

# Photoemission from K–Te photocathodes

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In this letter the photoemissive properties of K–Te films produced under ultrahigh vacuum conditions are reported. K–Te photocathodes were fabricated by vapor deposition of Te and K onto a Mo substrate into the preparation chamber of the Free Electron Laser of the University of Twente. The highest quantum efficiency obtained at 259 nm was 11.1%, measured just after evaporation; this value decreased in a few minutes to a stable quantum efficiency of 8.3%. The reported results show that K–Te can be considered a promising material for the use as a photocathode in photoinjectors. © 1996 American Institute of Physics. [S0003-6951(96)01650-6]

In recent years the research for a suitable material to be used as a photocathode in photoinjectors has been a major issue for the electron accelerator and free electron laser (FEL) communities.<sup>1,2</sup> The ideal material must display long lifetime under operating conditions and high (>1%) quantum efficiency (QE) for photoemission by visible or soft UV light. On the basis of fundamental considerations, we expected that K–Te could be a good candidate as a photocathode sensitive to UV light. Therefore, we have evaporated K–Te films and investigated their photoemissive properties under ultrahigh vacuum (UHV) conditions, reporting promising results in this letter. K–Te properties as a liquid semiconductor have been studied so far by Raman scattering,<sup>3</sup> neutron diffraction,<sup>4</sup> and electrical conductivity measurements,<sup>5</sup> but to our knowledge the photoemissive properties of K–Te have not yet been published.

The preparation chamber of the Twente FEL contains a Mo plug placed on an actuator, which is used to move the cathode from the preparation chamber into the first cell of the linac. The containers with the evaporation materials are mounted on an actuator perpendicular to the cathode and are placed in front of the Mo plug during the evaporation process. For measuring the QE, the photocathode is illuminated with light of different wavelengths, using a mercury lamp with different bandpass interference filters. By biasing the cathode with  $-90$  V, the photocurrent can be measured with a picoammeter. The fabrication of a K–Te cathode is carried out evaporating first a film of Te on the surface of the Mo plug, keeping the Te boat at  $300$  °C, then exposing it to K, keeping the K container at  $505$  °C and monitoring the photocurrent at  $259$  nm. The pressure in the preparation chamber rises during the evaporation from the middle  $10^{-10}$  Torr range up to the low  $10^{-9}$  Torr range. The Te evaporation time has been optimized by investigating the dependence of the QE on the evaporation time. The best results have been obtained for a Te evaporation time of  $30$  min. This time is used for the preparation of all the cathodes reported in this letter. Unfortunately, our experimental setup does not allow us to get information about the thickness of the evaporated layers.

Figure 1 shows the QE at  $259$  nm of a K–Te cathode as a function of the K evaporation time. During the preparation procedure the Mo substrate temperature was kept at  $120$  °C. After about  $15$  min of evaporation a very quick increase of the QE up to a  $8.15\%$  maximum value was observed; it was followed by an equally quick decrease to about half the peak value, after which the QE slowly increased up to a saturation value of about  $5\%$ . This shape of the QE as a function of the K evaporation time is a typical feature of the K–Te cathodes and is about the same when the evaporation process is performed keeping the substrate at  $90$  and  $26$  °C. For the latter temperature, the QE saturation value after the peak is very low (about  $0.1\%$ ), probably because of the presence of an excess of K at the surface, due to inefficient diffusion at room temperature of K through the already formed K–Te layer.

The shape of QE versus K evaporation time could be tentatively ascribed to a change of the film composition during the evaporation process itself. In fact, it has been demonstrated<sup>6,7</sup> that the K–Te phase changes as a function of increasing K concentration, first from  $K_2Te_3$  to  $K_2Te_2$ , then from  $K_2Te_2$  to a compound that is most probably KTe and

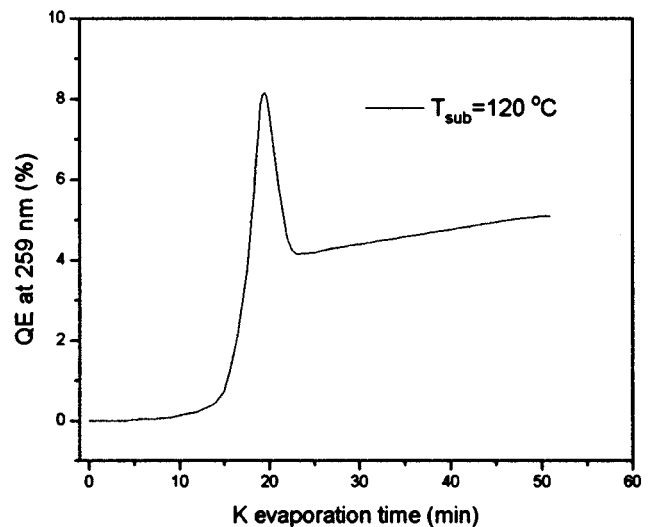


FIG. 1. QE at  $259$  nm of K–Te as a function of the K evaporation time.

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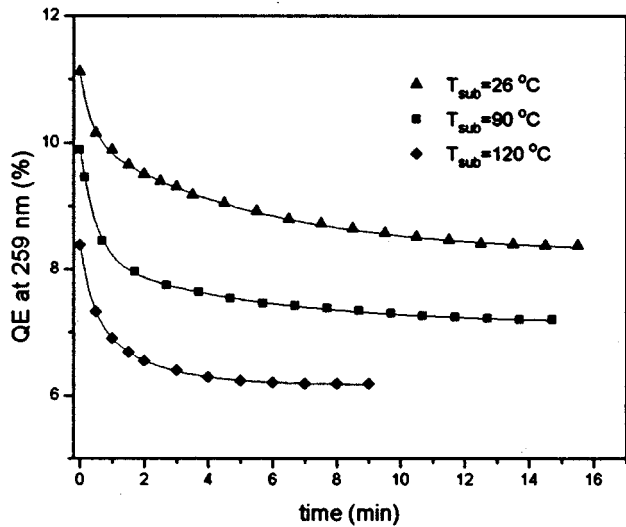


FIG. 2. Spontaneous decay after evaporation of QE at 259 nm for three MP cathodes evaporated at 26, 90, and 120 °C. The solid lines represent best fits of the experimental data and are  $8.25 + 1.03e^{-x/0.36} + 1.82e^{-x/5.33}$  (26 °C),  $7.13 + 1.03e^{-x/5.17} + 1.74e^{-x/0.5}$  (90 °C),  $6.17 + 1.07e^{-x/0.38} + 1.14e^{-x/1.82}$  (120 °C).

finally from KTe to  $K_2Te$ . The compounds  $K_2Te_3$ ,  $K_2Te_2$  and KTe have broad UV-absorption bands, whereas  $K_2Te$  has no absorption in the spectral region 220–700 nm (Ref. 7) and therefore, cannot be the photoemissive material we are investigating. We believe it is reasonable to expect that  $K_2Te_3$ ,  $K_2Te_2$ , and KTe have different photoemissive efficiencies at 259 nm; this circumstance could account for the change with K evaporation time of the QE at 259 nm.

Different optical properties of the material can be obtained by stopping the K evaporation either when the QE is at its maximum (preparation procedure called MP in the following) or when QE reaches the saturation value (preparation procedure called SP in the following). At the end of a MP preparation, the QE at 259 nm decreases spontaneously as the sum of two exponential curves, with decay times of the order of minutes, as demonstrated by Fig. 2 for three different temperatures of the Mo substrate during evaporation. This situation does not occur after a SP preparation. Nevertheless, the stable value reached after some minutes in the MP cathodes is, on the average, higher than the final value of a SP evaporation. In the following, due to their higher efficiency, we shall concentrate our attention mainly on the MP cathodes. In particular, the best QE (11.1% at the end of evaporation, 8.3% after decay and stabilization) in the MP case is obtained when the substrate is kept at room temperature, as shown in Fig. 2.

In Fig. 3 the spectral response of K–Te in the photon energy range 2.84–4.79 eV is shown for MP cathodes (measured just after the spontaneous decay described above) evaporated at different temperatures. The spectral response of a SP cathode evaporated at  $T_{sub} = 120$  °C is also shown for comparison. As can be seen the QE at 4.79 eV (259 nm) of the MP cathode evaporated at 120 °C (6.2%) is higher than the SP cathode's one (5.1%). For low energies the situation is reversed; in particular, at 2.84 and 3.06 eV no photocurrent can be measured from a MP cathode, whereas a very

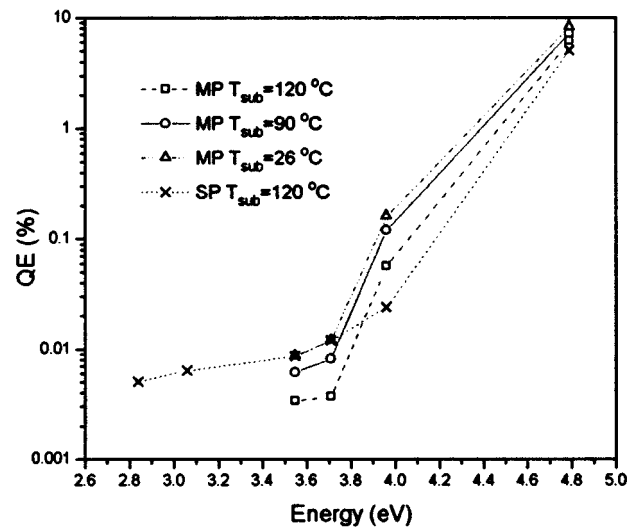


FIG. 3. Spectral response in the energy range 2.84–4.79 eV of K–Te cathodes.

low QE is still present for a SP cathode. It can also be seen that the QE for MP cathodes is highest if the substrate is kept at room temperature during the fabrication process.

The substrate temperature during evaporation seems also to affect the lifetime of the cathodes, kept in the preparation chamber at a pressure lying in the middle  $10^{-10}$  Torr range, as shown by Fig. 4. It is clear that both MP and SP cathodes evaporated at 120 °C have much shorter lifetimes than the ones evaporated either at 90 °C or at room temperature (results concerning SP cathodes evaporated at room temperature are not reported, because of their very low QE).

It is interesting to notice that illuminating a partially degraded cathode with 259 nm light causes a complete recovery of the initial QE at 259 nm. For example, a MP cathode evaporated at 120 °C with a 17% QE degradation, could be recovered to the initial QE after 48 min of illumination with the 259 lamp's light, without any heating of the substrate.

Degradation and regeneration of the photocathode are important issues as far as the operation of an electron accel-

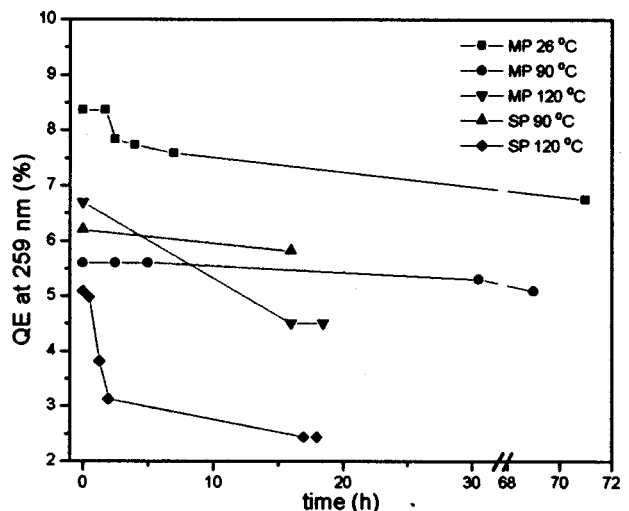


FIG. 4. QE at 259 nm of K–Te cathodes as a function of storage time at a pressure around  $5 \times 10^{-10}$  Torr.

erator is concerned. Therefore, we plan to run the Free Electron Laser of the University of Twente using the K–Te cathodes, in order to investigate these two particular aspects. Nevertheless, there are some remarks we can already infer from the data presented in this article. The MP K–Te cathode evaporated at 90 °C shows no degradation of the QE at 259 nm (Fig. 4) after storing for 5 h in the preparation chamber, a 5.2% degradation after 30 h and a 9% degradation after 69 h. It is of interest to compare this low degradation with that of Cs<sub>2</sub>Te cathodes,<sup>2,8,9</sup> considered so far to have the best lifetimes under UHV conditions, which is of about 7% after 24 h storage into the preparation chamber. Moreover, the observed beneficial effect of illumination of a partially degraded cathode with 259 nm light appears to be a very promising feature of the K–Te material as far as the lifetime is concerned, since during FEL operation the photocathode is illuminated with the 263 nm light of a frequency quadrupled Nd:YLF laser. Nevertheless, it must be noticed that laser power is much higher than mercury lamp power and that additional degrading factors are present in the accelerator (higher pressure, rf field). Therefore, it is not possible to draw any definitive conclusion on regeneration and lifetime at the moment.

In conclusion, we have demonstrated the photoemissive properties in the UV range of K–Te films fabricated by vapor deposition. According to our preliminary investigations they show very promising features, with respect to the use as an electron beam source for UV-driven linear accelerators.

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