ELSEVIER

Nuclear Instruments and Methods in Physics Research A 445 (2000) 422–426

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

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First operation of cesium telluride photocathodes in the TTF injector RF gun

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Abstract

During the run 1998/1999 a new injector based on a laser-driven RF gun was brought in operation at the TESLA Test Facility (TTF) linac at DESY, in order to produce the beam structure and quality required either by TeV collider and SASE FEL experiments. High quantum efficiency cesium telluride photocathodes, prepared at Milano and transferred to DESY, have been successfully operated in the RF gun. A bunch charge of 50 nC, only limited by space charge effects, was achieved. The photocathodes have shown an operative lifetime of several months. A new cathode surface finishing has showed a promising decrease of the photocathode dark current. Measurements of dark current, quantum efficiency and lifetime are reported.

PACS: 85.60.h; 41.75.i; 79.60.i

Keywords: Photocathode; RF gun; Electron source; Photoemission

1. Introduction

In the fall 1998 the injector II based on the laser-driven FNAL RF gun was installed at TTF in DESY, in order to produce the beam structure and quality required either by TeV collider and SASE FEL experiments. To reduce the requirements for the laser and to satisfy the electron beam structure and quality [1], a cathode with high quantum efficiency, low thermal emittance and fast response time is required. Moreover, the linac operation asks for a lifetime of the electron source in the order of months. The cathode selected for the Injector II operation is cesium telluride [2] already succesfully operated in RF guns [3,4]. It is illuminated by the 4th harmonic of an Nd:YLF laser whose pulse length is $\sigma = 7$ ps [5]. The cathode preparation chamber is independent of the gun-loading system and an UHV transport device allows to transfer the cathodes from one system to the other. In our case, cathodes are produced at Milano while the gun operates at DESY. Up to now two sets of cathodes are prepared and transported to DESY: in June and in December 1998. In July 1998, one blank cathode was used for conditioning the DESY RF Gun and in August, a Cs_2Te cathode replaced it. In November 1998, a second blank was used for the FNAL gun conditioning. In December, the second photocathode was installed into the gun and used

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0168-9002/00/$ - see front matter
PII: S0168-9002(00)00095-4

for operation until mid March and a second set of cathodes was transported to DESY consisting of two photocathodes, one blank and a blank with an UV scintillator. One of the photocathodes was tested in the gun in March 1999 at the end of the run.

In this paper we report the results obtained so far with cathode operation at DESY. In the following section, the cathode preparation process is described. We then report the results about dark current and its reduction with a new surface polishing. In the last section, a discussion on the photoemissive and lifetime performance of the photocathode during the transport and the gun operation is presented.

2. Cathode preparation

The photoemissive material consists of thin layers of tellurium and cesium deposited on a molybdenum substrate under UHV conditions. They react to produce Cs_2Te. This material has an energy gap of 3.2 eV and an electron affinity of 0.5 eV [6]. For these reasons, it is blind to visible radiation and UV light is required for photoemission. The Milano group has studied the procedure for the cathode preparation in the last years [7] applying also surface science techniques [8].

The developed recipe is based on a first evaporation of 10 nm of tellurium on a substrate heated at 120°C. Cesium is then evaporated with a rate of 1 nm/min while monitoring the cathode quantum efficiency (QE) with a mercury lamp, selecting the 254 nm line. When the QE is at maximum, the evaporation is stopped and the substrate is cooled down to room temperature. The final photoemissive layer thickness is of the order of some tens of nanometers. The final QE is routinely in the range of 8–10%.

The standard cathode characterization consists of a spectral response and a QE scan in order to check the uniformity of the cathode. Fig. 1 shows a typical spectral response of the cathode. The drop of the QE at long wavelengths is due to the physical properties of cesium telluride as mentioned at the beginning of this section. The absence of a sharp edge at long wavelengths was explained as due to the presence of more than one phase of the Cs_2Te

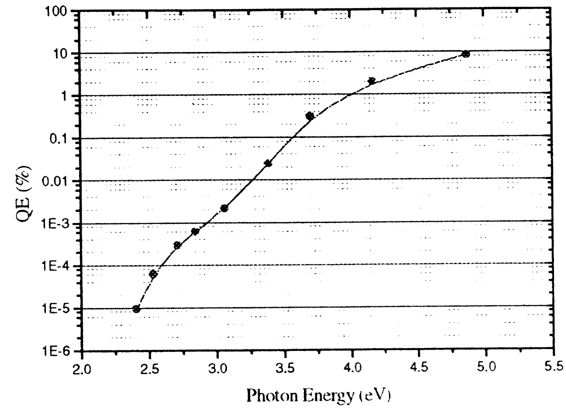

Fig. 1. Typical cathode spectral response. The UV laser light used has a photon energy of 4.7 eV.

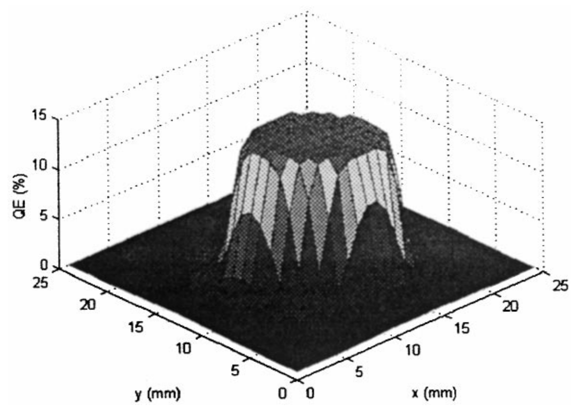

Fig. 2. Distribution of the quantum efficiency over the cathode area.

compound [9]. A plateau is reached at $E = 5.0$ eV close to the 4th harmonic of Nd:YLF (4.7 eV). A beam-steering system scans the cathode area by moving a UV light beam from an Hg lamp. The photocurrent emitted from the cathode is collected with an anode placed right in front of the cathode itself. The uniformity is a few percent with respect to the max QE over the whole cathode area (Fig. 2).

3. Dark current

The operation of the cathode in the gun exposes the cathode itself to a very high electric field, up to

50 MV/m. In these conditions, the field emission plays an important role. The current density due to field emission is given by the Fowler–Nordheim relation [10]

$$j \propto (\beta \cdot E)^{5/2} \cdot \exp\left(-\frac{B}{\beta \cdot E} \right)$$

where E is the amplitude of the electric field, β is an enhancement factor due to the geometry of the source and B is a material-dependent parameter. The sources of dark current are usually tips or needles on the surfaces exposed to the electric field that, due to their geometry, cause an increase of the β parameter. Part of the electrons produced in this way is then accelerated along the linac becoming a source of dark current.

The first test of an Mo substrate exposed to the high field of the gun was done in the summer of 1998. The current was collected over the RF pulse with a Faraday cup. After this measurement, we tested a coated substrate. The results are shown in Fig. 3.

High dark current values were observed in the first operation of the new Mo substrate in the gun. Its reduction to the values shown in Fig. 3 are due to gun conditioning. The coated substrate showed always higher dark current values, probably related to the cesium telluride.

Since both substrate surfaces were finished with a tooling machine, they were not mirror-like

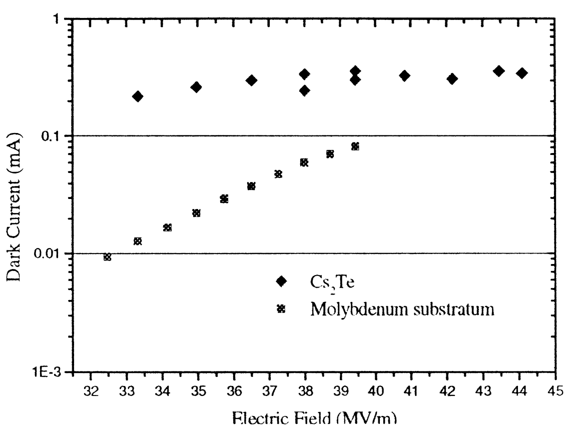

Fig. 3. Dark current from an uncoated and coated substrate with rough surface finishing measured in the gun test stand.

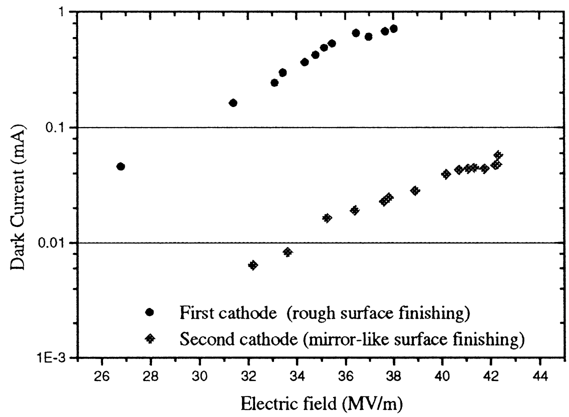

Fig. 4. Dark current measurements with respect to the different surface finishing of a coated substrate.

and an inspection with an optical microscope revealed deep scratches on the surface. For these reasons, a second set of cathodes was prepared with a better surface polishing in order to minimize the surface irregularities. We used diamond grinding powder with a size down to 50 nm. The final aspect of the surface was mirror like. The first cathode with this new surface finishing and a Cs_2Te coating layer was tested in the gun in March 1999 for one week of continuos operation. A significant reduction in the dark current was achieved. The comparison between the two types of cathodes is shown in Fig. 4. The new surface finished cathode had more than one order of magnitude less dark current than the old type cathode.

The cathode dark current was measured again at the end of July 1999, when the gun was brought back in operation. We measured a dark current value of 100 μA at 35 MV/m to be compared with the previous value of 16 μA. A significant drop of the QE was also measured that is reported in the following section.

4. QE and lifetime

Cathodes produced at Milano are transported under UHV condition at DESY with a dedicated transport system [11]. This procedure is necessary

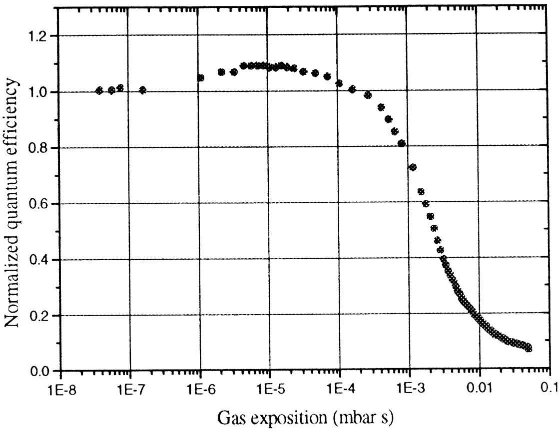

Fig. 5. Cathode sensitivity to oxygen exposition.

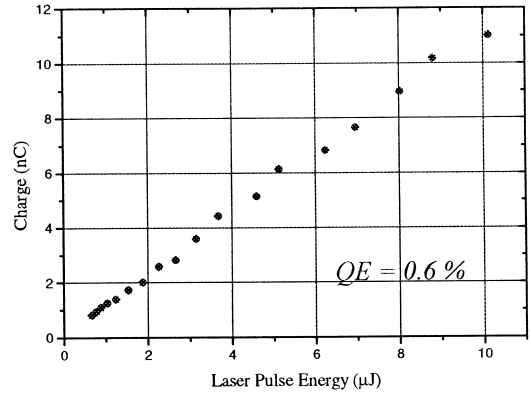

Fig. 6. Response of the Cs_2Te cathode in the RF gun as a function of laser pulse energy.

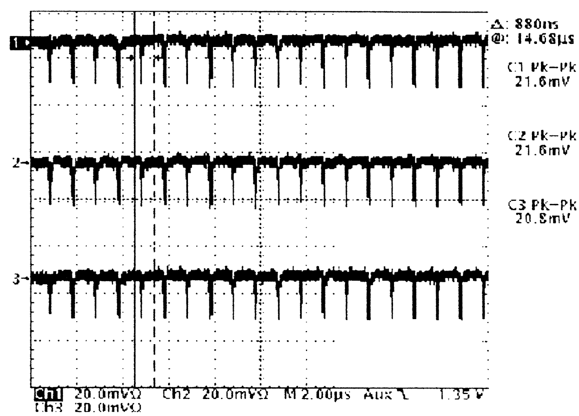

Fig. 7. Charge along the bunch train measured in different locations in the injector.

due to the high sensitivity of these photocathodes to gas exposition [12]. As an example, Fig. 5 shows the effects of exposition to oxygen on the QE. In the following, the influence of the cathode transport system on the QE degradation and the cathode performance when used in the RF gun are discussed.

To evaluate the effect on the cathode QE due to the transportation, we measured the QE just before leaving Milano and when arriving at DESY. During the travel of about 24 h, the pumping system of the transportation chamber was powered by a battery through a DC/DC converter and the vacuum was kept in the 10^{-10} mbar range. The measurements show no QE degradation during transportation. The reliability of the system was confirmed with the transportation of the second cathode set.

During the run from December 1998 to March 1999, we used a cathode with a rough surface finishing. Only at the end of the run, we tested one cathode with the new surface polishing.

The first cathode used in the injector had a high dark current as mentioned in the previous section. We measured from time to time the charge versus laser energy response. A typical set of data is shown in Fig. 6.

The corresponding QE is 0.6% far below the value of 6% measured in June 1998 but stable along the whole run. Electron bunches of 1 and 8 nC were routinely produced. Up to 30 bunches (1 MHz repetition rate) per train were used during the run and no saturation effect in the extracted charge was observed. Fig. 7 shows an oscilloscope trace of the charge pulse train measured with integrated current transformers installed along the injector beam line.

At the end of the run, the cathode with the new surface finishing was tested in the gun. The QE after the production was 10% with a uniformity of 5% over the whole cathode surface, the cathode remained three months in the transport system, mid March it was installed into the gun. We have already reported about the dark current performance in the dedicated section. Fig. 8 shows the charge measured in the gun for different laser pulse energies. The dependence between charge and pulse energy is linear up to 16 nC.

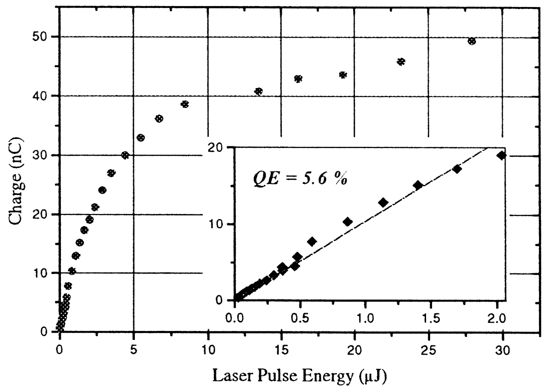

Fig. 8. Charge versus laser pulse energy for the cathode, which has a mirror-like surface finishing. In the inset, the linear part at low pulse energy is zoomed.

From the slope, the evaluated QE value is 5.6%, a factor of 10 larger with respect to the previous cathode. A saturation effect appeared at high laser pulse energies as expected, because of the build-up of space charge screening due to the high charge density on the cathode surface. A detailed discussion on this subject is reported at this conference [13]. The maximum charge extracted from the gun was 50 nC to be compared with 0.3 μC emitted from the cathode, assuming constant QE.

This cathode was measured again in July 1999 after 5 months of storage in the RF gun. The QE was 0.6%, a factor of 10 lower than in March. During this period, the pressure at the pump near the gun was stable at 3.5×10^{-11} mbar and, since the gun has never been baked, we expect a water partial pressure of some 10^{-10} mbar in the cathode region. Therefore, the cathode has been exposed to some 10^{-3} mbars of water. Since the expected effect of water is at least comparable to that of oxygen, the measured QE drop by a factor of 10 is consistent with the experimental data shown in Fig. 5.

5. Conclusion

Transportation and operation of cesium telluride photocathodes in the TTF injector was successfully commissioned during the run December 1998 to March 1999. Cathodes were transported from Milano to DESY without degradation of quantum efficiency. High dark current and low QE values were measured on a six months old photocathode with a rough surface finishing. However, a significant improvement is attained with a fresh cathode, which has a mirror-like substrate finishing. The dark current was a factor of 10 higher. Nevertheless, after five months storage, the QE dropped by a factor of 10, presumably due to water in the gun, while the dark current increased only by a factor of 6. Studies are in progress in order to investigate if QE drop and dark current are related. Moreover, new types of photocathodes will be tested in the RF gun in the next months, prepared with new recipes, which include Potassium. It has been shown [14] that these cathodes are less sensitive to gas exposition while maintaining high quantum efficiency.

The charge delivered over 30 bunches at 1 MHz repetition rate was not limited by saturation effect on the cathode itself. The maximum charge extracted from the gun was 50 nC well above the requirements for TTF.

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