Quantum efficiency and spatial resolution of Microsphere plates stacked with Microchannel plates

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ABSTRACT

The principles and a detailed study of the basic operation of a relatively new type of electron multipliers - microsphere plates (MSPs) has been reported recently. In this paper we extend these studies by presenting measurements of bare MSP quantum efficiency at incoming radiation wavelength range of 250-1450 Å. MSP efficiency appeared to be by an order of magnitude lower than that of bare microchannel plates (MCPs), having maximum of about 1% at 350-900 Å. We also extend the previous investigation of angular dependence of MSP gain and detection efficiency to an angular range of 90±40 degrees, when no gain depression was observed, while detection efficiency varied only by ~7%. The spatial charge cloud distribution of microsphere plates was measured with the help of a phosphor screen, showing that the dependence is quasi-symmetrical although featuring granular formations caused by the intrinsic structure of the plate.

We also present a detailed study of combined MCP/MSP stack operation, suggested earlier by L.B.C. Worth et al. The gain of the stack was measured to be relatively high (10^8) with pulse height distribution FWHM values as low as ~62% and dark noise count rates less than 0.1 counts cm^{-2} s^{-1}, limited by the front MCP. The spatial resolution reached the best value of about 80 μm with a 250 μm gap between the plates and an accelerating bias in the gap of 50V. The counting rate capabilities of this hybrid stack are much better (no gain drop was observed at count rates of 3.3×10^5 counts cm^{-2}s^{-1}) than those of purely MSP detector (10^3 counts cm^{-2}s^{-1}).

Keywords: MicroSphere plates, Microchannel plates, Electron multipliers, Imaging detectors

1 INTRODUCTION

The Microsphere Plates (MSPs) - a relatively new type of electron multipliers manufactured by El-Mul Technologies Ltd have been studied in detail in recent years. The principles of their operation are similar to those of widely used microchannel plates (MCPs) except for the fact that the electron avalanche development in an MSP takes place between irregularly packed spheres instead of straight channels in an MCP. Microsphere plates have some advantages over conventional microchannel plates which may make them preferable for specific applications. Previous studies showed that MSPs possess less severe constraints on operating pressure, higher modal gains and wider angles of allowed input radiation. At the same time the disadvantages of MSP based detectors are their high dark noise, lower count rate capabilities and relatively poor spatial resolution.
In this paper we expand investigations of microsphere plate characteristics. Section 2 presents results of our measurements of MSP absolute quantum detection efficiency in the wavelength range 250-1450 Å. We also extend the previous measurements of the angular dependence of MSP QDE to 0°-40° relative to MSP normal. Results of the measurements of the spatial charge cloud distribution of microsphere plates are described in section 3.

The relatively poor spatial resolution of a bare MSP detector (only ~500 μm, compared to ~30 μm for MCPs) limits their usefulness for many imaging applications. As suggested earlier an MCP placed on top of an MSP allows substantial improvement of the spatial resolution of a detector comprising an MSP. Section 4 summarises the detailed experimental evaluation of this hybrid pair operation.

2 MSP-MCP STACK OPERATION

We have evaluated a MSP-MCP stack with a production line microsphere plate (0.7 mm thick, 33 mm in diameter with the measured resistance of 350 MΩ) serving as a front plate, and a 0.5 mm thick, 12.5 μm pore, 70 MΩ resistance microchannel plate, serving as the rear plate in the detector. The gap between the plates was 100 μm. A wedge-and-strip anode8 positioned 7 mm from the rear plate was used for photon counting. No repeller mesh was used in the measurements. The detector was mounted on a four-axis manipulator which permitted both rotational and translational movement, and placed in a vacuum chamber operating at pressures below 10⁻⁶ mbar. The detector exhibited peaked pulse height distributions at biases higher than 1200V across each plate. Accelerating potentials of 1700V, 1000V and 500V were applied to MSP, MCP and across the stack-anode gap, respectively, while there was no bias between MSP and MCP. The modal gain of the detector at these settings was ~6.9-10⁷ with pulse height FWHM of about 175%. The dark noise images had several point-like noise hotspots and the total dark noise count rate was ~0.8 counts cm⁻² s⁻¹. This is consistent with the results obtained with a detector comprising two MSPs³,⁵ as the dark noise in both cases was defined by a relatively noisy front MSP. Fig.1 shows the image obtained under uniform full field UV illumination (2537 Å).

![Image](image_url)

Figure 1: UV flat field image of MSP-MCP pair obtained at 3500V across the stack.

The image exhibits distinct granularity corresponding to intrinsic structure of the front plate. Spatial resolu-
tion of such a hybrid pair is not to be expected to improve in comparison with pair of MSPs. However, no gain drop was observed for the count rates of up to $\sim 1.8 \times 10^4 \text{ cm}^{-2}\text{s}^{-1}$, which is substantially higher than previously reported limit of $\sim 10^3 \text{ cm}^{-2}\text{s}^{-1}$ for a pure MSP detector.\(^5\) This is because the charge extraction takes place in the rear MCP which has a better recovery time.

### 2.1 MSP quantum detection efficiency

The detection efficiency was measured with monochromatic radiation provided by a gas discharge hollow cathode source in combination with a 1 m grazing incidence monochromator. Absolute QDE’s were derived from flux measurement comparisons with reference standards - NIST calibrated ultraviolet windowless photodiode and far ultraviolet windowed photodiode, which have a most probable error of 10% in 68-2537 Å region. The measurements were performed at 10° incidence angle to MSP normal and are shown in Fig.2. The efficiency of the bare MSP appeared to be an order of magnitude lower than a bare microchannel plate, and exhibits a maximum QDE of about 1% in wavelength range 350-900 Å. This probably can be explained by the presence of "closed" areas on the MSP input surface leading to the spatial variations of the efficiency\(^7\) and by the differences in the process of electron avalanche development. In the case of an MSP some secondary electrons are reabsorbed by the randomly packed spheres without having enough energy to cause multiplication. An obvious way to enhance the quantum detection efficiency of microsphere plates is the well established method used with MCPs, that of coating the plate with a layer of photoemissive material on its input surface.\(^9\)

### 2.2 QDE vs input angle

Fig.3 shows the angular dependence of the detection efficiency obtained at 490 Å. The values of the count rate were normalized by the geometrical factor of influx variation with changing detector angle. No significant variation in the signal PHD was observed for incoming radiation angles from $+20°$ to $-40°$ with respect to the MSP normal while the efficiency changed only by 7%.

### 3 MSP SPATIAL CHARGE CLOUD DISTRIBUTION

A chevron stack of two MCPs (40:1 L/D, 12.5 µm pore, 8° bias angle, 70 MΩ resistance, 33 mm in diameter) combined with the MSP described in section 2, serving as a rear plate in the detector, was examined. All three plates were put in direct contact and a pinhole mask with holes of 50 µm in diameter was installed on the front surface of the input MCP. A P20 phosphor screen was positioned 5 mm behind the stack, while the digital imaging was performed with a PULNIX TM-7CN CCD camera. The input of the stack was negatively biased and a positive accelerating bias of several kilovolts was applied to the phosphor screen. The limiting spatial resolution of the image readout system was about 50 µm. The detector was illuminated by a mercury vapor UV lamp (2537 Å). Fig.4 shows the typical image obtained at detector gain 4.8 $\times$ 10$^6$ with a screen bias of 4500 V. The charge cloud footprints appeared to have granular structures although being azimuthally quasi symmetric. It seems to be most likely that the presence of the tails on the image of a pinhole can be explained by the electron funnelling effect due to the intrinsic structure of MSP\(^7\) and by the spatial non-uniformity of the distribution function of electrons at the output of the plate. For large enough charge cloud footprints these irregularities are averaged by centroiding charge division readouts, which in turn reduces the error in the event positioning.
Figure 2: Quantum efficiency of bare MSP measured at $V_{MSP}=1.7\text{kV}, V_{MCP}=1\text{kV}$, count rate $1.55\times10^4 \text{ cm}^{-2}\text{s}^{-1}$.

Figure 3: Variation of relative detector efficiency with angle of radiation incidence. $V_{MSP}=1.7\text{kV}, V_{MCP}=1\text{kV}$, 490 Å photons, 0.2 cm$^{-2}$ active area.
Figure 4: Image of a pinhole mask obtained with phosphor screen positioned at 5 mm from MCP-MSP stack operating at $4.8 \times 10^6$ gain and 4500 V screen accelerating bias. The mask has 50μm holes positioned 6 mm apart.

4 MCP-MSP STACK OPERATION

The intrinsic spatial resolution of microsphere plates was reported to be only 2 lines per mm,\textsuperscript{3,5} which is far less than required for many imaging applications. Therefore MSPs are often considered to be useful in non-imaging counters rather than in high resolution imaging detectors. The irregular geometrical structure of MSP explaining the presence of "closed" areas on the surface and electron funnelling is the main reason for poor spatial resolution. The scale of these irregularities is comparable to several diameters of the microspheres. Reducing the physical size of beads therefore would probably lead to better spatial resolution. The other alternative way to improve MSP spatial characteristics is to average this granularity over some surface area. For centroiding charge division readouts the addition of an MCP serving as the front plate in a hybrid stack\textsuperscript{3} substantially improves the resolution compared to a single MSP. The MCP electron cloud spreads out in the gap between plates and provides the surface integration over the MSP active area. We have studied an MCP/MSP stack comprising one 0.75 mm thick, 12.5 μm pore, 33mm in diameter, 70 MΩ MCP and the MSP described in section 2. Two gap distances between the plates were used, 250 and 125 μm. The characteristics appeared to be better with 250 μm gap, therefore the results reported below are obtained with 250 μm interplate distance. Accelerating biases on MCP and MSP varied over the range of 900-1600, while the interplate bias was between -10 and 200V. Mercury vapor UV lamp (2537 Å) was used in these measurements carried out at pressures below 10\textsuperscript{-6} mbar. A wedge-and-strip anode\textsuperscript{3} positioned 7 mm below the rear plate was used for photon counting. The active diameter of the detector in all cases was 20 mm.

The dark noise of the hybrid stack was determined by the front MCP and was uniform with a count rate less than 0.1 counts cm\textsuperscript{-2}s\textsuperscript{-1} for all operating parameters. The detector showed peaked pulse height distributions at biases higher than 1200 V across each plate. Fig.5 shows typical PHDs for a fixed MCP bias of 1600 V and Fig.6 shows variation of the stack gain and FWHM with MSP bias. The modal gain appeared to be relatively
high with values of $1.2 \times 10^8$ at 1600 V across each plate and typical pulse height FWHM of about 90%. Variation of the interplate gap bias (Fig. 7) improves the FWHM values (90% at bias 1600 and 1400 V on MCP and MSP, respectively) and reduces the modal gain since less active "channels" are involved in multiplication on the second stage of the detector.

### 4.1 Image characteristics

#### 4.1.1 Wire mesh under full-field illumination

The imaging properties of the hybrid MCP/MSP stack were first investigated with a fine wire mesh (70 lines per inch with 23μm wide wires) placed in direct contact with the front surface of MCP. The spatial resolution of the detector exhibit strong dependence on operating parameters, especially on interplate distance and bias. Fig. 8 shows two full-field images of the mesh obtained with the same operating parameters ($V_{MCP}=1.6$ kV and $V_{MSP}=1.4$ kV) except for the MCP-MSP gap bias: Fig. 8.a corresponds to the measurements when no accelerating gap bias was applied, while the image shown in Fig. 8.b was obtained with 100 V across the gap. Apparently in the latter case the electron cloud spreading between the plates is not enough to provide the integration over MSP surface and therefore the image shows bright granular structures dominating over the faint mesh footprint. Fig. 9 shows 5mm wide sections across the images shown in Fig. 8, indicating the presence of a clear periodic structure corresponding to the mesh (in case of zero bias in the interplate gap). The Fourier transform of these cross sections shown in Fig. 10 clearly confirms the ability of the detector to resolve the mesh.

Figure 5: Variation of MCP-MSP combined stack signal PHD with $V_{MSP}$ and bias in the interplate gap $V_{gap}$. PHDs are normalized to constant peak height. $V_{MCP}=1.6$ kV, $V_{MSP}=1250$ V, no bias in the gap; + $V_{MSP}=1400$ V, no bias in the gap; ◇ $V_{MSP}=1400$ V, $V_{gap}=50$ V; △ $V_{MSP}=1500$ V, no bias in the gap;
Figure 6: Variation of MCP-MSP pair modal gain (left) and pulse height FWHM (right) with MSP bias, at fixed $V_{MCP}=1.6$ kV and no bias in the interplate gap.

Figure 7: Variation of MCP-MSP pair modal gain (left) and pulse height FWHM (right) with interplate gap bias. $V_{MCP}=1.6$ kV. ♦ $V_{MS}$ 1500 V, △ $V_{MS}$ 1400 V.
Figure 8: Image of the mesh (70 lines per inch ~23μm wide wires) obtained with MCP-MSP combined stack. $V_{MCP}=1.6$ kV and $V_{MSP}=1.4$ kV. 250 μm interplate gap. (a) no bias in the gap; (b) $V_{gap}=100$ V.
Figure 9: Cross section (5mm wide) of the mesh images presented in Fig.8.

Figure 10: Fourier transforms of the mesh image cross sections, shown in Fig.9.
4.1.2 Pinhole mask image

Image characteristics of the combined MCP-MSP pair were also measured in detail by illuminating a pinhole mask positioned in direct contact with the front surface of the MCP. The test mask contained a regular array of 50 μm diameter holes with 2 mm distance between them (see Fig.11). Crosses and circles on the image correspond to measured and real pinhole positions, respectively. The image was collected at optimal (in terms of spatial resolution) voltage settings 1500V across each plate, 50V between them and 400V in the MSP-anode gap. The average output count rate was 3.4 counts-s⁻¹ per pinhole spot. Analysis of these data shows that the resolution of the hybrid stack can be as good as ~80 μm. A typical section across the pinhole image including one row of pinholes is shown in Fig.12. Although there was a variation of the number of events in each pinhole spot (600-1200 events per pinhole) determined by the MSP intrinsic structure, it was not as strong as in the case of a bare microsphere plate detector (10³-6·10⁴).

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6 REFERENCES


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Figure 11: Image of a pinhole mask obtained with MCP-MSP pair at biases of 1.5 kV across each plate and 50V between them. The mask had 50 µm regular array of pinholes positioned 2 mm apart. The count rate was 3.4 counts s⁻¹ per pinhole spot. Crosses and circles correspond to measured and real pinhole centers, respectively.

Figure 12: Cross section of the pinhole image (Fig.11).