TRANSVERSE ENERGY SPREAD MEASUREMENTS FROM GaAs PHOTOCATHODES AT VARIABLE WAVELENGTHS

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Abstract

The Transverse Energy Spread Spectrometer (TESS) is an instrument specially developed at Daresbury Laboratory to measure the intrinsic transverse and longitudinal energy distributions from photocathode materials. Early work on the instrument has focused on its use for the characterisation of GaAs photocathodes such as those commonly used in DC photoinjectors. More recently work has been conducted to extend the range of materials which can be evaluated using this apparatus, in particular by incorporating a monochromated white light source (250 - 1000 nm) permitting energy spread measurements on metallic and multi-alkali photocathodes. New results are presented using a broadband light source with variable wavelength and spectral width, referred to as a white light source (WLS), to measure the energy spread of a GaAs photocathode across a range of different illumination wavelengths, to evaluate how this excess photon energy translates into photoelectron transverse energy.

INTRODUCTION

Free Electron Laser facilities require a high brightness elecrton beam for reasons that are well documented [1]. Electron beam brightness in a linear accelerator is fundamentally limited by injector brightness, and this is itself limited by the source beam emittance or the intrinsic emittance of the cathode source. Electron beam brightness will be increased significantly by reducing the longitudinal and transverse energy spread in the emitted electrons, thereby creating a cold beam. The TESS system provides the ability to measure transverse energy, and to make direct comparisons between photocathodes which have been prepared in different ways or experienced different conditions during operation. When using photocathodes, the upper limit on transverse electron energy is determined by the illumination wavelength, the level of electron affinity and the photocathode temperature. Consequently, data from the TESS includes a contribution from the emission angle, and values returned from a TESS measurement place an upper limit on the mean transverse energy (MTE). This equipment is therefore a key enabling step towards discovering new materials which will provide high electron beams for future accelerator facilities [2, 3]. Recent work on the TESS instrument has seen an extension of the range of materials which can be evaluated using this apparatus.

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TESS EXTENDED CAPABILITY

The TESS system combines a reflection–mode photocathode holder under grazing incidence illumination with a retarding-field electron detector and imaging system. The photocathode holder can be electrically biased, and can also be cryogenically cooled to liquid nitrogen temperature. The source and detector have been designed to be symmetric and flat, and contain non-magnetic components. The addition of a mu–metal shield around the source and detector provides screening against external magnetic fields. A full description of TESS can be found in a previous publication [4].

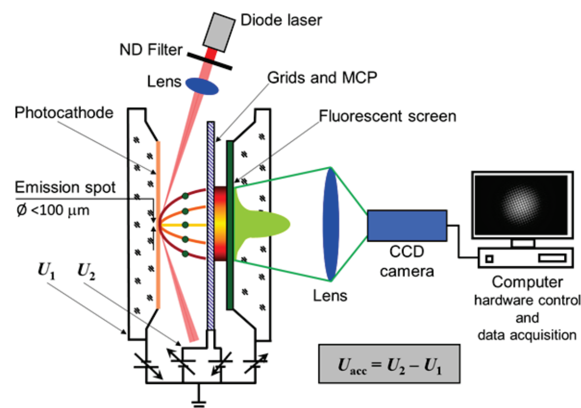

Figure 1: Schematic diagram showing the original experimental setup on the TESS system.

Previously the TESS system relied on several fixed wavelength laser diodes to provide the photon power necessary to stimulate electron emission, these sources ranged from 532-808 nm. Fig. 1 shows the original experimental setup on the TESS system, with fixed laser diodes in place. The photocathode electrode is mounted on the left-hand side which includes cryogenic feeds. The MCP detector is mounted on the Z-translation stage allowing the drift distance between the cathode source and front grid to be varied between approximately 7.5 and 50 mm. A slot cut into a mu-metal magnetic shield around the cathode electrode and detector permits cathodes to be inserted and removed, and a hole in the shield allows transmission of the photocathode illumination source. Photocathodes are operated in reflection mode, with the beam incident at 71° from the surface normal. The electron beam expands while in flight between the source and detector due to its transverse energy content ε_{tr}, and analysis of the beam footprint returns the Transverse Energy Distribution Curve

(TEDC). Activated GaAs photocathodes have a low work function and these photon energies at visible wavelengths are sufficient to generate electron emission. However, operating a Free Electron Laser at X-ray wavelengths relies on fast response metal photocathodes with much higher work functions, therefore to analyse such materials with the TESS apparatus a higher photon energy source operating at UV wavelengths must be applied. The white light source upgrade provides this wavelength extension and therefore significantly extends the capability of the TESS system.

Upgrade Description

Through the addition of the high power WLS, multi-wavelength light from UV to NIR can be delivered into the TESS system. The upgrade sees current laser probing systems removed and replaced with a new two-box system (one box containing the light source and monochromator, and the other the focusing, beam delivery and diagnostics elements), thus leaving an infrastructure ready for experimentation.

Similar to the setup of the TESS laser diode illumination system [3], several optical elements are used to achieve a tightly-focused beam, and the illumination beam profile at any working wavelength can be measured with a diagnostic camera placed at the equivalent working distance to the cathode show a beam size around 180 μm FWHM at the photocathode surface. The extension in wavelength range stems from the source which emits a broadband white ligh beam, generated from a 200 W Xenon bulb. This beam passes through a monochromator with two 1,200 l/mm gratings installed (one optimized for UV with a peak transmission of 65 % between 180 - 450 nm, and the other optimized for VIS-NIR with a peak transmission of 83 % between 330 - 1000 nm), and is then transported to the focusing assembly through an optical fibre. Other beam diagnostics are incorporated to measure beam power and beam bandwidth as these are variables dependent on wavelength.

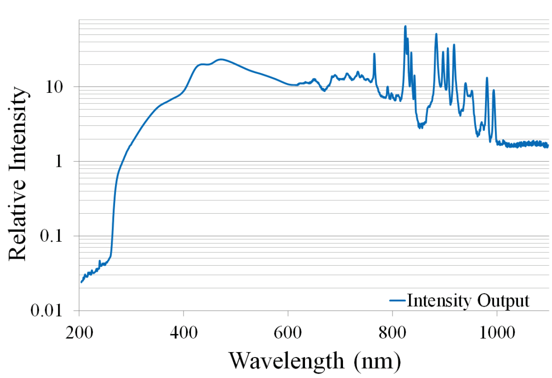

Figure 2: Logarithmic plot of relative intensity in the range (250-1000) nm, measured with two spectrometers (one sensitive to UV and the other sensitive to VIS-NIR) . Wavelength is selected with an integrated monochromator system. Light is generated from a 200 W Xenon bulb and passed through the monochromator which is installed with two gratings: one optimized for UV and the other optimized for VIS-NIR.

Using this apparatus a second instrument to measure Quantum Efficiency (QE) in our III-V Photocathode Preparation Facility (PPF) as a function of wavelength can be realised, thereby permitting spectral QE measurements.

A secondary optical path within the WLS can produce a modulated beam with transport to the existing QE measurement area on the PPF. By incorporating the WLS in with optical fibre connection, it allows most of the apparatus to be positioned away from the entrance port to TESS. The secondary box gives the required beam whilst being light and versatile, allowing for an easy interchange between it and existing laser systems. The new TESS light source dramatically extends the accessible range, and (250-1000) nm is now achievable, as shown in Fig. 2 with a range of spectral bandwidth possible, as shown in Fig. 3 The properties of the WLS make it ideal for the TESS system to further our knowledge of photocathode electron sources.

Experimental Details

Experiments were performed on a p^+-GaAs(100) photocathode supplied by the ISP and activated in the PPF following established procedures [5, 6], achieving about 7.5 % quantum efficiency at 635 nm. Once loaded into TESS, it was illuminated with the monochromated WLS at wavelengths; 500, 532, 550, 600, 650, 700, 750, 800 and 825 nm. The monochromator exit slit width was 0.3 mm, yielding a spectral bandwidth of ± 1.5-2 nm, with the effects of changing the exit slit width on the output resolution shown in Fig. 3 Prior to measurements, the beam power delivered to the cathode was adjusted using neutral density filters to establish emission conditions from the photocathode which did not involve the effects of space charge in the beam transport from the source to the detector. Data was taken with the cathode source at -15 V. The detector grids 1 to 3 and the MCP front plate were all held at + 15, + 22.5, + 30 and + 30 V respectively. Changing the source voltage controls the accelerating potential ($Uacc$), and therefore the electron time of flight (τ) - the longer flight time associated with a low accelerating voltage gives more time

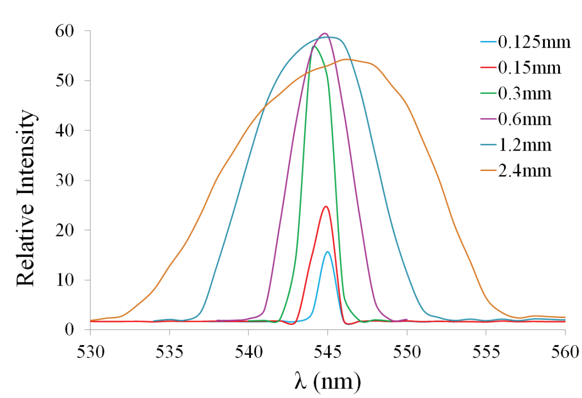

Figure 3: The monochromator exit aperture is a variable rectangular slit (2.4, 1.2, 0.6, 0.3, 0.15 and 0.125 mm). This plot of intensity at 545 nm, shows the resulting increase in bandwidth, ranging from 1 to 15 nm FWHM.

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for the transverse energy component to act and thereby expand the emission footprint. The MCP back plate was held at + 930 V, and the phosphor screen at + 3.5 kV. Screen images showing the electron emission footprint were acquired using camera exposures of 45 s, with extraneous light removed as far as possible. Emission and dark background images were taken at each wavelength, and the dark image then subtracted to create a true image of the emission footprint. The measurements were taken consecutively, thus avoiding any effect from the degradation state of the photocathode.

Data Analysis

With the background image subtracted, X- and Y- histograms of the true image were generated which summed each row and column in the data set. Analysis of the histograms was then applied to establish the image centroid, and a radial distribution function $I(r)$ was derived. The function $I(r)$ reflects the number of electrons incident in the annulus with radius r and thickness δr, with the radial displacement r of an electron from the image centroid (where r = 0) being dependent on its transverse energy ε_{tr}. The drift distance between the source and the detector was 23.5 mm, the effective longitudinal accelerating potential was $Uacc = +30$ V. TEDC were calculated for each data set by converting the radial distribution function $I(r)$ to an energy distribution function $N(\varepsilon_{tr})$ based on the radial displacement from the central emission point during the calculated flight time between the source and detector.

RESULTS

The TEDC's measured for this negative electron affinity GaAs photocathode are shown in Fig. 4 The curves have an exponential character, so the values of MTE were extracted from the spectra by fitting a curve of the form $y = A \times exp(-\varepsilon_{tr}/B)$, where A is the peak intensity and B is the MTE at the $1/e$ level.

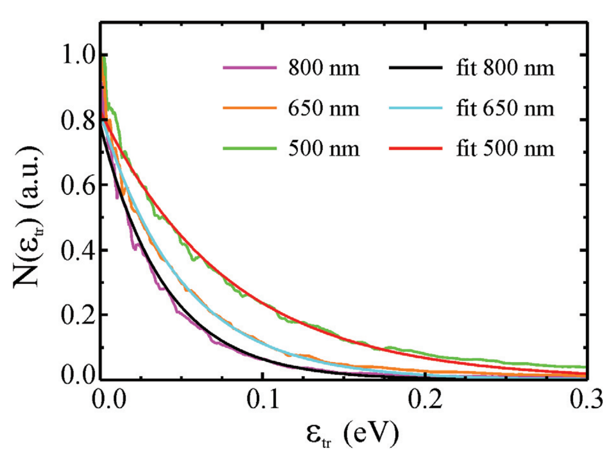

Figure 4: Measurements of the transverse energy distribution curves and their corresponding fitted exponential curves for the GaAs cathode at varying illumination wavelengths. MTE values are obtained at the $1/e$ level of the exponential plots.

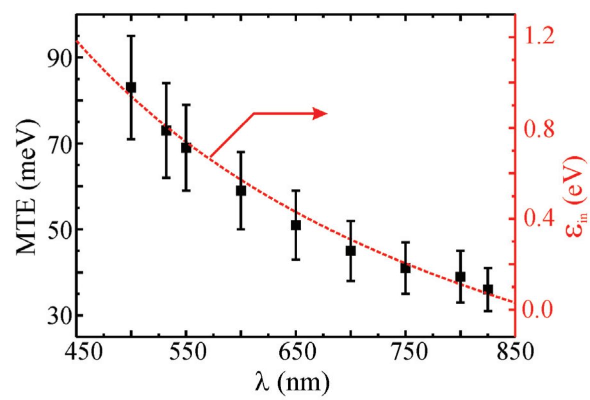

Figure 5: Mean Transverse Energy plot for the GaAs cathode under illumination over the wavelength range 500 - 825 nm. The curve represents how the initial energy of the electron (ε_{in}) depends on photon energy, it is clearly seen in the figure that an increase in ε_{in} causes an increase in MTE. The initial electron energy derives from the fact electrons are not fully thermalized before emission. Therefore we can represent $MTE = MTE_0 + k \times \varepsilon_{in}$, where MTE_0 is the mean transverse energy of thermalized electrons and k a coefficient, in our case MTE_0 is close to 32 meV.

Figure. 5 shows the MTE results for white light source measurements using the TESS system, with wavelengths ranging from 500 to 825 nm. The results indicate that the MTE of electrons emitted from a GaAs photocathode is $MTE_{500} = 83 \pm 12$ meV under illumination at 500 nm, falling to $MTE_{825} = 34 \pm 5$ meV under illumination at 825 nm. Our results are in good agreement with published measurements, and previously measured results on the TESS system [4,7,8].

CONCLUSION

Our results show the expected evolution in the transverse energy of photo-emitted electrons, according to the illumination wavelength, with the effective transverse energy falling as illumination wavelength increases. The work also demonstrates effective commissioning of our white light source, and further expands the capabilities of the TESS experimental system.

FUTURE WORK

Preparations to use the TESS instrument for metal photocathode analysis require only that a UV passing window will replace the current UV opaque window, allowing measurements to be taken at shorter wavelengths and higher photon energies. Development of software for spectral QE measurements and incorporate a new PPF instrument, to take measurements of QE dependent on illumination wavelength.

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