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Cs–K–Te photo cathodes: a promising electron source for free-electron lasers

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Abstract

The characteristics of Cs–K–Te photo-cathodes when used in a photo-cathode linear accelerator will be presented together with a short review of their photo-emissive properties. The cathodes have been illuminated by light pulses obtained by frequency quadrupling the light of a Nd:YLF laser. The emitted electrons have been accelerated in a 1.3 GHz RF linear accelerator operating at an energy of 6 MeV. The quantum efficiency of the Cs–K–Te cathodes at 259 nm decreases exponentially with operation time, but recovers partially during storage in UHV between successive operating sessions. These two effects tend to compensate for long times, so that saturation of the quantum efficiency value at about 2% is reached after 20 h of operation. A Cs–K–Te cathode, degraded by use in the accelerator, can be rejuvenated to about 60% of its initial quantum efficiency by heating it to 120°C for 1 hour.

1. Introduction

The lack of suitable photo-emissive materials for the use in photo-cathode linear accelerators (LINACs) for Free-Electron Lasers (FELs) has stimulated the search for new materials. In the last few years, thin films of Cs_2Te [1] and K–Te [2,3] have been evaporated under UltraHigh Vacuum (UHV) conditions on a molybdenum substrate. These films replaced the unstable photo-cathodes based on Cs, K, and Sb. Tellurium-based photo-cathodes display high-quantum efficiencies (QEs) for illumination by soft UV light and long lifetimes under accelerator operation. Recently, the excellent photo-emissive properties of a new telluride (Cs–K–Te), also evaporated in UHV on a molybdenum substrate, have been demonstrated [4]. It was shown that the QE at a wavelength of 259 nm averaged on five samples of Cs–K–Te (22.5%) is about twice the average QE of both Cs_2Te and K–Te photo-cathodes prepared in the same evaporation chamber. In this paper the behavior of the photo-cathodes during accelerator operation will be tested, with the main point of attention the stability of the QE in time. A photo-cathode can be regenerated after it has been used in the accelerator, this process has also been investigated.

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2. Experimental

The Cs–K–Te photo-cathodes have been evaporated in the preparation chamber of the Twente FEL. The fabrication of a Cs–K–Te layer was carried out following the recipe described in Ref. [4]. First, a film of Te is evaporated on the surface of the molybdenum plug, keeping the boat containing Te at 300°C. Then the plug is exposed to K (boat at 505°C) and finally Cs (boat at 565°C) is deposited. During the Te and K evaporation the substrate temperature was kept at 120°C, whereas during the Cs evaporation the temperature was kept at a slightly higher value of 150°C. Depending on the K evaporation time, two different K–Te cathodes can be produced [2,3]. In fact, the K evaporation can be stopped either at the peak of the QE (we call this the maximum point procedure: MP) or at the QE saturation (we call this the saturation point procedure, SP, see also Fig. 1). Evaporation of Cs on MP or SP K–Te cathodes yields about the same final QE at 259 nm. The Te evaporation time used to fabricate the photo-cathodes investigated in this paper was 30 mins. Unfortunately, our experimental setup does not allow us to determine the thickness of the evaporated layers and therefore, in order to give information about the evaporation process, we shall refer in the following to evaporation times. A mercury lamp with various band-pass interference filters has been used to illuminate the photo-cathode with light of various wavelengths, in order to measure its spectral sensitivity. The photo-current produced by the illumination of the photo-cathode and a small potential difference (90 V) between the cathode and the evaporation station was measured with a picoamperemeter.

For research on the behavior of the photo-cathodes under normal operations the following setup was used. The electron beam was generated in a 1.3 GHz RF LINAC operating at a nominal energy of 6 MeV. A mode-locked Nd:YLF laser system, delivering 60 ps pulses at a repetition rate of 81.25 MHz and at a wavelength of 1053 nm was used to illuminate the photo-cathode. The pulses are compressed in a fiber-grating pulse compressor to a duration of 20 ps [5]. Then, a pulse train of 10 μs duration, containing 800 pulses, is sliced out by a traveling wave acousto-optic modulator. This pulse train is amplified in two double-pass flash-lamp pumped Nd:YLF amplifiers [6]. Since the Cs–K–Te cathodes are sensitive in the UV spectral range, the light in the pulse train is frequency quadrupled in order to obtain a wavelength of 263 nm. Finally, the Cs–K–Te photo-cathodes are illuminated by trains of 10 ps long UV pulses, with energy up to 2 μJ [7]. The resulting charge per bunch in

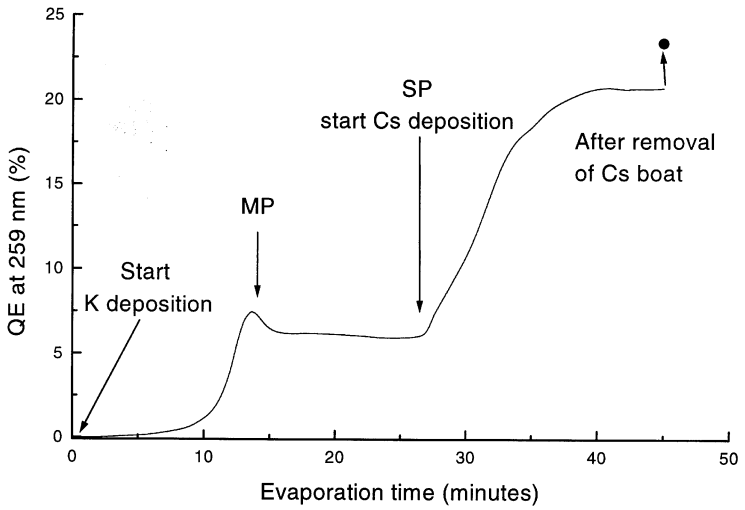

Fig. 1. The photo-current measured during the preparation of a Cs–K–Te photo-cathode. The Cs deposition is started at the position marked with SP (about the same final QE is obtained when Cs evaporation is started at the position marked with MP).

the electron beam for the lifetime experiments is between 1 and 7 nC at an electron energy of 6 MeV.

In order to investigate the lifetime of the Cs–K–Te cathodes, QE measurements were performed as a function of operating time. To this purpose, the accelerator operation was stopped for a few minutes and the photo-cathodes were moved under UHV conditions to the preparation chamber, where the photo-current produced by the Hg lamp was measured. An operating session lasted 3 h on average; in the time between successive sessions the photo-cathodes were kept in the preparation chamber, at a pressure in the low 10^{-7} Pa range. During operation, the maximum pressure in the accelerator was 7×10^{-7} Pa.

3. Results and discussion

Fig. 1 displays the QE at 259 nm monitored while K and Cs are evaporated on a Te film. After about 13 min of K evaporation the QE reaches a peak at 7.5%, then decreases and saturates to 6% in about 20 min. As soon as the Cs evaporation starts the QE increases in about 15 min to 20.8%. The measured QE is further increased to 23.4% when the Cs boat in front of the cathode is removed, demonstrating a partial shielding of the UV light by the Cs boat during evaporation. This QE is about twice the QE of a Cs_2Te cathode (evaporated in the same preparation chamber), that has been considered so far the best photo-emissive material in the soft UV spectral range. It must be noticed that the reproducibility of both Cs–K–Te and Cs_2Te cathodes is very good. Moreover, the final QE at 259 nm of a Cs–K–Te cathode does not depend on the K evaporation time [4], whereas the K–Te properties have been demonstrated to be very sensitive on this parameter [2,3].

Fig. 2 shows a comparison of the spectral responses in the energy range 2.8–4.8 eV of a Cs–K–Te and a Cs_2Te evaporated in the same preparation chamber; Cs–K–Te displays a higher QE at low energies (2.8, 3.4 eV) and the highest energy 4.8 eV (259 nm), whereas Cs_2Te has the best QE in the intermediate energy range (3.4–4.5 eV). It is reasonable to expect that the QE of Cs–K–Te might even be higher for the fifth harmonic of the Nd : YLF laser (207 nm). We can also infer a more stable operation of Cs–K–Te at 207 nm, since this wavelength is more removed from the photo-emission threshold wavelength of the material. However, it must be noticed that the possible advantage of a higher QE at 207 nm could be counteracted by a lower available power in the laser beam illuminating the cathode, due to a lower conversion efficiency from the fundamental to the fifth harmonic of the Nd : YLF laser.

The degradation of a Cs–K–Te cathode, obtained by evaporation of Cs on a MP K–Te cathode, is

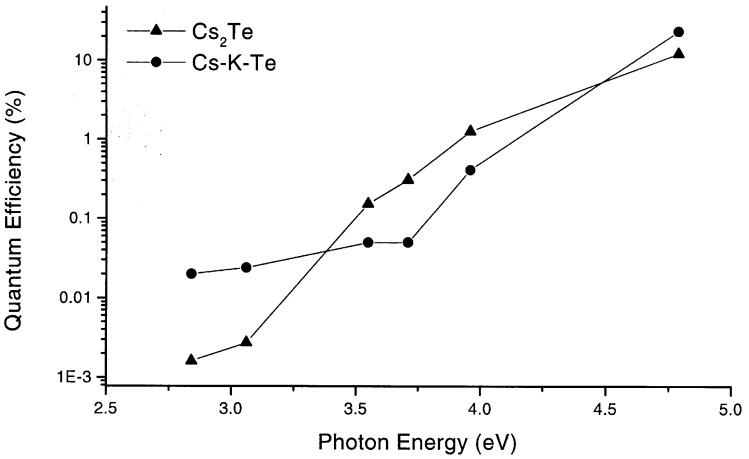

Fig. 2. The quantum efficiency of three members of the telluride family, as a function of the photon energy.

shown in Fig. 3 as function of operation time. The repetitive rise of the QE is due to partial recovery of the QE during storage times (indicated by arrows in the graph, where the storage time is reduced to zero hours). During the operation sessions the Cs–K–Te cathodes undergo exponential decays. The degradation can be fitted to two exponential decays of which the first half-life time is about 1 h. The second exponential decay has a half-life time of 12.0 h. At the beginning, the degradation is strong, but after several hours it saturates around a 2% QE value. The saturation in the decay process can be described by a iterative effect of degradation and regeneration. The degradation during operations is about equal to the recovering during storage time between the successive operations.

A Cs–K–Te obtained by evaporating Cs on a SP K–Te photo cathode has a very similar degradation

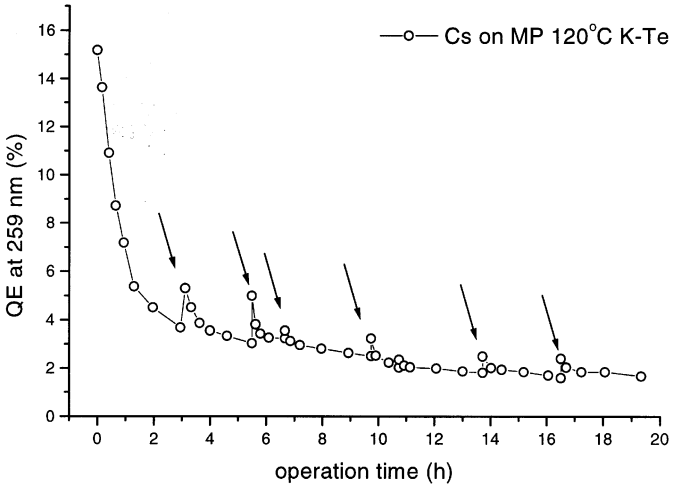

Fig. 3. The decay of a Cs–K–Te cathode under operating conditions in the linear accelerators. The arrows indicate partial regeneration of the cathode during storage in the preparation chamber between operating sessions.

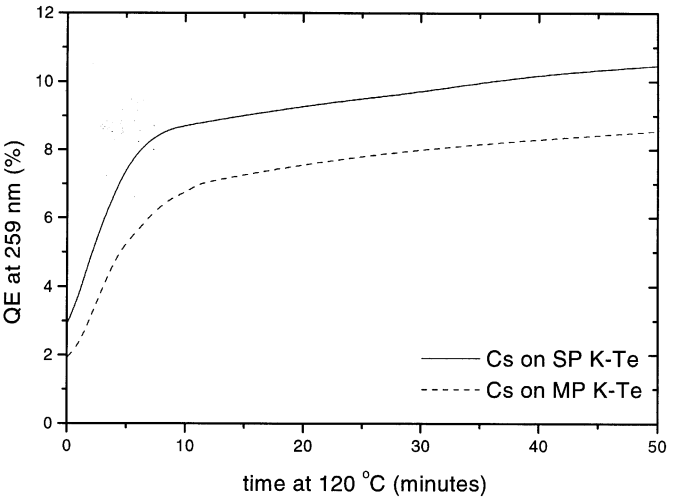

Fig. 4. Partial regeneration of a Cs–K–Te photo cathode by heating it to 120°C.

behavior, whereas, as already mentioned, K–Te SP and MP cathodes show very different degradation behaviors.

Since the Cs–K–Te cathode showed a significant and spontaneous recovery of the QE it is likely that an active rejuvenation of the cathode should have success. Except from the spontaneous recovery, there is no increase in QE when the cathode is heated to a temperature below 120°C. When the cathode is set at a temperature of 120°C the rejuvenation starts. Fig. 4 displays the rejuvenation of a Cs on Sp K–Te cathode to a QE of 10.5% (at 259 nm), which is 71% of the initial value obtained after evaporation. The 10.5% QE is reached in about 50 min. The QE before regeneration was 2.9% in this experiment. A similar behavior has been shown by a Cs on MP K–Te cathode (QE after regeneration is 56% of the initial one).

4. Conclusions

The new Cs–K–Te photo-cathode has an initial quantum efficiency of 23.4% at 259 nm. This is the highest QE of the Telluride family known so far. The decay of the quantum efficiency shows a double exponential character, of which the first half-lifetime is about 1 h. The second exponential decay has a half-lifetime of 12.0 h. The QE saturates at a value of 2% in about 20 h of accelerator operation. The cathode can be rejuvenated to about 60% of its initial value by heating it to a temperature of 120°C for 1 h. We believe these preliminary results are very promising and therefore we plan to investigate the fundamental properties of this new material by Auger electron spectroscopy and X-ray photoelectron spectroscopy.

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