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DEMONSTRATION OF FAST, SINGLE-SHOT PHOTOCATHODE QE MAPPING METHOD USING MLA PATTERN BEAM

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Abstract

Quantum efficiency (QE) is the chief figure of merit in the characterization of photocathodes. Semiconductor photocathodes, especially when used in high rep-rate photoinjectors, are known to show QE degradation over time and must be replaced. The total QE is the basic diagnostic which is used widely and is easy to obtain. However, a QE map indicating variations of QE across the cathode surface has greater utility. It can quickly diagnose problems of QE inhomogeneity. Most QE mapping techniques require hours to complete and are thus disruptive to a user facility schedule. A fast, single-shot method has been proposed using a micro-lens array (MLA) generated QE map. In this paper we report the implementation of the method at Argonne Wakefield Accelerator facility. A micro-lens array (MLA) is used to project an array of beamlets onto the photocathode. The resulting photoelectron beam in the form of an array of electron beamlets is imaged at a YAG screen. Four synchronized measurements are made and the results used to produce a QE map of the photocathode.

INTRODUCTION

Quantum efficiency (QE) of photocathodes in photoinjectors is an important figure of merit. Improved and efficient QE mapping techniques are desired to diagnose the homogeneity of the cathode surface, a key factor in maintaining the high-brightness beams required for advanced light source facilities [1]. In this paper, we describe a method demonstrated at the Argonne Wakefield Accelerator (AWA) to quickly generate a QE map of the Cesium Telluride photocathode surface in the high-charge drive gun [2], [3]. This is achieved using an optical system that includes a pair of Micro-lens Arrays (MLA), transport and imaging optics and beam-splitters, an integrating charge transformer (ICT), a laser energy meter and two cameras. The method has been demonstrated but requires some additional refinement. Some preliminary results are presented. In principle, the measurement can be single-shot but it is usually better to acquire some statistics. In any case, the method is very fast and even at the rather unimpressive 2 Hz repetition rate, making the measurement took only a few minutes.

QE MAPPING METHOD

An experimental diagram is shown in Fig. 1 The laser wavelength of 248 nm is in the near ultraviolet (UV) and a UV camera is required to record the laser intensity. The laser pulse is directed to the MLA optical setup which is arranged to project a rectangular array of small dots onto the photocathode [4]. A 50-50 UV beam splitter sends a portion of the laser pulse to a UV camera which records the laser image at the virtual cathode position. The rest of the light is transmitted to the photocathode. The resulting electron beam is focused using the bucking/focusing and matching solenoids of the photoinjector until an image of the array is produced at the first scintillator screen (YAG1). The image is rotated slightly by the solenoids. The imaging screen is located immediately after the ICT which measures the total charge of the transmitted beam.

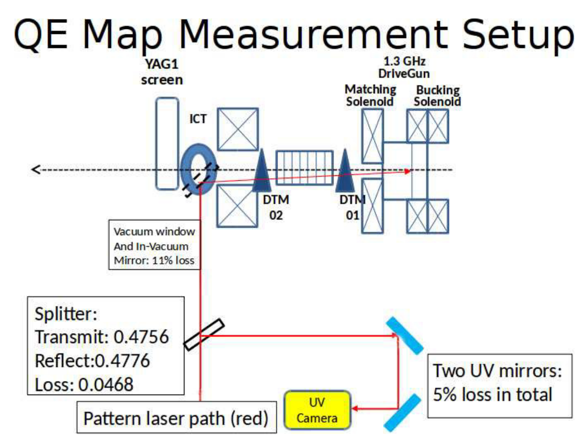

Figure 1: Schematic of the experimental setup. The laser path begins AFTER the MLA optics.

The measurement requires 4 synchronized data acquisition channels:

- UV laser image sent via a calibrated UV splitter
- laser energy measurement
- electron beam image (from YAG1)
- total charge (from the ICT)

In order to do the calculations, it is necessary to calibrate the UV beam splitters and measure all sources of loss such as mirrors and the UV input window. An example of the laser image is shown in Fig. 2 along with the corresponding electron beam image, each consisting of a regular array of

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dots or beamlets covering a relatively small area (the cathode in the AWA drive gun is quite large - almost 30 mm in diameter, and the laser spot size for high-charge operation can be up to 25 mm, almost completely filling the active area).The maximum laser beam size possible was limited by the size of the rectangular UV camera aperture, which is 18 mm by 22 mm. In principle, it is possible to vary the size of the array as well as the number of beamlets by selecting a portion of the pattern using an iris placed at the imaging point and by varying the magnification. For a NxN MLA, the number of beamlets can vary from 1 to N^2, in principle. In practice, the full array cannot be handled by the optics used to transport the pattern beam image produced. In the measurement presented here, 32 points were selected covering a circle about 12 mm in diameter at the cathode. The physical size as well as the array size can be adjusted within the limitations of the optics.

A Matlab script was prepared and used for the data analysis. The position and intensity of each beamlet was evaluated and assigned a value based on the relative intensity and total charge for the beam image. Similarly, the laser image was evaluated and each dot was assigned an energy value based on the total laser energy and the distributed intensity for the laser image. The relative image rotation is carefully analyzed, and the beamlets are mapped to each other. These two values (laser energy and charge) per beamlet are used to calculate the QE for each corresponding point on the cathode, using the standard equation, essentially the ratio of number of photoelectrons detected to the number of photons transmitted to the cathode. A map is produced showing the QE calculated at each position on the cathode.
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It is important to note that the QE measured in a photoinjector is the practical QE, meaning the calculation uses the number of photoelectrons that are emitted and accelerated to the collection point downstream, rather than the total number of photoelectrons emitted. This type of QE measurement is subject to variability. The QE measured thus can vary due to various parameters including gun gradient, the laser injection phase and space charge. In this case the laser phase was chosen to be 50 degrees (maximum energy) and the gradient 70 MV/m. Space charge was minimized by using a low intensity laser beam generating about 440 pC of charge for an average of 14 pC per beamlet.

MEASUREMENT RESULTS

Preliminary measurement results are presented in Fig. 3. For the measurement presented here, the MLA and associated optics were configured to produce a 32 beamlet array projected onto the center of the cathode. The data was taken using a relatively low total charge beam of about 440 pC with a pulse length of 6 ps Full Width Half Maximum (FWHM). An example of the results are shown in Fig. 3. The apparent point to point QE variation is quite high, from 0.94% at position number 7 to 14.42% at position number 23.

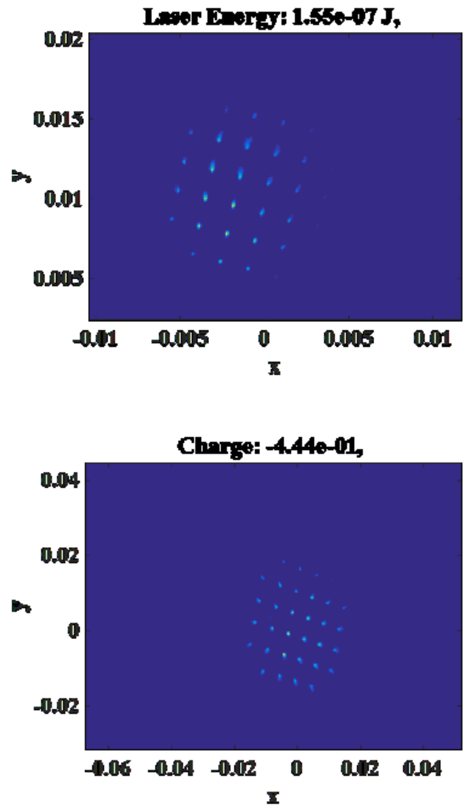

Figure 2: A typical laser image (top) and corresponding electron beam image.The maximum laser beam size is limited by the UV camera aperture. The scale is in meters.

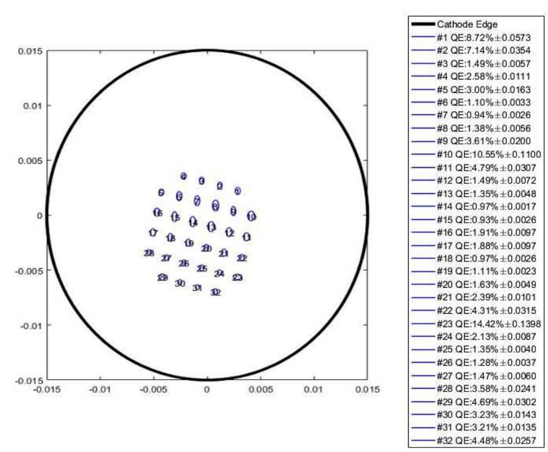

Figure 3: A QE map produced by this method with a 32 beamlet array. The scale is in meters.

Given that the average QE of the cathode is currently about 5%, the results are certainly reasonable. However, the accuracy of the result was compromised by the poor quality of the laser image produced by the existing UV laser camera. As can be seen in the typical laser image shown in Fig. 2, the dots along the edges of the array are very faint, nearly invisible to the eye unlike the corresponding electron beamlet

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images. This is due to some problems with the UV camera most likely a result of cumulative damage to the camera sensor. The UV camera was certainly the weak link in the data acquisition. Therefore, these results do not well represent the homogeneity of the QE of cathode (or lack thereof), but rather a proof-of-principle of the measurement method.

In order to improve the measurement quality, the next step is to identify and purchase a high quality laser profile camera that can accept a UV beam size up to 25 mm. It is hoped that in the near future AWA will have the means to upgrade the UV camera and thus be able to produce a better data-set. With that required improvement in data-acquisition capability, it is hoped that additional studies of the effect of gun gradient, laser input phase, laser pulse length, beamlet size, array size and other factors may be planned and executed as well.

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