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PERFORMANCE CHARACTERISATION OF A Cu (100) SINGLE-CRYSTAL PHOTOCATHODE

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The search for high performance photocathode electron sources is a priority in the accelerator science community. The surface characteristics of a photocathode define important factors of the photoemission including the intrinsic emittance, the quantum efficiency and the work function of the photocathode. These factors in turn define the electron beam performance which are measurable as emittance, brightness and energy spread.

We have used ASTeC's Multiprobe (SAPI) [1] to characterise and analyse photocathode performance using multiple techniques including XPS, STM, and LEED imaging, and their Transverse Energy Spread Spectrometer (TESS) [2] to measure mean transverse energy (MTE).

We present characterisation measurements for a Cu (100) single–crystal photocathode sample, with data from SAPI confirming the crystallographic face and showing surface composition and roughness, supported by data from TESS showing the photocathode electron beam energy spread.

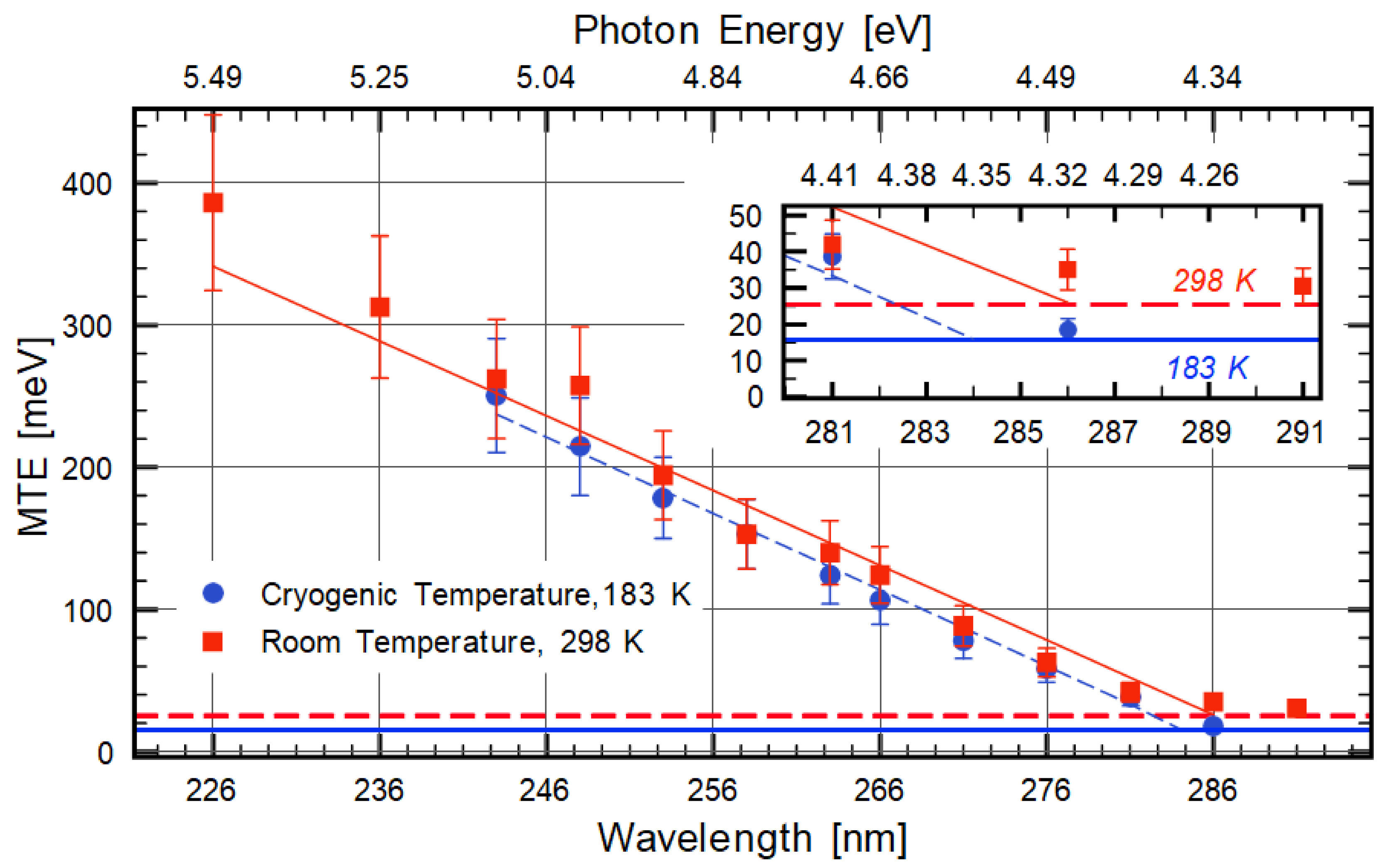

Figure 1: MTE values for a copper (100) single–crystal cathode at two different temperatures. The MTE lower threshold defined by kBT is shown by the red and blue horizontal dotted lines for T = 298 K and 183 K respectively, with the inset showing the detail close to the photoemission threshold.

A single-–crystal copper sample was sourced from Surface Preparation Laboratory B.V., cut to expose the (100) face and polished to a surface roughness of Ra < 30 nm. The cathode was prepared and cleaned in the Multiprobe system [1] by performing repeated argon ion bombardment and thermal annealing cycles until no oxygen or carbon contamination signatures were present in the XPS survey spectra. Once clean, the surface roughness was verified using in–vacuum STM, and the crystallographic face confirmed using LEED. The sample was then transferred into our Photocathode Preparation Facility (PPF). The cathode was stored in the PPF until required, and was thermally cleaned to 823 K (550 ◦C) immediately before its transfer into the TESS for MTE measurements.

Data was taken using 3 accelerating fields with potential differences between the photocathode source and electron detector of 150 V, 100 V and 60 V. The TESS detector and principle of operation is described in detail by Jones *et al*. [2] The electron photoemission footprint images produced on the phosphor screen were recorded using a camera exposure time of 100 s for each illumination wavelength, with the same camera exposure and detector voltages used for the corresponding 'dark' image. Transverse Energy Distribution Curves (TEDCs) were measured for each illumination wavelength, with an exponential curve fitted to each TEDC as described in [3] to determine the MTE at each wavelength.

Figure 1 shows the MTE measurements as a function of the illumination wavelength. The red squares show the MTE values measured at room (298 K) temperature, and the blue circles those at cryogenic (183 K) temperature. The chain– dotted lines denote the minimum achievable MTE defined by kBT where T is the lattice temperature.

The data shows the linear dependence of the MTE on illumination wavelength at high photon energies away from the photoemission energy threshold, with high values of MTE obtained for short illumination wavelengths, and a progressive decrease in the MTE as the wavelength is increased. The minimum value of MTE which is set by the crystal lattice temperature (kBT) is reached as the illumination wavelength approaches the photoemission energy threshold, and it can be seen that the linear dependence breaks down at this point.

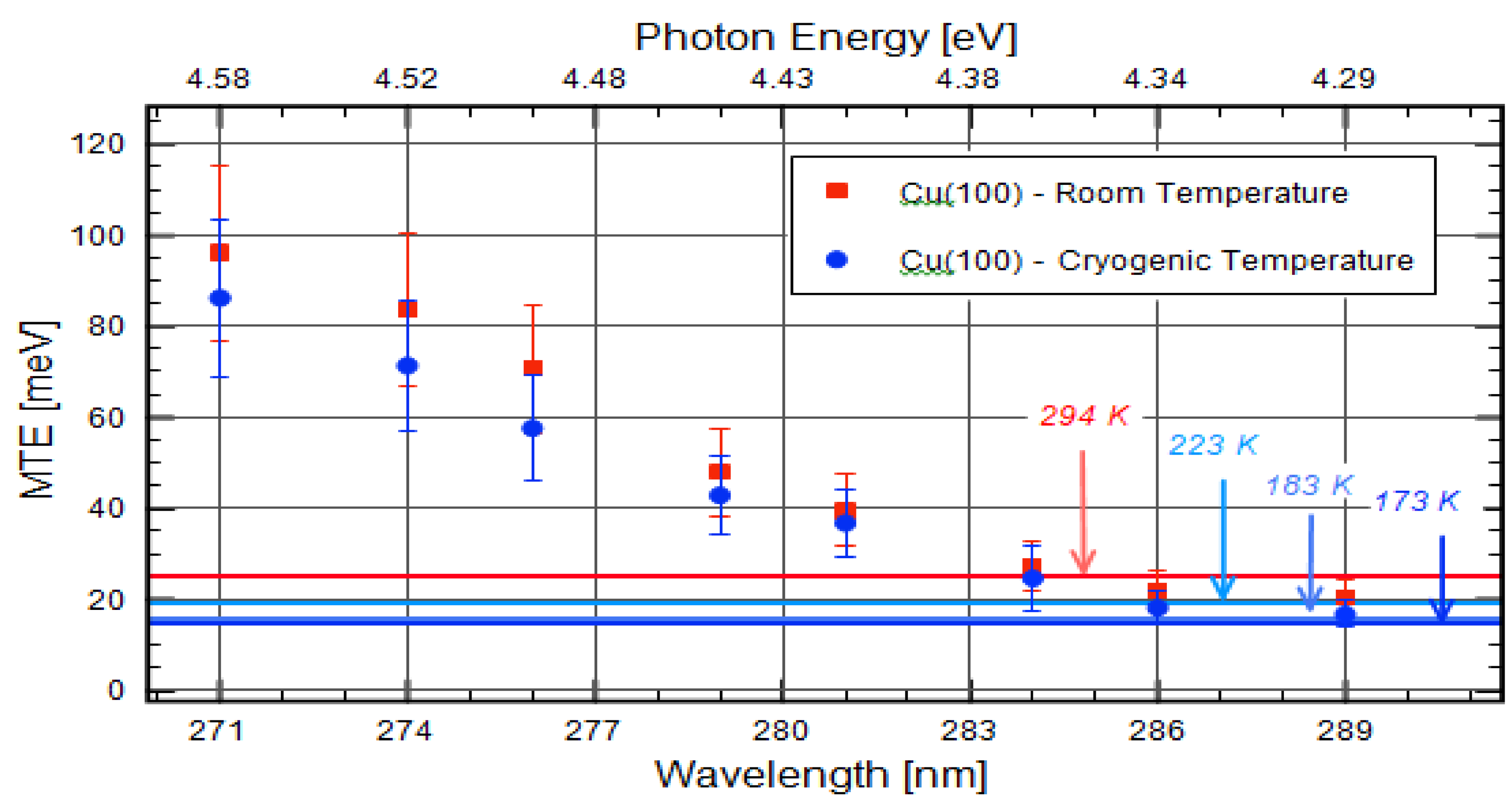

Figure 2: MTE values for a single crystal Copper (100) cathode at two different temperatures. The lower energy limit at different temperatures is shown by dotted lines.

Figure 2 shows MTE measurements close to the energy threshold as the illumination wavelength progressively changed over the range 271 nm – 289 nm in 2 nm steps. Room temperature measurements at 294 K are shown by the red squares, and the blue circles denote measurements taken in a temperature range from 173 K – 183 K.

Wavelength [nm]	MTE [meV] at 294 K	MTE [meV] at 178 K
271	96.2	86.2
274	83.5	71.4
276	70.7	57.6
279	48.0	42.9
281	39.5	42.9
284	27.3	24.6
286	22.0	18.2
289	20.5	16.7

Table 1: MTE values for a Cu (100) photocathode close to the photoemission energy threshold.

These detailed measurements highlight a crucial aspect of photoemission physics close to the photoemission energy threshold where very low MTEs are achievable, but where the linear relationship between illumination wavelength and MTE appears to break down, and also that photoemission is possible and measurable at illumination photon energies which are less than the accepted work function. The ability to generate electron beams with such low energy spread demonstrates significant advances towards increasing electron beam brightness for ultra–fast electron scattering and XFEL applications.

References:

[1] B.L. Militsyn, 4-th EuCARD2 WP12.5 meeting, Warsaw, 14-15 March 2017

[2] L.B. Jones, K.J. Middleman et al.; Proc. FEL '13, TUPS033, 290 – 293

[3] L. B. Jones, H. E. Scheibler et al.; J. Appl. Phys. 121, 225703 (2017)

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