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FABRICATION AND CHARACTERIZATION OF CESIUM
TELLURIDE PHOTOCATHODES: A PROMISING
ELECTRON SOURCE FOR THE LOS ALAMOS
ADVANCED FEL

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FABRICATION AND CHARACTERIZATION OF CESIUM TELLURIDE
PHOTOCATHODES: A PROMISING ELECTRON SOURCE FOR
THE LOS ALAMOS ADVANCED FEL

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The Advanced FEL at Los Alamos embodies a K_2CsSb photocathode as an electron source. The photocathode consists of a K_2CsSb film deposited on a molybdenum plug that can be inserted into the linac of the FEL. However, because K_2CsSb is easily contaminated and has a half-life of less than a day when in use, switching to a more rugged high quantum efficiency (QE) material such as Cs_2Te is considered as a means to lengthen the beam time. Cs_2Te films were deposited on molybdenum plugs in an ultrahigh-vacuum research chamber. Several Cs_2Te films were measured *in-situ* for their spectral responses with a bias voltage of 90V; the resulting QEs were 12-18% at a wavelength of 254 nm, 0.2-1.2% at 334 nm, 10^{-4} - 10^{-3} at 365 nm, and 10^{-7} - 10^{-5} at 546 nm. For this cathode to be useful, we need to frequency quadruple the 1052 nm line of the Nd:YLF laser to achieve a wavelength of 263 nm. Initial studies showed that the 251-nm QE of Cs_2Te is much less sensitive to contamination than the 526-nm QE of K_2CsSb . We exposed Cs_2Te photocathodes to air at 10^{-4} torr for five minutes. As a result, the QEs dropped from 16-18% to 1-2% at 254 nm. However, heating the cathode to 165°C revived the QE to about 10%. We conclude that Cs_2Te is a very rugged photocathode material for use in an rf photoelectron source.

1. Introduction

The Los Alamos Advanced free electron laser uses a photocathode driven by a Nd:YLF modelocked laser as a source for 1-3 nC electron pulses of 10-30 ps length. The electrons liberated from the photocathode are accelerated in an rf linear accelerator to an energy of 14-20 MeV. Initially, we have used K_2CsSb photocathodes, because they have high quantum efficiencies in the green. However, the operational lifetime of these cathodes is very short, on the order of one to three days of normal operations. Photocathode materials used by other groups as electron sources for electron accelerators include Cu and LaB_6 , which are very rugged but have relatively low quantum efficiencies and must be driven by UV light.^{1,2}

Recently, cesium telluride photocathodes have been successfully used in the operation of the Los Alamos Advanced FEL.³ In this paper we report on their fabrication technique, and on the experiments performed in the fabrication chamber concerning their contamination and rejuvenation properties.

2. Experimental setup

Cesium telluride photocathodes were fabricated in a separate ultra-high vacuum research chamber with an ambient pressure in the middle 10^{-10} torr range which rose to the low 10^{-9} torr range during the fabrication. The tellurium source consisted of a small molybdenum can of 99.9999% pure tellurium pieces. The can was heated by thermocoax heater wires wound around the can. The Te atoms escaped through a small hole on the top of the can. Cesium was dispensed from a similar can packed with a powdered mixture of cesium chromate and titanium. The substrate is a molybdenum plug that can be inserted into the linac. The sources were positioned

about 1.25 inches from the face of the plug so that simultaneous deposition was possible. Due to this geometry, the deposition occurred at an angle of about 10° from normal. A mask was used to confine the deposition to a 1cm^2 area.

The deposition rate of the Te boat was calibrated by using a quartz crystal thickness monitor. The quartz crystal can be placed in front of the sources in place of the Mo plug. Several thicknesses were calibrated by exposing the cathode to the Te source at a given temperature for a given amount of time and noting the resulting thickness reading. However, we cannot monitor or control the temperature of the quartz crystal. A systematic error may arise from the variation of the sticking coefficient with the substrate temperature. Since the fabrication of the Cs_2Te films was carried out at an elevated temperature, the calibration numbers were probably high. The Cs source was not calibrated.

A battery was used to bias the cathode by -90V relative to the chamber over a distance of about one to two inches resulting in an accelerating field of $1.8\text{--}3.6\text{ kV/m}$. The photocurrent was measured with a picoammeter. An Oriel 350W Hg arc lamp followed by a f1 condenser lens, a dichroic mirror, and a bandpass interference filter was used to illuminate the photocathode with light at several different wavelengths. The light transmitted through the bandpass filter was reimaged onto the photocathode through an uncoated fused silica vacuum window. When accurate measurements of QE were required, the light intensity after the f4 focusing lens was measured with a calibrated silicon photodiode before measuring the photocurrent. The transmission of visible and UV light through the fused silica viewport was taken to be $90\pm 3\%$ in the calculations for the incident light intensities. The absolute uncertainty of the QE measurements

is about $\pm 15\%$. The relative uncertainty between measurements made at the same wavelengths is about $\pm 5\%$.

3. Fabrication procedure

The Mo plugs were precleaned with soap and water followed by ethanol before mounting them in a ladder that holds up to seven plugs in a vacuum transport chamber. This pack of cathodes was mounted onto a six-way cross that served as the vacuum interlock. The cross and the cathode pack were pumped out and baked at 200°C . After the bake, a single cathode was inserted into a portable oven on the end of an actuator and moved to the main chamber. The Mo plug was baked at 300°C for several hours to further clean the cathode surface.

The fabrication procedure is similar to that for cesium antimonide, Cs_3Sb .⁴ First, we deposited a film of Te with a thickness between $100\text{\AA}$ - $300\text{\AA}$ onto the surface of the Mo plug. While monitoring the photocurrent at 251 nm , the film of Te was reacted with Cs until the photocurrent peaked and has decreased by 10-20%. Then the deposition of Cs was stopped by turning off the boat heater. The photocurrent started to recover and eventually reached a level near where it peaked. During this process, the plug was kept at the fabrication temperature to help prevent excess Cs and contaminants from condensing on the film and to facilitate the reaction of Cs with Te. The whole process starting from the deposition of Te typically took about one hour. As a precaution against Cs contamination in the linac, some photocathodes were heated to about 170°C to ensure removal of any free Cs from the surface. This step is probably necessary only when fabricating near room temperature.

4. Spectral Response

The QEs of the five Cs₂Te photocathodes were measured at several wavelengths using a 350W Hg arc lamp and several band pass filters. The UV spectral response of PC1 compares well with data taken by Powell (Fig. 1).⁵ However, the PC1 data have a broader cutoff below 4 eV due to the relatively large spectral width of the incident light (8-35 nm). The PC1 data also have a larger low energy shoulder. This discrepancy is expected since the low energy shoulder varies in size significantly from different data sources and even among our Cs₂Te photocathodes (Fig. 2).

In Figure 2, we see that the quantum efficiencies of the five photocathodes compare very well at 251 nm. Variations are progressively larger at lower photon energies. In particular, the response to visible light is significantly less for PC4 and PC5 which were fabricated differently from the other photocathodes in the set, as described above. The smaller variations in the spectral response among PC1, PC2, and PC3 are probably due to variations in the cesium content.

5. Exposure to air

An important issue is the level of vacuum necessary to keep Cs₂Te photocathodes from degrading below the point where they become useless. Of particular interest is their tolerance to vacuum levels on the order of 10⁻⁷ torr, which can easily be achieved without requiring a bakeout of a vacuum chamber. Also of interest is the tolerance to vacuum conditions greater than 10⁻⁴ torr, which will determine the degree of care needed when transferring the photocathode from the fabrication chamber to the photoinjector.

PC1 was exposed for 17 hours to an average vacuum of 1x10⁻⁷ torr. This was accomplished by isolating the photocathode in the vacuum interlock cross and pumping on this section with a

turbo pump through a partially closed valve. During the exposure, the vacuum pressure dropped from 4×10^{-7} torr to 5×10^{-8} torr. After the exposure, the PC1 was transferred back to the main chamber and the spectral response was remeasured (Fig. 3). The 251-nm QE dropped from 15.7% to 5.2% and the shoulder at 3 eV was no longer well defined. With the same procedure, PC1 was exposed for another 91.5 hours to a vacuum with an average pressure of 4×10^{-7} torr. Afterwards, the spectral response was measured again (Fig. 3). The 251-nm QE dropped to 3.1%. If an exponential decay in QE is assumed, then a $1/e$ time constant of 15 hours is obtained for the first stage and 177 hours for the second stage. Clearly the decay in QE is not exponential. This result suggests that as the photocathode is exposed to contamination, the surface becomes passivated. Thus, it is apparent that Cs_2Te is reasonably rugged and the possibility of its use in a medium vacuum system is promising.

PC3 was exposed to air through a variable leak valve at an average pressure 2×10^{-4} torr range for five minutes. The 251-nm QE dropped from 17.8% to 0.70%. After measuring the spectral response, PC3 was exposed to air at an average pressure of 2×10^{-4} torr for 55 more minutes, which further dropped the QE to 0.50%. Table 1 summarizes the uv spectral response following these stages. The first five minutes of exposure is quite detrimental and further exposure of less consequence. Therefore, any attempt to transfer Cs_2Te in nitrogen will probably require the ability to rejuvenate the photocathode after the transfer.

PC5 and PC4 were also exposed to air for 5 minutes followed by 55 minutes at a level of 2×10^{-4} torr. The 251-nm QE of PC5 dropped from 15.8% to 2.0% and 1.1%, and the 251-nm QE of PC4 dropped from 16.4% to 1.1% and 0.79% (Table 1). We observe that PC5 appears to be more rugged than PC3 and PC4, and can conclude that fabricating photocathodes at room

temperature does not affect their ability to withstand degradation by exposure to air. Furthermore, a small enhancement in durability may be expected, but this is not a firm conclusion since PC5 probably has a thicker film, which may also result in a more rugged photocathode.

6. Rejuvenation of degraded photocathodes

We have found that heating photocathodes that have been degraded by exposure to poor vacuum conditions can be rejuvenated by heating them above 100°C for several hours. After PC2 was degraded by the method mentioned in §5, it was held at 110°C for about 12 hours. A noticeable increase in QE was noted when the photocathode temperature rose above 100°C. The photocathode was allowed to cool to room temperature before the spectral response was measured (Fig. 3). The 251-nm QE recovered to 11.3%, which is a very respectable value. After storing the rejuvenated photocathode in a vacuum of 10^{-9} torr for three weeks, the 251-nm QE dropped to 4.7%.

Similarly, PC3 and PC5 were partially rejuvenated by heating it to 175°C for about 12 hours and 2 hours, respectively (Table 1). We observed that after one hour at 175°C, further heating increases the QE insignificantly. From experience, we have found that the rejuvenation of these heavily contaminated photocathodes is best achieved when heated to 150°C - 200°C. The 251-nm QE of PC3 peaked at 15.0% while hot and stabilized at 10.4% after cooling to room temperature. The 251-nm QE of PC5 stabilized at 9.4%.

In order to evaluate the ruggedness of rejuvenated photocathodes, PC3 was given another round of exposure to 2×10^{-4} torr of air. After 5 minutes of exposure, the 251-nm QE dropped from 10.4% to 2.74%. Further exposure for 55 minutes resulted in a 251-nm QE of 1.2%. The

results are again summarized in Table 1. Clearly, the ultraviolet QE of the rejuvenated PC3 is less affected by exposure to air than the virgin PC3.

7. Conclusions

Several Cs₂Te photocathodes were fabricated with 251-nm QEs ranging from 16-18%, which are in agreement with Powell's data. Exposure to 4×10^{-7} torr vacuum reduces the 251-nm QE to 3.1% after five days. At this point, the surface appears to be passivated by the contaminants so that further degradation in QE is at a much slower rate. Therefore, operations at 10^{-8} to 10^{-7} torr vacuum levels may be possible. Exposure to 2×10^{-4} torr vacuum reduces the 251-nm QE to 0.5-1.0% in one hour. This implies that a transfer process will significantly degrade Cs₂Te unless good vacuum is maintained. However, the rejuvenation results are very encouraging. Cs₂Te photocathodes degraded by air can be partially rejuvenated by heating them to 150-200°C. This suggests that transfer in poor vacuum or pure nitrogen may be feasible. Furthermore, it may be possible to extend the operational lifetime of Cs₂Te photocathodes by heating them while in use or after they are contaminated.

TABLES

[1] The quantum efficiencies of PC3, PC4, and PC5 are listed for three different wavelengths. The QEs separated by slashes represent measurements made prior to air exposure, after 5 minutes of air exposure, and after 60 minutes of air exposure. The photocathodes were exposed to 2×10^{-4} torr of air.

FIGURE CAPTIONS

[1] Spectral response data measured for Cs_2Te photocathode PC1 are compared with Powell's data from Ref. 5.

[2] Spectral response data for Cs_2Te photocathodes, PC1, PC2, PC3, PC4, and PC5.

[3] Spectral response data for photocathode PC1 before and after 17 hours of exposure to 1×10^{-7} torr of outgassing followed by 91.5 hours of exposure to 4×10^{-7} torr of outgassing. The spectral response data for PC1 after rejuvenation are also displayed.

Photocathodes	251-nm QEs (%)	304-nm QEs (%)	328-nm QEs (%)
PC3	17.8 / 0.70 / 0.50	2.1 / 0.050 / 0.043	0.49 / 0.013 / 0.012
Rejuvenated PC3	10.4 / 3.0 / 1.2	1.5 / 0.30 / 0.070	0.26 / 0.067 / 0.014
PC4	16.4 / 1.1 / 0.79	2.4 / 0.063 / 0.038	0.63 / 0.013 / 0.009
PC5	15.8 / 2.0 / 1.1	3.0 / 0.21 / 0.080	0.73 / 0.041 / 0.018
Rejuvenated PC5	9.4	1.7	0.46

Table 1

Fig. 1 7119

Fig 2 7/19

Fig. #3

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