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Production And Studies Of Photocathodes For High Intensity Electron Beams

E. Chevallay, S. Hutchins, P.Legros, G. Suberlucq, H.Trautner

Abstract

For short, high-intensity electron bunches, alkali-tellurides have proved to be a reliable photo-cathode material. Measurements of lifetimes in an RF gun of the CLIC Test Facility II at field strengths greater than 100 MV/m are presented. Before and after using them in this gun, the spectral response of the Cs-Te and Rb-Te cathodes were determined with the help of an optical parametric oscillator. The behaviour of both materials can be described by Spicer's 3-step model. Whereas during the use the threshold for photo-emission in Cs-Te was shifted to higher photon energies, that of Rb-Te did not change. Our latest investigations on the stoichiometric ratio of the components are shown. The preparation of the photo-cathodes was monitored with 320 nm wavelength light, with the aim of improving the measurement sensitivity. The latest results on the protection of Cs-Te cathode surfaces with CsBr against pollution are summarized. New investigations on high mean current production are presented.

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PRODUCTION AND STUDIES OF PHOTOCATHODES FOR HIGH INTENSITY ELECTRON BEAMS

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For short, high-intensity electron bunches, alkali-tellurides have proved to be a reliable photo-cathode material. Measurements of lifetimes in an RF gun of the CLIC Test Facility II at field strengths greater than 100 MV/m are presented. Before and after using them in this gun, the spectral response of the Cs-Te and Rb-Te cathodes were determined with the help of an optical parametric oscillator. The behaviour of both materials can be described by Spicer's 3-step model. Whereas during the use the threshold for photo-emission in Cs-Te was shifted to higher photon energies, that of Rb-Te did not change. Our latest investigations on the stoichiometric ratio of the components are shown. The preparation of the photo-cathodes was monitored with 320 nm wavelength light, with the aim of improving the measurement sensitivity. The latest results on the protection of Cs-Te cathode surfaces with CsBr against pollution are summarized. New investigations on high mean current production are presented.

1 INTRODUCTION

In the CTF II drive beam gun, Cs-Te photocathodes are used to produce a pulse train of 48 electron bunches, each 10 ps long and with a charge of up to 10 nC [1]. In CTF, the main limit to lifetime is the available laser power, which requires a minimal quantum efficiency (QE) of 1.5 % to produce the nominal charge. Although Cs-Te photocathodes are widely used, a complete understanding, especially of their aging process, is still lacking. Spectra of the QE against exciting photons may help to understand the phenomenon.

2 MEASUREMENTS OF QE AGAINST PHOTON ENERGY

According to Spicer [2], the spectra of the quantum efficiency (QE) of semiconductors with respect to the energy of the exciting photons ($h\nu$) can be described as:

$$QE = \frac{c_1(h\nu - E_T)^{\frac{3}{2}}}{c_2 + (h\nu - E_T)^{\frac{3}{2}}}, \qquad (1)$$

where E_T is the threshold energy for photoemission, c_1 and c_2 are constants.

2.1 The OPO

To measure the spectral response of photocathodes, wavelengths from the near UV throughout the visible are necessary. To attain these, an **O**ptical **P**arametrical **O**scillator was built [3]. A frequency-tripled Nd:YAG laser pumps a BetaBarium Borate (BBO) crystal in a double-pass configuration, as shown in Fig. 1. The emerging signal-beam, with wavelengths between 409 nm and 710 nm, is frequency doubled in two BBO crystals. The wavelengths obtained are between 210 nm and 340 nm. The idler-beam delivers wavelengths between 710 nm and 2600 nm.

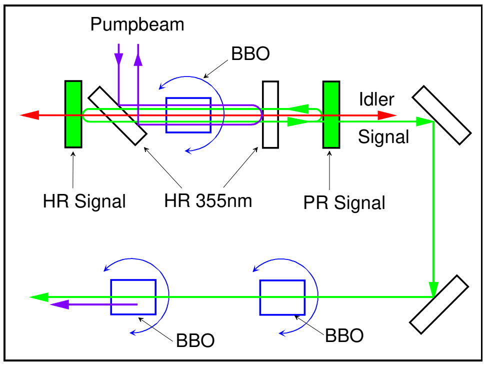

Figure 1: OPO scheme with following doubling crystals

The measurements of the spectral response of photocathodes were made in the DC-gun of the photoemission lab at CERN [4], at a field strength of about 8 MV/m. Spectra were taken shortly after the evaporation of the cathode materials onto the copper cathode plug, as well as after use in the CTF II RF-gun [5] at fields of typically 100 MV/m.

2.2 Cesium Telluride

To be able to interpret the spectra in terms of Spicer's theory, it was necessary to split the data into 2 groups, one at "low photon energy" and one at "high photon energy", see Fig. 2. Then, the data can be fitted well with two independent curves, following Eq. (1), which give two threshold energies. For a typical fresh Cs-Te cathode, the high energy threshold is 3.5 eV, the low one is 1.7 eV, as shown in Fig. 2, upper curve. This might be a hint that two photo-emissive phases of Cs-Te on copper exist. Several explanations are possible: The copper might migrate into the Cs-Te, creating energy levels in the band gap; or possibly not only Cs_2Te, but also other Cs-Te compounds might form on the surface and these might give rise to photoemission at low photon energy. A hint to this might be that the ratio of evaporated atoms of each element is not corresponding to Cs_2Te, see below.

After use, we found that not only the complete spectrum shifted towards lower quantum efficiency, but also that the photoemission threshold for high QE increased to 4.1 eV, which is shown in Fig. 2, lower curve. One might expect that the photocathode is poisoned by the residual gas, preventing low-energy electrons from escaping. However, be-

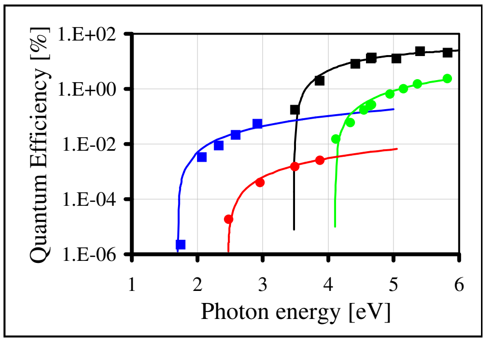

Figure 2: Spectra of a Cs-Te photocathode on copper. Before (square points) and after use (round points) in the CTF II drive beam gun

cause typical storage lifetimes are of the order of months, the effect must be connected to either the laser light, or the electrical field.

We also produced a Cs-Te cathode on a thin gold film of 100 nm thickness. As shown in Fig. 3, the shoulder in the low energy response disappeared. It is difficult to fit a curve for the Spicer model to the low energy data. The "high" photoemission threshold is at 3.5 eV. At the moment, this cathode is in use in the CTF II gun and will be remeasured in the future. In terms of lifetime, this cathode is comparable to the best Cs-Te cathodes, as it has already operated for 20 days in the RF-gun.

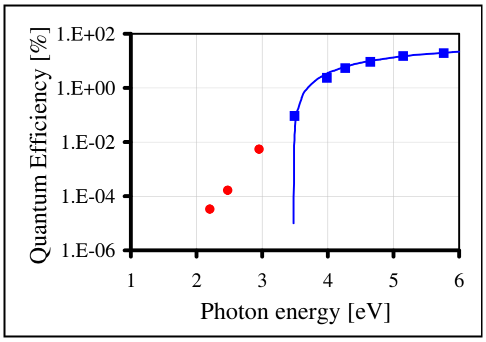

Figure 3: Cs-Te cathode, evaporated on a gold film of 100 nm thickness. The round points are not used for the fit.

2.3 *Rubidium Telluride*

As a new material presented first in [1], we tested rubidium-telluride. We took spectra of QE before and after use in the CTF II gun, as for Cs-Te. Remarkably, with this material, there was no shift in the photoemission threshold towards higher energies, but only a global shift in QE, see Fig. 4. This might be due to the lower affinity of rubidium to the residual gas. Detailed investigations are necessary to clarify this.

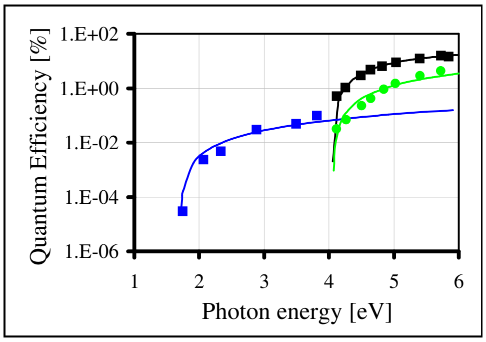

Figure 4: Spectra of a Rb-Te cathode before use (square points) and after use (round points) in the CTF II drive beam gun

2.4 *Coating with CsBr*

Long lifetimes for Cs-Te cathodes are achieved only when they are held under UHV ($\leq 10^{-8}$ mbar). Other photocathode materials like K-Sb-Cs are immunized against gases like oxygen by evaporating thin films of CsBr onto them [6]. Therefore, we evaporated a CsBr film of 2 nm thickness onto the Cs-Te. Fig. 5 shows the spectrum before the CsBr film (square points) and after it (round points). The

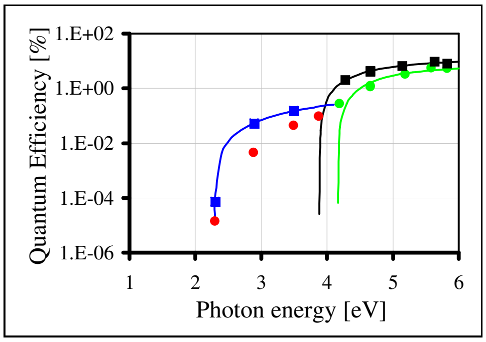

Figure 5: Spectra of a Cs-Te cathode without CsBr (square points) and with CsBr coating (round points)

QE at 266 nm dropped from 4.3 % to 1.2 %. In addition, the photoemission threshold was shifted from 3.9 eV to 4.1 eV. A long-term storage test showed no significant difference between uncoated and coated cathodes. More investigations will determine the usefulness of these protective layers.

2.5 *Preparation with other wavelengths*

In order to increase the sensitivity of the on-line QE measurement during evaporation of the photocathodes, we monitored the process with light at a wavelength of 320 nm. We did not see any significant improvement in sensitivity, notably in the high QE region.

3 STOICHIOMETRIC RATIO

Film thicknesses are measured during the evaporation process by a quartz oscillator [4]. Typical thicknesses for high quantum efficiencies at $\lambda = 266$ nm are 10 nm of tellurium and around 15 nm of cesium. This results in a ratio of the number of atoms of each species of $N_{Te}/N_{Cs} = 2.85$, far from the stoichiometric ratio of 0.5 for Cs_2Te. It is known that tellurium interacts strongly with copper [7], so that not all of the evaporated tellurium is available for a compound with subsequently evaporated cesium. Therefore, we used also Mo and Au as substrate material. However, the ratio between the constituents necessary for optimum QE, did not change significantly. Another reason might be that instead of Cs_2Te, Cs_2Te_5 is catalytically produced on the surface. This compound, as well as some others, was found to be stable [8].

4 LIFETIME IN CTF II

Lifetime in CTF depends on parameters like maximum field strength on the cathode, vacuum and especially extracted charge. Typically, a cathode is removed from the gun, if the QE falls below 1.5 %. As shown in Fig. 6, lifetime does not depend on the initial QE; a cathode having an initial QE of 15 % (round points) lasted as long as one with 5 % (triangles).

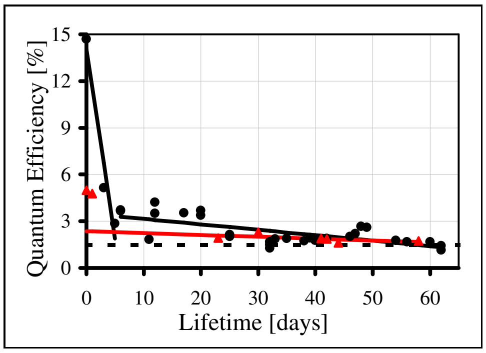

Figure 6: Lifetime in CTF of two different cathodes

5 HIGH CHARGE TEST

As shown in Table 1, the average current produced in CTF II is nearly a factor 10000 lower than what is required for the CLIC drive beam. A test to produce 1 mC is under preparation in the photoemission laboratory at CERN. The exact reproduction of the CLIC pulse structure would require the CLIC laser, which is still in the design stage in a collaboration between Rutherford Appleton Laboratory and CERN. A test which is compatible with our current installation is the production of 1 mA of dc current, which requires a UV laser power of 300 mW at the cathode. For this test, we will illuminate the cathode with pulses of 100 ns to 150 ns pulse length, at repetition rates between 1 kHz and 6 kHz. As Table 1 shows, this is a factor 1000 more average current than in CTF II, and also demonstrates the basic ability of the cathodes to produce the CTF 3 drive beam (I=26μA). CLIC is still a factor 75 away. We are currently searching for ways to produce higher charges as well.

Table 1: Comparison of cathode relevant parameter

	CTF II	CLIC 3 TeV	"Test 1 mC"
Current	0.008 mA	75 mA	1 mA
Power	0.072 mW	35 W	300 mW

6 CONCLUSION

Measurements of QE against photon energy are routinely made after production and after use of photocathodes. We have demonstrated that both low energy and high energy responses agree well with Spicer's theory. A gold buffer layer reduces the low energy response of Cs-Te cathodes. More work is needed to understand the measurements of the stoichiometric ratio of Cs-Te. Coating with 2 nm CsBr significantly decreased the quantum efficiency, without improving the storage lifetime. For the high-charge drive beam of CLIC, it is still necessary to demonstrate the capabilities of Cs-Te, for which first tests will be done soon.

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