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PHOTOCATHODE R&D AT DARESBURY LABORATORY: NEW TRANSVERSE ENERGY SPREAD MEASUREMENTS AND THE DEVELOPMENT OF A MULTI–ALKALI PHOTOCATHODE PREPARATION FACILITY

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Abstract

The minimum achievable emittance in an electron accelerator depends strongly on the intrinsic emittance of the photocathode electron source. This is measurable as the mean longitudinal and transverse energy spreads in the photoemitted electron beam from the cathode source.

ASTeC[†] constructed the Transverse Energy Spread Spectrometer (TESS) experimental facility to measure both the transverse and longitudinal electron energy spectra for III–V semiconductor, multi–alkali and metal photocathodes. Our R&D facilities also include in–vacuum quantum efficiency measurement, XPS, STM, plus ex–vacuum optical and STM microscopy for surface metrology.

Photocathode intrinsic emittance is strongly affected by surface roughness, and the development of techniques to manufacture the smoothest photocathode is a priority for the electron source community. Other factors such as crystal face, illumination wavelength and temperature have a significant effect on photocathode intrinsic emittance. We present an update on advances in our photocathode R&D capabilities and some preliminary results from new measurements.

INTRODUCTION

The intrinsic emittance of a photocathode is the combination of many physical attributes such as composition, crystal face, surface roughness, cleanliness, quantum efficiency (QE), work function (ϕ) and illumination wavelength (λ). Intrinsic emittance expressed in microns per mm of laser illumination spot diameter ($\mu m/mm$) defines the lower limit of emittance in a well–configured linear accelerator.

In the absence of space charge effects, the source emittance can be preserved throughout acceleration in machines of this class [1]. The impact of reducing intrinsic emittance is therefore significant, and can potentially reduce both the physical size and capital cost of a Free-Electron Laser (FEL) facility driven by such an accelerator [2] while also increasing the X–ray beam brightness and hence the FEL performance. This is the primary justification for our work in this area in support of the CLARA [3] linear accelerator project.

Our Transverse Energy Spread Spectrometer (TESS) [4] experimental facility measures the photocathode electron emission footprint for low–energy electrons (typically <100 eV) from which the transverse and longitudinal energy distribution curves (TEDC and LEDC respectively) can be extracted [5]. TESS is connected to our III–V Photocathode Preparation Facility (PPF) [6] which provides storage for up to 6 photocathode samples under XHV conditions and supports thermal and atomic hydrogen cleaning.

The factors which affect photocathode performance require a suite of diagnostic techniques so our R&D facilities also include XPS, LEED and AFM/STM in our SAPI (Surface Analysis, Preparation and Installation) system [7, 8], with ex–situ interferometric optical and AFM microscopes for surface roughness measurements. We have a range of laser and broadband light sources which permit QE measurements at various wavelengths on different cathode materials.

Recently the TESS experimental system has been further upgraded and we have constructed a vacuum suitcase system which facilitates the movement of up to 4 photocathode samples between our various experimental systems under UHV conditions. This vacuum suitcase can also be used to bring photocathodes from other laboratories for characterisation using our systems. Our photocathode manufacturing capabilities are also being expanded through the construction of a multi–alkali photocathode preparation facility.

TESS CRYOGENIC UPGRADE

The TESS detector was originally specified as a general–purpose instrument to image the photoemission footprint of semiconductor photocathodes under illumination by solid–state laser modules [4]. The detector combined 3 independent grid meshes with a microchannel plate (MCP) electron multiplier and a P43 ITO phosphor screen, using a sensitive camera to record the electron emission footprint.

The detector was recently upgraded and now uses a single demountable grid mesh which facilitates the same transverse and longitudinal energy spread measurements, but with increased sensitivity [9]. This upgrade included the installation of a broadband Energetiq EQ–99 laser plasma–driven light source coupled through nitrogen–purged off–

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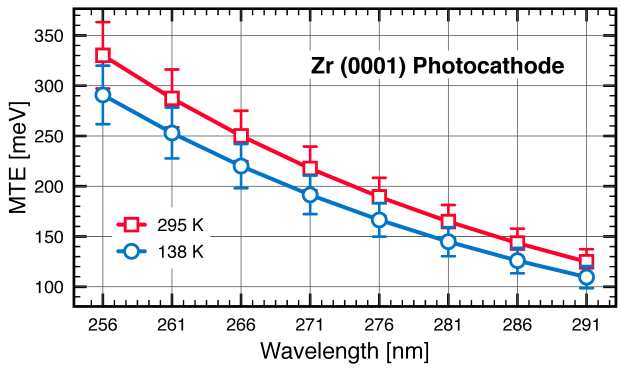

Figure 1: MTE as a function of illumination wavelength for a Zr (0001) photocathode at room and cryogenic temperatures.

axis parabola optics to a Bentham TMC300 $f/4$ monochromator which delivers considerably higher flux over the range $\lambda = (200 - 800)$ nm, but particularly at UV wavelengths.

The latest upgrade adds the ability to cool a photocathode using liquid nitrogen (LN_2), supporting MTE measurements at photocathode temperatures down to -140 °C (≈ 135 K). FEA modelling at the TESS design phase some years ago had shown that the cooling method applied should allow the system to reach -196 °C (96 K). It is not known whether the present shortfall is due to an instrumentation issue, or if there is a significant heat leak which limits the cryogenic performance.

A commissioning measurement has been carried out using a Zr (0001) single–crystal supplied by MaTeck (4N purity, > 99.99%) with a typical work function of $\phi = 4.05$ eV [10]. The results are listed below in Table 1 and shown in Fig. 1.

Table 1: Summary of Extracted MTE Values for a Zr (0001) Photocathode under Illumination at Various Wavelengths, λ

Illumination Wavelength λ [nm] / energy [eV]	MTE [meV] T = 300 K	T = 140 K
256 / 4.84	330	291
261 / 4.75	287	253
266 / 4.66	250	220
271 / 4.58	218	191
276 / 4.50	189	167
281 / 4.41	164	145
286 / 4.34	143	126
291 / 4.26	125	110

SURFACE ANALYSIS FOR PHOTOCATHODES

To facilitate in–vacuum surface analysis, we constructed our Surface Analysis for Photocathodes Instrument (SAPI) [8], also known as *Multiprobe*.

The system operates at UHV and supports XPS, LEED and AFM/STM for samples mounted on the Omicron 'flag' sample plate. Sample loading is achieved via a fast–entry airlock or through our vacuum suitcase (described later). Sample cleaning can be carried out using a Thermo Fisher EX-05 ion source for ion bombardment and annealing or thermal cleaning by e-beam heating to around 1,300 °C.

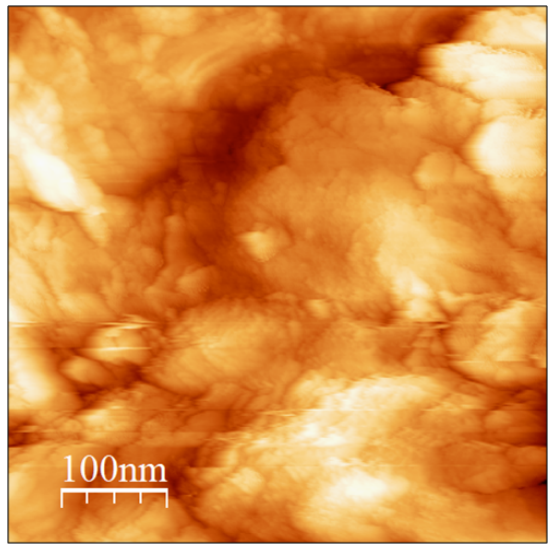

Figure 2: STM Surface image for an Nb (100) sample with a measured surface roughness of R_a =16.3 nm RMS.

The XPS capability combines a PSP CTX400 twin–anode X-ray source with a Thermo Fisher Alpha 110 hemispherical energy analyser. This combination can deliver an energy resolution of better than 5 meV under optimal conditions.

Sample microscopy is achieved using an Omicron UHV STM 1 which provides both AFM and STM functions. It features eddy current damping, in–vacuum I/V conversion, UHV sample and tip exchange from an in–vacuum storage carousel with capacity for up to 8 samples/tips at any one time. Fig. 2 shows a commissioning measurement for a Nb (100) single–crystal sample.

VACUUM SUITCASE

The requirement to move photocathodes under UHV/XHV conditions between our experimental systems and even laboratories at other sites has prompted us to build a vacuum suitcase. Our solution is based on a magnetic linear transfer arm supporting a magazine which accommodates up to 4 photocathode samples.

The magazine accepts sample plates which are directly compatible with our III-V PPF and TESS vacuum systems, or the combination of an Omicron 'flag' sample plate (compatible with our SAPI AFM/STM/XPS system and multi-alkali PPF) and a III-V PPF/TESS adapter. The 'flag' sample plate and its adapter are shown in Fig. 3. The suitcase is sealed with a VAT DN63 all–metal gate valve.

The suitcase includes a SAES NEXTorr D100-5 SIP/NEG pump which maintains a vacuum level below 1×10^{-10} mbar. The suitcase has a custom–made transit crate and the pump can be operated with a FerroVac LSA2.1 battery power pack

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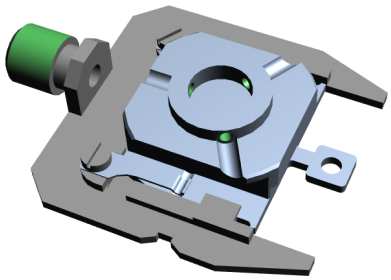

Figure 3: 'Flag' style photocathode sample holder (silver) and adapter plate (grey), designed for sample 'pucks' with dimensions 6 mm $\phi \times 2$ mm.

which can be driven from the 12 V accessory system in a car or van, making this suitcase portable over long distances.

The suitcase is shown in Fig. 4 coupled to the loading system of our multi–alkali photocathode preparation facility.

MULTI–ALKALI PPF

There has been a migration towards the use of alkali–telluride photocathodes illuminated at UV wavelengths around 266 nm or alkali–antimonides illuminated at visible wavelengths around 532 nm. This is driven by continual progress in techniques to manufacture such photocathodes which offer significantly increased QE over simple metallic photocathodes, coupled with superior temporal response characteristics and operational lifetime over semiconductor photocathodes. The alkali–antimonide photocathode family convey the additional benefit of operation at visible wavelengths, so reducing the complexity of the drive laser system and simplifying the application of transverse and longitudinal laser pulse shaping to improve electron beam quality.

We are constructing a multi–alkali photocathode preparation facility to provide multi–alkali electron sources for the CLARA accelerator [3]. The PPF shown in Fig. 4 is partly constructed, and will shortly receive a suite of alkali metal sources and a sample manipulator.

The initial configuration of the PPF includes a sample loading interface compatible with our vacuum suitcase. This will allow us to grow multi–alkali photocathode surfaces on a variety of substrate materials mounted on the 'flag' sample holder which can then be transferred under vacuum to our TESS and SAPI systems for further characterisation.

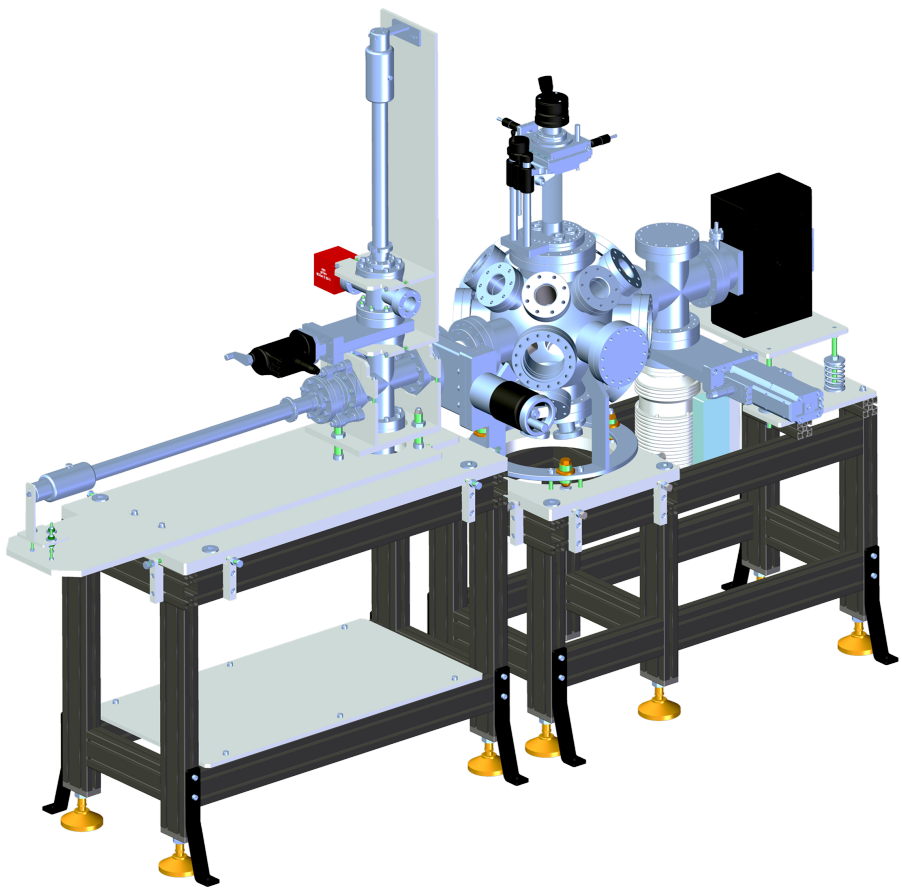

Figure 4: Engineering model of our multi–alkali photocathode preparation facility coupled to our vacuum suitcase. The photocathode preparation chamber, pumps and vacuum instrumentation are mounted on the right–hand table. The left–hand table supports the sample loading transfer arm (horizontal), to which is connected a UHV vacuum suitcase (vertical).

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At a later date, an interface with an additional vacuum suitcase will be added to the side port of the preparation chamber to support the loading of an INFN-style photocathode puck [11] and its transport carriage such that our multi–alkali photocathodes can be prepared and transferred to the CLARA RF gun.

FUTURE WORK

We hope to be in a position to grow multi–alkali photocathodes by the middle of 2020, and plan to begin with Cs_2Te. The photocathodes grown will be transferred to our TESS and SAPI instruments using our vacuum suitcase to facilitate composition and performance analysis.

In the shorter term, our TESS and SAPI systems will be used to continue a programme of work to characterise various metal photocathodes with the aim of further evaluating the effect of surface roughness and operational temperature on photocathode performance.

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