion see [8].

Figure 4: Surface of two cathodes. Left, cathode 42.2 after 80 days of operation at TTF, cathode 60.1 after 2 month (middle) and 4 month of operation (right) in the present gun at PITZ.

DARKCURRENT

During operation in the RF gun, the cathode is exposed to a very high electric field. Field emission from the cathode and the gun backplane form darkcurrent which is then accelerated and emitted by the RF gun. As usual, a solenoid close to the gun exit is used to compensate space charge induced emittance growth. The darkcurrent transmission to the Faraday Cups is effected by the solenoid field. Hence, the darkcurrent is measured at the RF gun exit as a function of the solenoid fields.

Fig. 5 shows the measurement for two cases: when a pure molybdenum cathode without emissive film is inserted (left) and with cathode 42.2 (right). The RF power in the gun was in both cases 3.2 MW. The darkcurrent measured at TTF is comparable to the measurements earlier at PITZ.[9] For a solenoid field of 240 A we have a maximum in transmission of the darkcurrent to the Faraday Cups, the acceptance of the Cup close to the gun is better for higher solenoid currents. The working point for the solenoid is 277 A, where only 100 μA of the darkcurrent is transported. The level of darkcurrent for maximal acceptance is higher

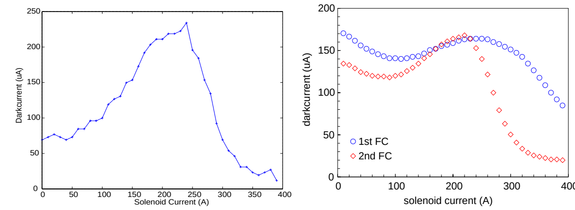

Figure 5: Darkcurrent of the RF gun measured with a pure molybdenum cathode inserted (without emissive film) at Faraday Cup 2 (left), and with the Cs_2Te cathode 42.2 after 80 days of operation at Faraday Cup 1 (right) (80 cm from the cathode – 1st FCup, blue) and 2 (130 cm from the cathode – 2nd FCup, red).

then during the last two years of operation of the phase 1 RF gun G3 (less than 100 μA), but much less than at the beginning of the TTF phase 1 operation in 1998.[3]

CONCLUSION

During the commissioning of the new TTF injector for the VUV-FEL we tested two different Cs_2Te cathodes. Both show a remarkable high quantum efficiency. One cathode has been operated for 80 days with 5 Hz. The total charge delivered during this time is in the ball park of 0.1 C. The gun has a high and constant level of darkcurrent emission at 3.2 MW RF power of about 100 μA for our solenoid working point.

ACKNOWLEDGEMENT

We like to thank our colleagues from the DESY vacuum group (MVP) for the organization of the cathode transports and their continuous maintenance of the cathode vacuum system at TTF.

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