High efficiency photoemission from Cs–K–Te

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Cs–K–Te films have been fabricated under ultrahigh vacuum by vapor deposition of Te, K, and Cs onto a Mo substrate into the preparation chamber of the free electron laser of the University of Twente. Their photoemission properties are reported in this letter. The average quantum efficiency at 259 nm measured on 5 evaporated Cs–K–Te photocathodes is 22.5%, whereas the best quantum efficiency obtained at 259 nm is 23.4%. To our knowledge, this is the highest quantum efficiency at 259 nm reported so far, being about twice that of Cs$_2$Te photocathodes. The reported results demonstrate that Cs–K–Te photocathodes are very promising for the use in photoinjectors.

Very bright electron beams, with high current densities, can be generated by illumination of photocathodes with a cw or pulsed laser. In past years, a major issue for the electron accelerator and free electron laser (FEL) communities has been the search for a suitable material to be used as a photocathode in photoinjectors. High (>1%) quantum efficiency (QE) for photoemission by visible or soft UV light and long lifetime under operating conditions are ideal photocathode’s features. This, however, is difficult to achieve. Recently, two materials (Cs$_2$Te$^{3-6}$ and K–Te$^{7,8}$) have been demonstrated to have both high QE in the soft UV range (around 260 nm) and long lifetime under accelerator operation. In this letter, we report on the photoemissive properties of a new photocathode displaying a QE at 259 nm which is about twice that of Cs$_2$Te and K–Te. This material, which is a compound of Cs, K, and Te, also shows a long lifetime after storage in ultrahigh vacuum (UHV), suggesting it could be an ideal photocathode for photoinjectors.

Cs–K–Te photocathodes have been evaporated in the preparation chamber of the Twente FEL on a Mo substrate placed on an actuator, with which the cathode can be moved from the preparation chamber into the first cell of the linear accelerator. The containers with the evaporating materials are mounted on an actuator perpendicular to the cathode and are placed in front of the Mo plug during the evaporation process. The QE is measured by illuminating the photocathodes (biased at -90 V) with light of different wavelengths, delivered by a mercury lamp in combination with different bandpass interference filters, and by detecting the produced photocurrent with a picoparameter.

The fabrication of a Cs–K–Te cathode is carried out by first evaporating a film of Te on the surface of the Mo plug, keeping the boat containing Te at 300 °C, then exposing it to K (boat at 505 °C) and finally evaporating Cs (boat at 565 °C). During the whole process, the photocurrent at 259 nm is monitored. It is also possible to fabricate a Cs–K–Te cathode by evaporating Cs immediately after Te, and before K, thus inverting the last two steps of the procedure described above. Although the final QE at 259 nm of the Cs–K–Te layer obtained with the latter sequence (Te→Cs→K) is much higher than that of the Cs–Te layer alone, the first mentioned sequence (Te→K→Cs) gives the best QE. Therefore, we will describe in this letter only the results of Cs–K–Te layers fabricated with the first sequence (Te→K→Cs). The pressure in the preparation chamber rises during the evaporation process from the low $10^{-10}$ Torr range up to the high $10^{-10}$ Torr range. A 30 min Te evaporation time has been used to fabricate all the photocathodes investigated in this letter. It has already been demonstrated that this time gives the optimum layer thickness for both Cs$_2$Te$^0$ and K–Te cathodes. Unfortunately, our experimental set-up does not allow us to determine the thickness of the evaporated layers and therefore, in order to give information about the evaporation recipe, we shall refer in the following to evaporation times.

Figure 1 shows the QE at 259 nm measured during the evaporation of K and Cs on a Te layer. The substrate temperature was kept at 120 °C during the Te and K evaporation, and at 150 °C during the Cs evaporation. The QE de-
pendence on the K evaporation time is a typical feature of
K–Te, already known from Ref. 7. It shows in this case a
peak value of 7.5%, followed by a decrease and a final satu-
ration of 6% QE. When Cs evaporation is started, a steep in-
crease of the QE occurs, giving in about 15 min a value of
20.8%, which remains constant with time until the end of
the evaporation process. After removal of the Cs boat, a 23.4%
QE is measured. The difference between the QE saturation
value and the final QE measured after boat removal must be
ascribed to a partial shielding of the mercury lamp light dur-
ing evaporation, due to the presence of the boat in front of
the cathode. The reason why the substrate temperature has to
be increased to 150 °C before the Cs evaporation starts is
that we have observed an excess amount of Cs at the cath-
ode’s surface at lower temperatures, resulting in a lower final
QE at 259 nm. When a substrate temperature below 150 °C
is used during Cs evaporation, an additional heating of the
substrate at 150 °C, after the evaporation process has been
accomplished, produces an increase of the QE at 259 nm,
due to diffusion of the Cs excess into the already formed
Cs–K–Te film. In view of a possible use of Cs–K–Te cath-
odes in an electron accelerator, it is important to remove any
free Cs from the surface, since it can prevent the accelerator
from being contaminated by Cs.10

The dependence of the final QE at 259 nm of Cs–K–Te
photocathodes on the K evaporation time has been investi-
gated. For a given K evaporation time, the corresponding Cs
evaporation time has been taken as long as required to reach
the QE saturation. To this purpose, a Cs evaporation time
which is roughly half the K evaporation time is required. It
has been found that the QE of the Cs–K–Te photocathodes
does not change significantly by changing the K evaporation
time in the range 13–27 min. The limits of the range corre-
spond to a K evaporation process stopped at the QE max-
imum (13 min) or at the QE saturation (27 min, as shown in
Fig. 1). Further investigations are necessary in order to ex-
plain this surprising result.

The 23.4% QE reported in Fig. 1 is a very high value. It
is definitely higher than the reported QE3,6 of Cs2Te, which
has been considered so far the best cathode in the soft UV
spectral range. Nevertheless, it is important to notice that, in
general, the photocathode evaporation process, and hence the
photocathodes final QE value, is strongly dependent on the
system in which they are fabricated. Even when evaporation
parameters like the purity of the chemicals used for evapo-
ration, the thicknesses of the evaporated layers, the tempera-
ture of the substrate during evaporation, and the substrate
itself, are the same, it is possible that different evaporation

*See Refs. 8 and 9.

The spectral response of a Cs–K–Te photocathode in the
energy range of 2.84–4.79 eV is shown in Fig. 2, where
also the typical spectral responses of K–Te and Cs2Te
photocathodes have been reported for comparison. As could
be reasonably expected, the shape of the spectral response
for Cs–K–Te is somewhere in between the Cs2Te and K–Te
ones. Moreover, Cs–K–Te displays the highest QE at low
energies (2.84, 3.06 eV) and at 4.79 eV (259 nm), whereas
Cs2Te has the best QE in the energy range 3.55–3.96 eV.

A Cs–K–Te cathode can be stored for about 100 h at a

Table I. The average QE at 259 nm calculated on five evaporated samples for Cs–K–Te, Cs2Te, and K–Te.
The recipes used to evaporate Cs2Te and K–Te are the ones delivering the best QE at 259 nm in our system, as reported.3 The third and fourth column show the average QEs normalized to that of Cs–K–Te and minimum and maximum (QEs) within every group of samples, respectively.

<table>
<thead>
<tr>
<th>Photocathode</th>
<th>Average on five samples of the QE at 259 nm (%)</th>
<th>Average QE at 259 nm normalized to Cs–K–Te QE</th>
<th>QEs range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cs–K–Te</td>
<td>22.5</td>
<td>1</td>
<td>21.9%–23.4%</td>
</tr>
<tr>
<td>Cs2Te</td>
<td>11.42</td>
<td>0.51</td>
<td>10.33%–12.2%</td>
</tr>
<tr>
<td>K–Te</td>
<td>8.9</td>
<td>0.4</td>
<td>6.95%–11%</td>
</tr>
</tbody>
</table>

See Refs. 8 and 9.
pressure in the low $10^{-10}$ Torr range, without any significant change of both the QE at 259 nm and the spectral response. This is a good indication of the ruggedness of this material, suggesting it could be used successfully as a photocathode into an electron accelerator. It is important to notice that the power of the laser illuminating the cathode during accelerator operation is much higher than the mercury lamp power and that additional degrading factors are present in the accelerator (e.g., higher pressure). Therefore, it is not possible at the moment to draw any definitive conclusion on usability and lifetime of Cs–K–Te in a photoinjector. Nevertheless, it has been demonstrated\textsuperscript{7,8} that the photocathodes lifetime in UHV is strongly related to the lifetime in operating conditions and that photocathodes showing the best lifetimes in UHV display also the longest lifetimes in operating conditions. Therefore, we plan to run the Twente FEL using the Cs–K–Te cathodes, in order to investigate their lifetime under operating conditions.

In conclusion, we have reported on a new photocathode, which is a compound of Cs, K, and Te, displaying a very high QE at 259 nm and a long lifetime in UHV conditions. These features allow us to consider this material as a very promising photocathode for electron photoinjectors, possibly displaying better performances than the currently used Cs$_2$Te. Future research will deal with optimization of the layer thicknesses of Te, K, and Cs, which could further improve the QE at 259 nm, and with investigation of usability and lifetime under operating conditions in an electron accelerator.

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