ISBN: 978-3-95450-227-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2022-THPOPT044

THE ALKALI-METAL PHOTOCATHODE PREPARATION FACILITY AT DARESBURY LABORATORY: FIRST CAESIUM TELLURIDE DEPOSITION RESULTS

H. M. Churn[1*], C. Benjamin[2], L. B. Jones[1], T. C. Q. Noakes[1],
ASTeC, STFC Daresbury Laboratory, Warrington, UK
[1]also at The Cockcroft Institute, Daresbury Laboratory, Warrington, UK
[2]also at University of Warwick, Coventry, UK

Abstract

Fourth generation light sources require high brightness electron beams. To achieve this a photocathode with a high quantum efficiency and low intrinsic emittance is required, which is also robust with a long operational lifetime and low dark current. Alkali-metal photocathodes have the potential to fulfil these requirements, so are an important research area for the accelerator physics community.

STFC Daresbury Laboratory are currently commissioning the Alkali-metal Photocathode Preparation Facility (APPF) which will be used to grow alkali photocathodes. Photocathodes produced by the APPF will be analysed using Daresbury Laboratory's existing Multiprobe system and the Transverse Energy Spread Spectrometer (TESS). Multiprobe can perform a variety of surface analysis techniques while the TESS can measure the Mean Transverse Energy of a photocathode from its Transverse Energy Distribution Curve over a large range of illumination wavelengths.

We present an overview on our current progress in the commissioning and testing of the APPF, the results from the first Cs-Te deposition and detail the work planned to facilitate the manufacture of Cs_2Te photocathodes for the CLARA accelerator.

INTRODUCTION

X-ray free electron lasers (FELs), a type of 4th generation light source, require high brightness electron beams. The beam brightness, a key factor in FEL cost and performance [1], depends on the beam current, which should be maximised, and beam emittance, which should be minimised [2]. To achieve this, a photocathode with high quantum efficiency (QE) and low intrinsic emittance is required. Caesium Telluride, Cs_2Te, photocathodes fulfil these requirements, demonstrating measured levels of QE as high as 20 % at 266 nm and a low intrinsic emittance, all while being sufficiently robust to survive inside a electron gun [3]. As such, they are currently used in accelerator facilities around the world [4, 5].

The photocathode research group at Daresbury Laboratory currently operates two experimental systems: Multiprobe and the Transverse Energy Spread Spectrometer (TESS). Multiprobe is equipped for surface preparation and characterisation and is able to measure important photocathode performance properties such as quantum efficiency and work function [6]. TESS can measure the transverse energy distribution curve of a photocathode across a range of illumination wavelengths. From this, the mean transverse energy (MTE) can be extracted [7], which is related to the photocathode intrinsic emittance.

Daresbury Laboratory have constructed, commissioned and are in the final stages of calibrating a new machine, the Alkali-metal Photocathode Preparation Facility (APPF), which, when combined with Multiprobe and TESS, will enable the growth and extensive characterisation of Cs_2Te photocathodes. The design, construction and ongoing commissioning of the APPF is discussed below.

SYSTEM OVERVIEW

The APPF consists of a loading chamber and a deposition chamber. The loading chamber has a base pressure of 3×10^{-9} mbar and allows samples to be quickly loaded from atmosphere via a fast–entry port, or under UHV conditions via a vacuum suitcase. The deposition chamber is shown in Fig. 1. Pumping to the deposition chamber is provided by an ion pump (Fig. 1a.i) and a turbo-molecular pump (Fig. 1b.iv). This combination yields a base pressure of approximately 5×10^{-10} mbar. Residual gases can be monitored using an MKS Instruments Residual Gas Analyser (RGA) (Fig. 1a.vii).

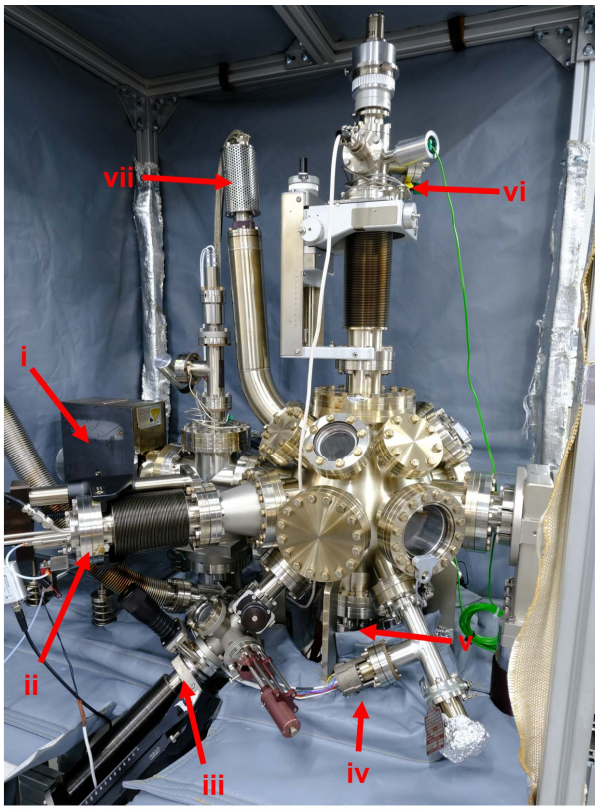
The APPF deposition chamber is equipped with a UHV Design goniometer (Fig. 1a.vi) designed for compatibility with INFN-style photocathode pucks. Currently an adapter is installed to support initial work with Omicron 19 mm flag-style sample plates (Fig. 2i). The goniometer provides 3–axis translation, $-180\,^\circ$ to $+180\,^\circ$ rotation and sample tilt from $-5\,^\circ$ to $+50\,^\circ$ for alignment with particular instruments in the system. An yttria coated tantalum foil heater is used to heat the sample up to approximately 400 °C. The sample is electrically–isolated so can support a DC bias or drain current measurement using a RBD Instruments picoammeter (Fig. 1b.v). A mask assembly (Fig. 1b.vi, Fig. 2.iii) protects the goniometer during deposition, and limits the exposed region of the photocathode substrate.

A PSP ISIS 3000 Ion Source (Fig. 1b.i, Fig. 2.vii) is fitted approximately 100 mm from the sample and allows the sample to be cleaned using argon ion bombardment. The ion energy is typically 2 keV, with an available range of 100 to 3000 eV, and the drain current is between 12 and 18 μA.

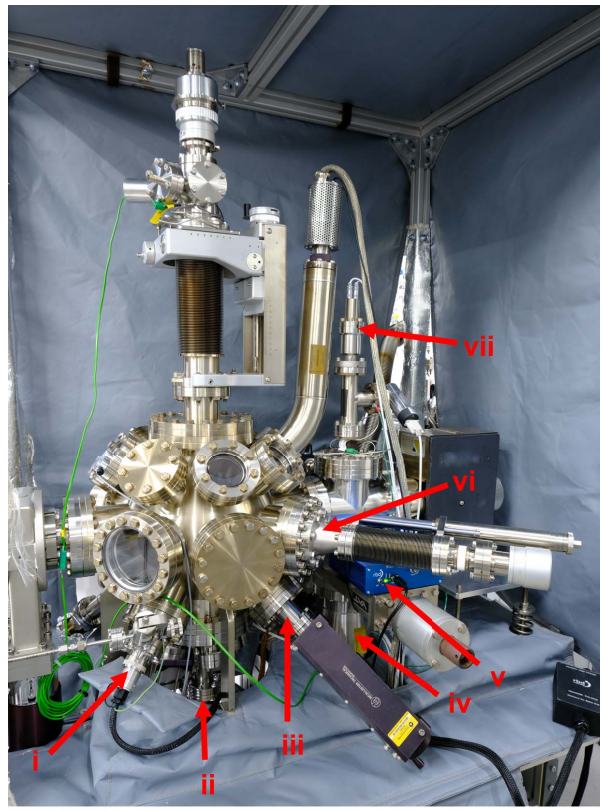
The APPF is equipped with a RBD Instruments Cylindrical Mirror Analyser (CMA) (Fig. 1b.iii, Fig. 2v). This

* hugh.churn@stfc.ac.uk

ISBN: 978-3-95450-227-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2022-THPOPT044



(a) Left side view of the APPF showing: i) the ion pump, ii) the quartz crystal microbalance, iii) the caesium deposition source, iv) the extractor gauge, v) the tellurium deposition source, vi) the goniometer and vii) the residual gas analyser.



(b) Right side view of the APPF showing: i) the argon sputter gun, ii) the sample viewports, iii) the cylindrical mirror analyser, iv) the turbomolecular pump, v) the picoammeter, vi) the mask and vii) the cold cathode pressure gauge.

Figure 1: Photographs of the Alkali-metal Photocathode Preparation Facility (APPF).

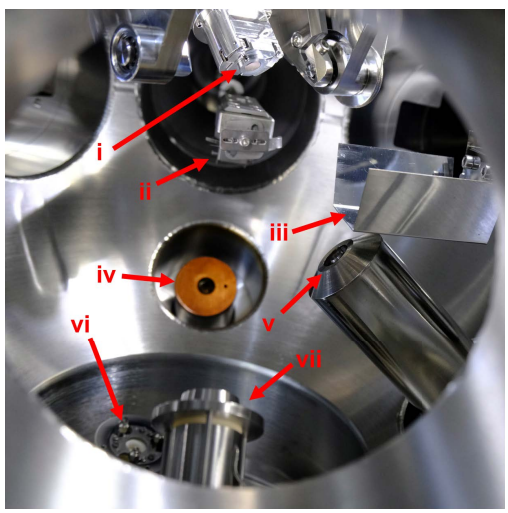


Figure 2: View inside the APPF showing: i) the Omicron-style sample, ii) the quartz crystal microbalance, iii) the mask, iv) the caesium source, v) the cylindrical mirror analyser, vi) the tellurium source and vii) the argon sputter gun.

allows in–situ surface characterisation by Auger Electron Spectroscopy (AES) over an energy range of 30 to 1030 eV, giving quantitative information on surface composition and thin film growth [8]. More extensive surface characterisation can be performed using the neighbouring Multiprobe system and our UHV vacuum suitcase.

We can measure the QE using a UV LED with an illumination wavelength of 265 ± 5 nm delivering a nominal power level of 0.5 mW into a beam with a half–angle of 4 °. This beam is focused onto the sample using a Thorlabs LB4842-UV biconcave lens with an effective focal length of 184 mm at 265 nm. The optical power at the sample working distance from the focusing lens was measured, using a power meter, to be 0.1 mW. The vacuum window (Fig. 1b.ii) has a characterised broadband anti–reflection coating. Measurement of the total yield drain current provides in–situ QE data. We plan to upgrade this system to provide reflectivity data, and also add an optical camera on the goniometer rotational axis to provide visual feedback during photocathode growth.

ALKALI METAL DEPOSITION SOURCES

Current work on the APPF involves calibrating the caesium and tellurium deposition sources. Caesium is deposited by a Createc Low Temperature Cell (Fig. 1a.iii, Fig. 2.iv) and tellurium is deposited by a Createc Valved Cracker Cell (Fig. 1a.v, Fig. 2vi). Deposition rates are monitored using

ISBN: 978-3-95450-227-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2022-THPOPT044

a Inficon Quartz Crystal Microbalance (QCM) (Fig. 1a.ii, Fig. 2ii). For calibration, the QCM is cooled by 18 °C water and placed at the sample position. This gives a tooling factor, the relationship between the flux seen by the QCM and the flux seen by the sample, of 100 %. Post calibration the QCM can be held offset from the sample to provide additional information on deposition rates during photocathode growths.

Tellurium Source

The tellurium source is a Createc V-CRC model, located 150 mm from the sample at an angle of 13 ° from the sample normal. Small adjustments to the distance and angle can be made using the goniometer. The tellurium source consists of a crucible filled with 99.99 % pure tellurium and a cracker stage where the evaporated tellurium is cracked into its monomer form. A water cooling jacket around the crucible allows independent control of the evaporation and cracking temperatures. The deposition rate across an evaporation temperature range of 250 °C to 400 °C is being investigated. Further work will also involve investigating the optimal temperature at which to run the cracker zone and investigating how the sticking coefficient changes when moving from the QCM to the molybdenum substrate.

Caesium Source

The caesium source is a Createc ULTC model, located 150 mm from the sample at an angle of 45 ° from the sample normal. Again, small adjustments to distance and angle can be made using the goniometer. Caesium of 99.99 % purity is used. The caesium is additionally cooled while being heated to provide fine control of deposition temperature. The cooling is provided by passing 0.6 bar of dry nitrogen gas passed through a liquid nitrogen cooling loop. The deposition rate across a temperature range of 50 °C to 150 °C is being investigated.

SAMPLE CHARACTERISATION

To calibrate the CMA, we used a clean poly–crystalline copper sample with the CMA positioned approximately 3 mm from the surface. The photocathode sample is held at a + 90 V DC bias and the drain, or target, current is measured using an RBD Instruments picoammeter. A built-in electron gun emits 3 keV electrons towards the sample and a target current of -300 nA is maintained. The CMA was calibrated such that the differentiated low energy Cu(MNN) peak occurred at 60 eV and the differentiated high energy Cu(LMM) peak occurred at exactly 920 eV. Figure 3 shows the AES survey of copper with small amounts of carbon and oxygen present. A QE of 7.6×10^{-5} was measured with the substrate at a -18 V bias using the LED described previously.

FIRST CS-TE DEPOSITION

An initial deposition test was performed on a 6 mm diameter poly-crystalline copper substrate held at approximately

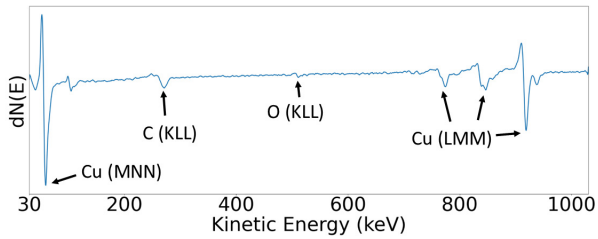


Figure 3: An Auger Electron Spectroscopy survey of poly-crystalline copper. Surface composition is 81.9 % copper, 16.3 % carbon and 1.8% oxygen.

120 °C. The tellurium source was held at a 320 °C evaporation temperature and a cracker temperature of 445 °C and deposition ran for 1 hour. The caesium was then heated to 85 °C and deposited until the QE stopped increasing (approximately one hour). Figure 4 shows the AES scan performed after deposition showing 24 % caesium and 32.5 % tellurium. The final QE was measured to be 2.7×10^{-3}, or 0.27 %, a factor of 35 increase over the bare copper.

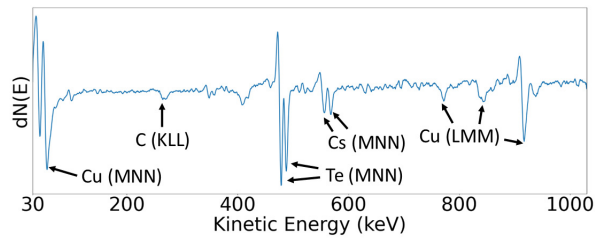


Figure 4: An Auger Electron Spectroscopy survey of copper following the deposition of caesium and tellurium. The surface composition is 38.1 % copper, 5.5 % carbon, 24.0 % caesium and 32.5 % tellurium. The ratio of caesium to tellurium is 0.74:1.

CONCLUSION AND FURTHER WORK

Work is progressing on the commissioning and calibration of the APPF at Daresbury laboratory, with a photoemissive Cs-Te film having been deposited. Cs_2Te photocathodes will be grown in a UHV environment and characterised in-situ using AES and QE measurements. All major components have been installed and tested, and we are currently in the final stages of calibrating the sources. Once final calibrations are completed, investigations into the effect of changing various growth recipe parameters can begin. This will include investigating sequential verses co-deposition as well changing growth rates and substrate temperatures. For regular growths of Cs_2Te photocathodes, 6 mm diameter 99% pure poly-crystalline molybdenum substrates will be used. Successful samples will be fully characterised using the Multiprobe and TESS systems. Long term plans for the APPF involve switching from Omicron-style to INFN-style pucks and growing samples that can be tested inside the CLARA accelerator [9].

ISBN: 978-3-95450-227-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2022-THPOPT044

REFERENCES

[1] M. Divall *et al.*, "Intrinsic emittance reduction of copper cathodes by laser wavelength tuning in an rf photoinjector," *Phys. Rev. ST Accel. Beams*, vol. 18, p. 033 401, 2015, doi:10.1103/PhysRevSTAB.18.033401

[2] D. Dowell *et al.*, "Cathode R&D for future light sources," *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, vol. 622, pp. 685–697, 3 2010, doi:10.1016/j.nima.2010.03.104

[3] M. Gaowei *et al.*, "Codeposition of ultrasmooth and high quantum efficiency cesium telluride photocathodes," *Phys. Rev. Accel. Beams*, vol. 22, p. 073 401, 7 2019, doi:10.1103/PhysRevAccelBeams.22.073401

[4] S. Schreiber, S. Lederer, P. Michelato, L. Monaco, and D. Sertore, "Update on the Lifetime of Cs2Te Photocathodes Operated at FLASH," in *Proc. FEL'17*, Santa Fe, NM, USA, Aug. 2017, pp. 415–418, doi:10.18429/JACoW-FEL2017-WEP003

[5] E. E. Wisniewski *et al.*, "Kelvin probe studies of cesium telluride photocathode for AWA photoinjector," *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equip-ment*, vol. 711, pp. 60–64, 2013, doi:10.1016/j.nima.2013.01.045

[6] T. Noakes, B. Militsyn, R. Valizadeh, K. Middleman, A. Hannah, and L. Jones, "Commissioning of the SAPI for Operation with Metal Photocathodes," 2014, https://cds.cern.ch/record/1664319

[7] L. B. Jones *et al.*, "The Commissioning of Tess: An Experimental Facility for Measuring the Electron Energy Distribution From Photocathodes," in *Proc. FEL'13*, New York, NY, USA, Aug. 2013, pp. 290–293, https://jacow.org/FEL2013/papers/TUPSO33.pdf

[8] A. Di Bona, F. Sabary, S. Valeri, P. Michelato, D. Sertore, and G. Suberlucq, "Auger and x-ray photoemission spectroscopy study on Cs_2Te photocathodes," *Journal of applied physics*, vol. 80, no. 5, pp. 3024–3030, 1996.

[9] D. Angal-Kalinin *et al.*, "Design, specifications, and first beam measurements of the compact linear accelerator for research and applications front end," *Physical Review Accelerators and Beams*, vol. 23, no. 4, p. 044 801, 2020, doi:10.1103/PhysRevAccelBeams.23.044801