

OPTICAL PROPERTIES OF CESIUM TELLURIDE

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Abstract

Cesium telluride is the photoemissive material used in many laser-driven RF-guns like in TTF-FEL. The material has been already used since few years but a detailed study of its optical properties is still missing. In this paper, we present the measurements of the cesium telluride reflectivity versus wavelength and incidence angle. These measurements are used to calculate the real and complex part of the refractive index and to have a better understanding of the energy band structure of the cesium telluride. The knowledge of these properties is relevant in view of the measurement of the thermal emittance of this material that is in progress in our lab using a Time of Flight spectrometer. The thermal emittance is the key parameter for choosing the photocathode for the future high brightness machines.

1 INTRODUCTION

The use of cesium telluride (Cs_2Te) photocathodes as electron source for laser-driven RF guns is established since years. Nevertheless its physical properties are yet not completely known. Powell studied the energy band in the 70's [1] and previously Taft and Apker [2]. The only information to our knowledge about optical properties of cesium telluride is an estimation presented by Johnson [3]. Due to the importance of optical parameters in the analysis of the model used to study the thermal emittance of cesium telluride, we start studying the optical properties of the photoemissive film. Due to the sensitivity of this film to gas exposure, the film is prepared and analyzed in Ultra High Vacuum (UHV) condition. Since the cathode is grown on a thick substrate, we are only able to study the reflection properties of the film. We measure the reflectivity R with unpolarized light and R_s and R_p with s-polarized and p-polarized light respectively. Moreover the film itself is only tens of nanometers thick and the interplay between the Mo substrate and the Cs_2Te film has to be taken into account. Since the material is photoemissive, we use the measured Quantum Efficiency (QE) to further understand the properties of the material. The final goal of this activity is to determine the real (n) and complex (k) value of the refractive index of the material specifically at 254 nm. These parameters play a key role in understanding the physics of the photoemission process from Cs_2Te and as a consequence on the estimation of the thermal emittance of these kind of photocathodes.

2 EXPERIMENTAL SETUP

The Mo substrate was machined from a sheet of Mo (pure 99.99 %) and then optical polished achieving a reflectivity of 55.3 % (theor. 68.4 %) at 254 nm. The

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sample was then loaded into the vacuum system for the photocathode deposition. The vacuum system, shown in figure 1, operates in UHV condition (base pressure $< 10^{-10}$ mbar). It consists of a preparation chamber, where the photocathode has been grown, and an analysis system for optical and electron spectroscopy. The analysis chamber, equipped with six Suprasil2 viewports and a rotating sample holder, allows measuring reflectivity at different angles. The light sources available for the optical spectroscopy vary from femtosecond laser to continuous sources (He-Ne lasers, Ar laser, Hg and Deuterium lamp). The electron spectroscopy is based on a Time Of Flight spectrometer able to detect very low energy electrons ($E_k < 5$ eV) with an energy resolution of 15 meV @ 1.9 eV. Furthermore, the spectrometer allows studying energy spectra collected at different angles.

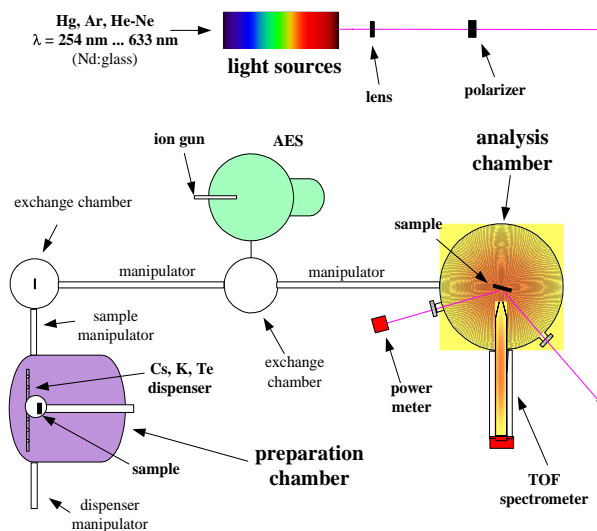


Fig. 1. Sketch of the experimental apparatus. The UHV system allows exchanging samples between different chambers. Different wavelengths are available ranging from red to UV.

2.1 Photocathode preparation

Cesium telluride photocathode was prepared using a well-established recipe [4]. The Mo sample was heated at 120 °C. A film of 10 nm of tellurium was firstly deposited at 1nm/min rate. After that, the cesium evaporation started at the same rate. The photocurrent was monitored shining UV light ($\lambda=254$ nm) on the cathode. Once the maximum of the photocurrent was reached, the cesium evaporation was stopped and the cathode cooled down to room temperature. The typical cesium evaporation time was 70-80 min. The final QE was 9%. During tellurium and cesium evaporation we monitored the sample reflectivity using $\lambda = 254$ nm. Measurements showed an overall decrease of the reflectivity as shown in figure 2. Tellurium evaporation induced a slow reflectivity

reduction from about 54 % to 46.5 %. In the first 20 minutes of cesium evaporation, the reflectivity abruptly dropped from 45 % to 10 % then it slowly reached a final value of 3 % after 75 min.

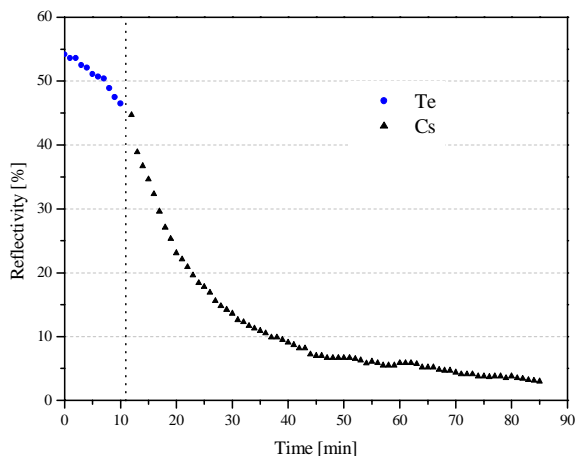


Fig. 2. Measured reflectivity during tellurium and cesium evaporation @ $\lambda = 254$ nm.

2.2 Optical set-up

The optical set-up is shown in figure 3. The light shines from viewport at 0° and it is collected from the other viewports placed at 20° , 40° , 110° , 130° , and 150° . The light source mainly used is an Hg lamp with interferential filters ($\Delta\lambda = 10$ nm) and it is measured with an OPHIR calibrated photodiode. The selectable wavelengths are: 254 nm, 297 nm, 334 nm, 365 nm, 405 nm, and 436 nm. For longer wavelengths, Ar laser and He-Ne laser are used. Along the optical beam path, a lens focuses the beam to have a small spot on the cathode and at the exit of the vacuum chamber.

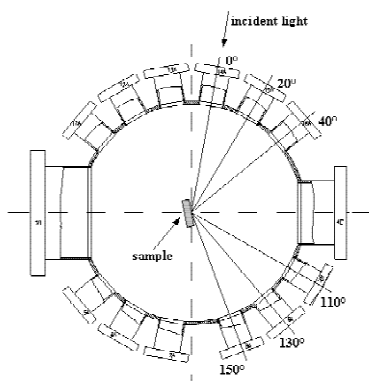


Fig. 3. Setup for optical measurements in the analysis chamber. The different viewports available for optical measurements are shown with the respective angles.

3 RESULTS

The determination of the optical properties of thin film needs knowledge of the optical properties of the substrate. In our study we have firstly determined the n and k value for Mo at 254 nm. These values, together with the reflectivity measurements, have been used to calculate the refractive index of cesium telluride.

3.1 Molybdenum

After the preparation of the sample, as discussed in the previous section, we measured its optical properties. Due to the strong dependence of the reflectivity on the sample roughness σ , we have firstly determined it assuming bulk properties [5] and the following relation [6]:

$$\frac{R}{R_0} = \exp\left(-\left(\frac{4 \cdot \pi \cdot \cos(\theta) \cdot \sigma}{\lambda}\right)^2\right) \quad [1]$$

where R_0 is the reference reflectivity, θ the angle used and λ is the wavelength. The result of the fit procedure, $\sigma = 9.6$ nm, is shown in figure 4.

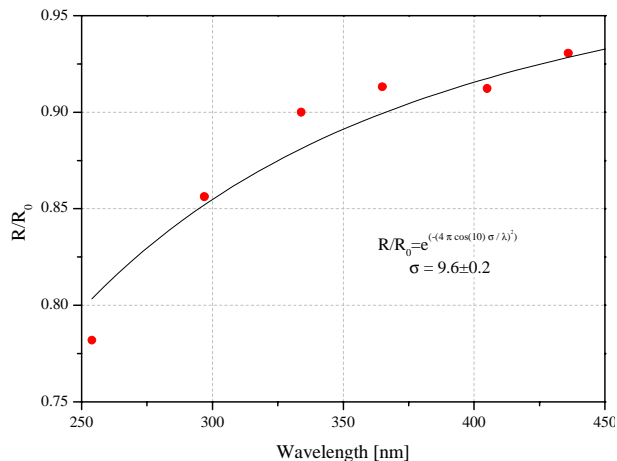


Fig. 4. Fit of R/R_0 with $\theta = 10^\circ$.

We calculated the complex index of refraction applying a well-known method [7] based on the ratio R_p/R_s where R_p and R_s are respectively the reflectivity for p-polarized and s-polarized light. This method is independent from the roughness of the sample. The ratio R_p/R_s from measured value (@ $\lambda = 254$ nm) and the corresponding fit is reported in figure 5.

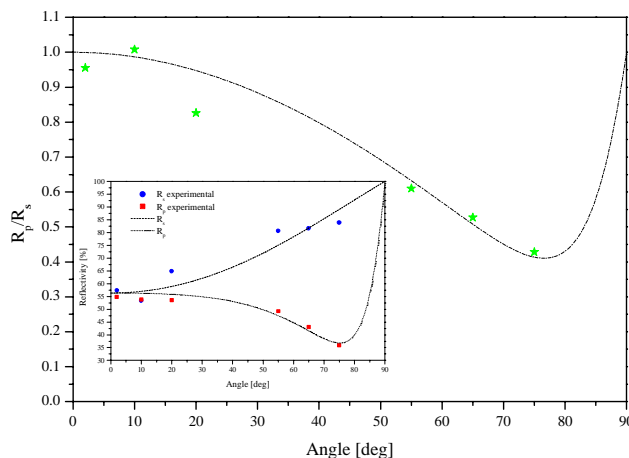


Fig. 5. Fit of experimental R_p/R_s data of Mo for the calculation of n and k @ $\lambda=254$ nm.

The values obtained, $n = 1.76$ and $k = 3.61$, agree within 5% with the theoretical $n = 1.65$ and $k = 3.72$.

3.2 Cesium Telluride

The spectral response of the photoemissive film is shown in fig. 6 and the typical shoulder, starting at around 3.6 eV and extending to lower energy, is clearly visible. From the structure in the spectral response, we assign to it a double structure with $E_G + E_A$ (respectively energy gap and electron affinity) of 3.7 eV and 2.6 eV assuming a dependence of the QE from photon energy as derived by Sommer [8].

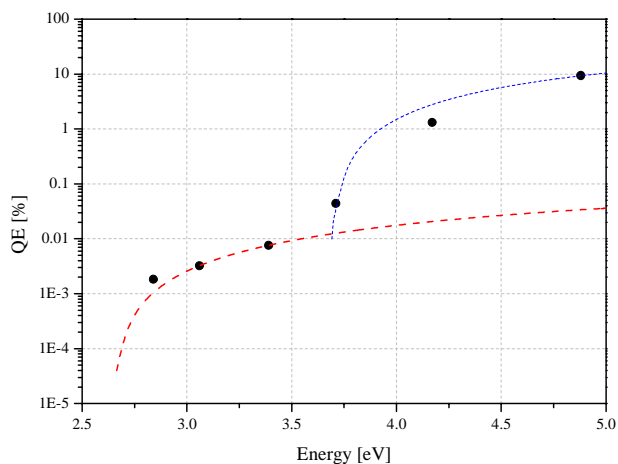


Figure 6. Spectral response of Cs_2Te film. The dashed curves correspond to a theoretical dependence of QE vs E_{photon} assuming two structures at 3.7 eV and 2.6 eV.

We measured then the reflectivity of Cs_2Te , using $\lambda=254$ nm, at different angles and for different polarizations. A summary of our measurements is shown in figure 7.

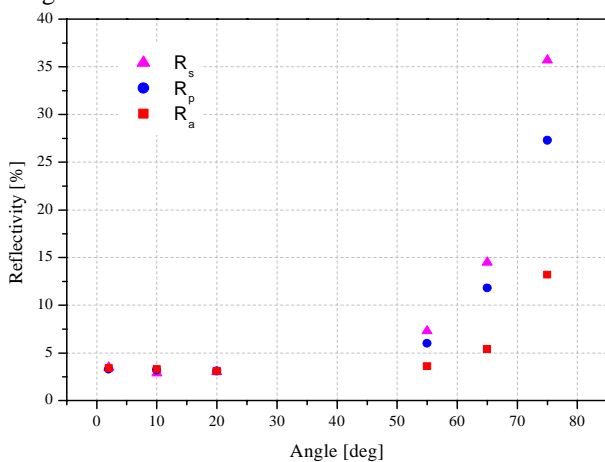


Figure 7. Reflectivity of Cs_2Te film (@ $\lambda=254$ nm) as a function of different angles and polarizations.

The reflectivity near to normal incidence is below 5 % and then rises, as expected from Fresnel laws, at larger angle. At small angle the reflectivity is more affected by the roughness of the sample as indicated by formula [1]. In the present case, we are not able to calculate directly the roughness of the Cs_2Te film since no reference values

for n and k are known. Moreover since the expected thickness of the film is only few tens of nanometers, the effect of the interaction between the Mo substrate and the thin film optical properties has to be considered. From reflectivity measurements with different wavelengths at 10° and 20° (fig. 8) in respect to the normal, and assuming that the difference in values is only due to roughness, we estimate the Cs_2Te film roughness $\sigma = 25 \pm 8$ nm. Concerning the refractive index of Cs_2Te , a preliminary analysis, based on dispersion relations and R_p/R_s data, gives values for the real part n in the range 0.8-1.8 and for the complex part k in the range 0.3-0.7.

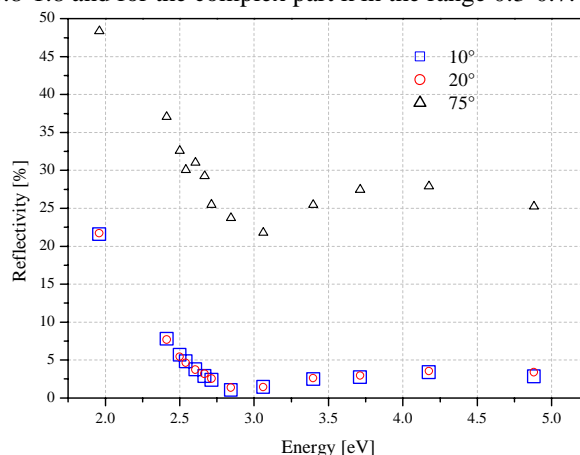


Figure 8. Cs_2Te reflectivity with different wavelengths at different incidence angles. The 10° and 20° measurements were used to calculate Cs_2Te roughness

4 CONCLUSIONS

We have characterized the optical properties of the Mo substrate obtaining good agreement with the theoretical expectations. The reflectivity of Cs_2Te film has been measured as a function of the angle, wavelength and polarization of the incident light. We obtained a reflectivity of about 4 % at near normal incidence in correspondence of a QE of about 9 %. The preliminary analysis of the results allows setting a boundary on the value of n (0.8-1.8) and k (0.3-0.7). Knowledge of these values is essential to model the photoemission process and hence the angular resolved energy distribution of the photoemitted electrons, which finally determines the thermal emittance of the cathode.

5 REFERENCES

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