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RUBIDIUM TELLURIDE PHOTOCATHODES FOR HIGH QUANTUM EFFICIENCY AND LOW MEAN TRANSVERSE ENERGY ACCELERATOR APPLICATIONS

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Abstract

High brightness electron sources are required to drive next generation light sources. This can only be achieved by photocathodes with high quantum efficiency (QE) and low intrinsic emittance, whilst also having long operational lifetimes and minimal dark current. Cesium telluride (Cs-Te) photocathodes are currently the favored material for many accelerators around the globe, typically chosen for its high QE and significant operational lifetime compared to other alkali-based alternatives, such as alkali antimonide and bi-alkali materials. Rubidium telluride (Rb-Te) has the potential to have a QE of a few percent with a higher work function than Cs-Te. This would lead to a lower mean transverse energy and reduced susceptibility to field emission, improving brightness and reducing dark current. In this paper, thin film Rb-Te photocathodes were grown and are characterized using X-ray photoelectron spectroscopy and QE measurements.

INTRODUCTION

Next generation accelerators demand more specialised photocathode materials to drive them. Ultrafast relativistic electron diffraction (UED) systems require high coherence, low beam emittance, and a beam with a short pulse width. In contrast, X-ray free electron lasers demand a high brightness electron sources with a focus on relatively high beam currents. These requirements highlight the need for the investigation and characterisation of novel photocathode materials. The photoemissive properties of a photocathode are predominantly governed by the surface properties, surface roughness and work function (WF), as they strongly influence both the QE and intrinsic emittance.

The linear accelerator CLARA at the STFC Daresbury laboratory is based on a 2.5 cell S-band RF photocathode gun driven by the third harmonic of a Ti:sapphire laser (266 nm) [1]. CLARA currently uses a Cu metal photocathode. However, for future operation there are plans to operate the photoinjector with Cs-Te photocathodes, Which are widely adopted as electron sources for particle accelerators. Cesium telluride (Cs_2Te) is used due to its high QE and its acceptable robustness when ultrahigh vacuum (UHV) is maintained. The chemical reactivity of alkali metals increases with atomic number. Therefore, Rb-Te should be a more robust cathode with lower emittance. This will come at the cost of lower QE, compared to CsTe. Previous research on Rb-Te as a photocathode is very limited, with some work reporting a higher WF (4.1 eV) and a lower QE when compared to Cs-Te[2].

In this work, we discuss the synthesis and characterisation of a Rb-Te thin film photocathode, using Te ion beam deposition and Rb dispensers as a potential alternative to other alkali based photocathodes. X-ray photoelectron spectroscopy (XPS) is utilised to investigate RbTe bonding environment and stoichiometry, whilst the spectral response at numerous wavelengths is measured.

EXPERIMENTAL DETAILS

Sample Preparation

Synthesis of the Rb-Te followed a similar procedure reported by R.Valizadeh *et. al.*[3] and their Cs-Te production. Molybdenum foil is cut into disks and cleaned in isopropanol and acetone ultrasonic baths to remove adventitious carbon and other contaminates from the foil production. The foil recieved further cleaning *in situ* using cycles of 5 keV Kr^+ sputtering and sample annealing at roughly 300 °C, with cycles being repeated until no contaminant species was detected using XPS. The Rb_xTe thin film was deposited sequentially. The Te film is deposited using ion beam sputtering of a Te target with Kr^+ ions at a beam energy of 5 keV. The Te target current is monitored during deposition to maintain an average current of 30 μA without any secondary electron suppression. The Mo substrate during deposition is positioned about 3 cm away from the target. The deposition of Rb is deposited immediately after tellurium deposition using a Rb dispenser (supplied by SAES Getters) held at 5 A for 1 hr.

Photocathode Characterisation

XPS spectra were acquired using a non-monochromated Al Kα x-ray source and a Thermo Alpha 110 hemispherical analyser. The analyser transmission function was determined experimentally using the technique described by Ruffiuex *et al.* [4], and the effective WF of the analyser was calibrated using the Fermi edge of Ag. Survey and core region spectra were acquired with pass energies of 50 and 20 eV, respectively. XPS data analysis was conducted using the CasaXPS software package [5].

QE measurements were taken at a number of wavelengths: 265, 340, 405, 430, and 525 nm using calibrated LEDs. Photocurrent was measured by the drain current of the sample under a high voltage extraction electrode.

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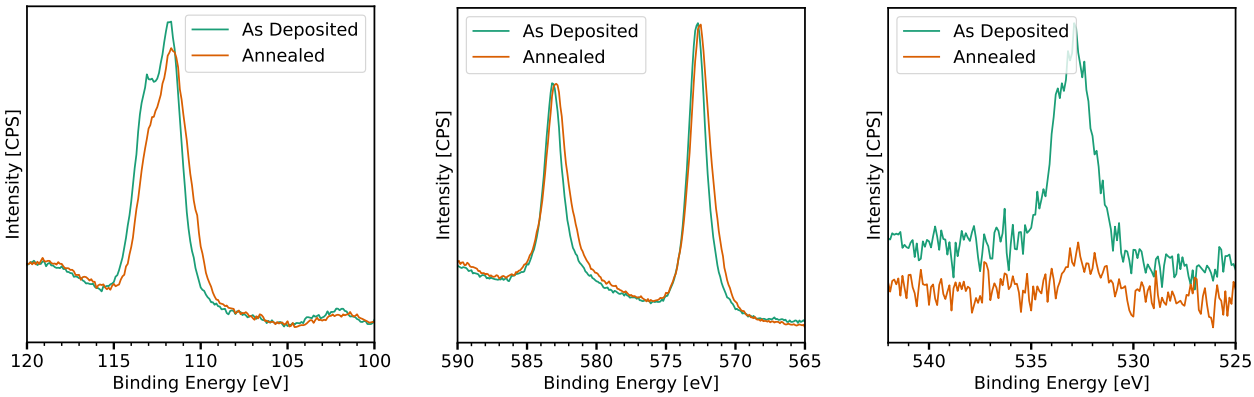

(a) Rb 3d (b) Te 3d (c) O 1s

Figure 1: XPS core region spectra of: Rb 3d, Te 3d and O 1s after deposition of Rb and annealing the sample for 1 hr at about 150 °C.

EXPERIMENTAL RESULTS

Figure 1 shows the core region XPS spectra for: Rb 3d, Te 3d and O 1s spectra, immediately after deposition and post annealing at 150 °C. In both cases, the Te 3d (Fig. 1b) shows only two distinct peaks corresponding to the Te $3d_{5/2}$ and Te $3d_{3/2}$ spin-orbit splitting. The reference BE for Te(0) is 573.0 eV and a very small shift is observed in the deposited spectra to 572.7 eV and after annealing the sample shifts further to 572.5 eV. The shift to a lower BE is an expected response to the formation of Rb-Te and is frequently reported when discussing Cs-Te deposition [3, 6]. The Rb 3d core region as deposited, shown in Fig. 1a, suggests overlapping peaks since Rb $3d_{5/2}$ and Rb $3d_{3/2}$ have a spin orbit splitting of 1.48 eV. The BE corresponding to the peak which should be associated with Rb $3d_{5/2}$ is measured to be 111.7 eV, a shift of 0.2 eV relative to Rb metal reference value of 111.5 eV [7]. After annealing, a change in the spectral lineshape is observed which is discussed in more depth below. The only contamination observed in XPS is oxygen present after the synthesis of Rb-Te, shown in Fig. 1c. After annealing the oxygen is no longer present in the spectra.

The QE after deposition and post annealing, was measured to be 2.1 and 3.7 % at 265 nm respectively. The spectral response at numerous wavelengths was also characterised, which is shown in Fig. 2. Photoemission was measured from a photon energy of 2.37 eV (λ = 525 nm) with a measured QE of 1.3×10^{-6} %. As the photon energy increases the QE increases exponentially.

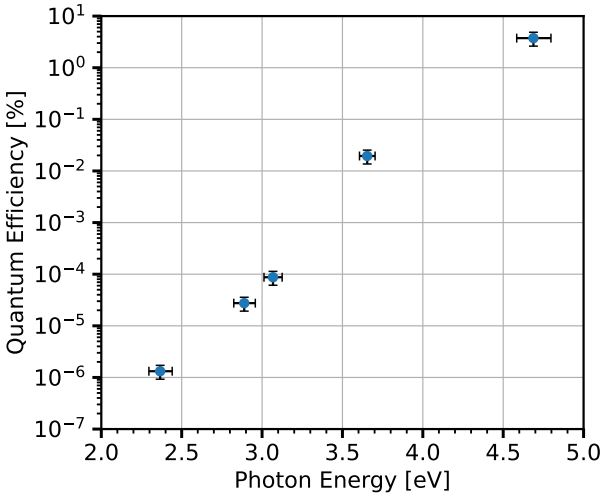

Figure 2: Measured quantum efficiency of the annealed RbTe photocathode at several wavelengths: 265, 340, 405, 430 and 525 nm. LED sources were used and calibrated using a Thorlabs PM400 power meter and sensor.

DISCUSSION

In-depth fitting of the Rb 3d core region spectra is shown in Fig. 3. As deposited the spectra can be fitted with two peaks corresponding to Rb $3d_{5/2}$ (BE = 111.7 eV) and Rb $3d_{3/2}$ (BE = 113.2 eV) in the same bonding environment. As mentioned previously, this matches closely to the reference value of Rb metal. Annealing the sample led to a broadening of the lineshape and can be fitted with the addition of two additional peaks. These have been assigned to Rb-Te. Unfortunately, reference spectra of Rb-Te is not yet reported and may correspond to the several stable Rb-Te phases[8]. The removal of the O present on the surface after annealing may be as a result of Rb-O decomposition or sublimation from the surface, which may be advantageous when rejuvenating a used photocathode and suggests an improved robustness to residual gases in a UHV enviroment.

The QE of 3.7 % at 4.7 eV is lower than the reported QE of Cs-Te, which is expected due to the difference in WF. However, photoemission is still observed at photon energies lower than 4 eV up to 2.4 eV. This is likely due to excess Rb (WF = 2.16 eV [9]) on the surface of the sample, which is supported by the presence of multiple peaks contributing to the Rb 3d XPS spectra. This may contribute to an increased

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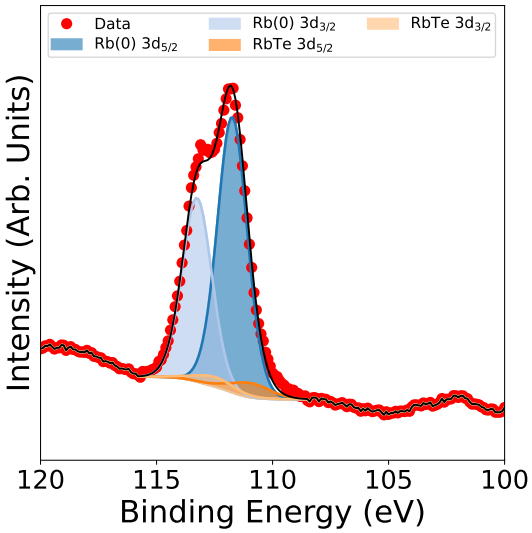
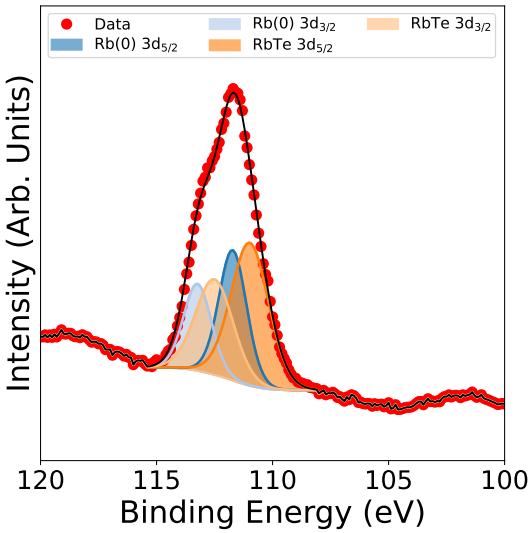
beam emittance and dark current if subjected to high electric field resulting in field emission. The growth may be improved by substrate heating during deposition and using co-deposition methods. This may reduce excess Rb and help with the formation of a uniform Rb-Te film.



(a) Rb 3d Deposition



(b) Rb 3d annealed

Figure 3: XPS spectra of Rb 3d core regions a) as deposited b) after annealing, quantified using CasaXPS.

CONCLUSION

In this proceeding, we have investigated a Rb-Te photocathode, an underexplored alternative alkali based photocathode. Sequential deposition of Rb-Te yielded a QE of 3.7 % at 4.7 eV. XPS spectra shows excess of Rb on the surface of the cathode contributing to the QE at very low photon energies which may contribute to increased beam emittance and dark current.

FUTURE WORK

Further characterisation of these photocathodes is paramount to fully understand the photoemissive properties observed. Investigation of co-depostion methods will be explored to improve homogeneity of the Rb-Te thin film, potentially improving QE and spectral response. Futhermore, Rb-Te's mean transverse energy, a key parameter of a photocathode's intrinsic emittance, will be measured using the tranverse energy spread spectrometer (TESS) located at Daresbury Laboratory[10].

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