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Examination of the spatial-response uniformity of a microchannel-plate detector using a pulsed high-voltage electron gun

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ABSTRACT: In this paper we describe an alternative method to examine the spatial-response uniformity of a microchannel-plate (MCP) detector to a ~1 ns pulse of soft x-rays. The examination was performed by illuminating the MCP surface with energetic electrons rather than with x-rays. It is shown that the MCP features similar, yet not identical, response to pulses of soft x-ray photons or energetic electrons, making such examinations much simpler and less expensive. The building of the electron-gun system is relatively easy and inexpensive, and in addition to verifying the spatial uniformity of the response of the MCP to incoming particles and radiation, it can be used to detect damaged areas on the detector. A comparison between the results obtained using the electron-gun with those obtained using a laser-produced-plasma x-ray source, demonstrating the reliability of the method, is presented.

KEYWORDS: X-ray detectors; Plasma diagnostics - high speed photography

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1 Introduction

Microchannel-plate (MCP) detectors have long been used for temporally- and spatially-resolved detection and intensification of charged particles and radiation, with applications such as astronomy, electron imaging, and time-gated x-ray imaging [1].

It is obviously highly beneficial to check the MCP response to radiation of the same properties as that emitted by the real-life experiment to be recorded, since the detector might feature a different response to different particles or to beams of different wavelengths or time-scales. In our case, the MCP will be used to record the spectra of a short ($\lesssim$10 ns) pulse of soft x-rays, emitted by a Z-pinch plasma source, with exposure times of the order of $\sim$1 ns [2]. The common sources of such radiation usually involve expensive and complex devices such as synchrotrons [3] or laser-produced-plasma sources [4], where the latter can also feature short time-scales.

In this paper, we report on a simple and inexpensive method for verifying the spatial uniformity of the MCP response and detecting damaged areas on the detector, by illuminating it with high-energy electrons, emitted by a rather simple pulsed electron gun. It is shown that the response of the MCP to these electrons is similar, yet not identical, to the response obtained for soft x-rays.

2 Experimental system

The experimental system consists of a vacuum chamber, $\sim$70 cm in length, with the MCP detector mounted on one side, and a source on the other. The source is either a self-made electron gun [5] or a laser-produced-plasma (LPP) x-ray source. The small physical size of both sources compared to the source-MCP distance, as well as the non-directional nature of the emission of particles, ensure that the incoming particles will impinge the MCP surface uniformly. A drawing of the two layouts of the experimental system is given in figure 1.

The electron gun is comprised of a large number ($\sim$ 1000) of carbon fibers, each with a diameter of $\lesssim$ 10 μm, that emit electrons when a negative high-voltage pulse of the order of a few kV is applied. These electrons are directed using a grounded metal mesh of $\sim$10 mm diameter, positioned $\sim$20 mm from the fibers, and uniformly bombard the photocathode surface of the MCP. A simple b-dot $(\dot{B})$ probe and a current-probe were used to determine the current flowing through the brushes during operation, giving typical values of $\sim$30 A with a pulse duration of $\sim$3 ns.

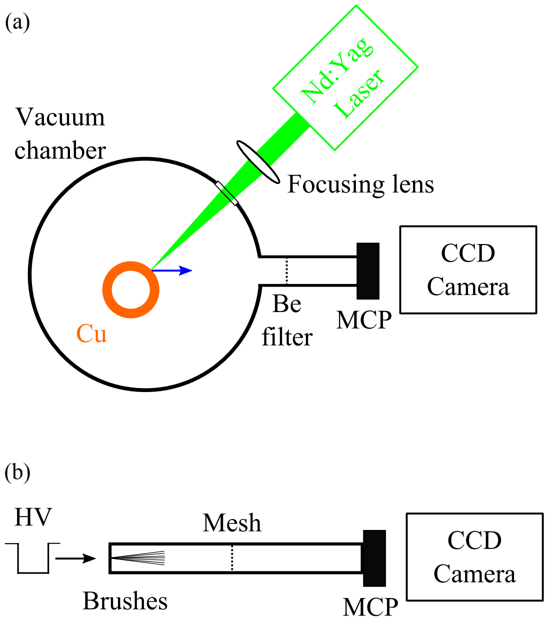


Figure 1: Layout of the experimental system: (a) The LPP system: laser in green, Cu target in orange, and emitted x-rays in blue, and (b) The electron-gun system. The flux of photons or electrons impinges on the MCP surface uniformly, producing an image recorded by the CCD camera.

In a preliminary procedure, a Faraday-cup was installed instead of the MCP, in order to measure the amount of charge that reaches the MCP. It was found that $\lesssim 1\%$ of the electrons that are emitted by the brush eventually hit the MCP surface, which is consistent with the signal emitted by the MCP from each shot. This value is supported by a back-of-the-envelope calculation of the space-charge effect, which causes the electron beam to blow-up due to electron accumulation. In order to increase the percentage, one can use a larger cathode, or position the MCP closer to the mesh.

The MCP is operated in a positive mode, where the front Au-coated surface of the MCP (facing the experiment) is grounded, and the back side (facing the gap) is kept floating. A positive ~6.5 kV pulse is applied between the Al-coated phosphor and the grounded front side of the MCP, see figure 2. The amplitude of the triggering pulse is capacitively divided between the MCP plate ($\epsilon \approx 8$) and the gap between the phosphor and MCP back side ($\epsilon = 1$), such that $\frac{V_{\mathrm{gap}}}{V_{\mathrm{MCP}}} = \frac{C_{\mathrm{MCP}}}{C_{\mathrm{gap}}} \gtrsim 5$. It is worth mentioning that the charging (RC) time in this triggering scheme is short compared to the alternative option of only triggering the MCP. The reason is the smaller capacitance resulting from connecting the large capacitance of the MCP in series with the smaller gap capacitance.

The MCP illuminates a phosphor screen, which is imaged using a fiber-optic taper and a cooled CCD camera. The camera uses a CCD with 2048×2048 pixels of $13.5 \times 13.5\,\mu\mathrm{m}^2$ area, and is mounted with two Nikon 50 mm f/1.2 lenses in tandem, allowing for 1:1 imaging of the MCP output.

The pulser used for triggering the two units discharges a transmission-line charged to ~ 13 kV into a matched line composed of 4 parallel outputs, 50 Ohm each, yielding a voltage of ~ 6.5 kV on

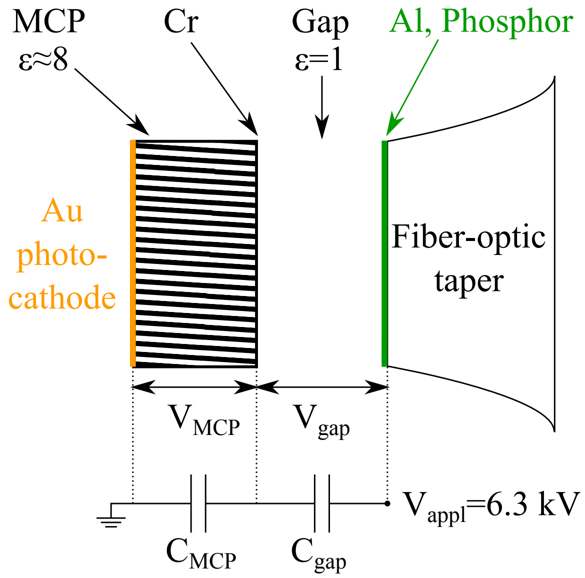


Figure 2: Schematic drawing (not to scale) of the MCP and its equivalent electrical circuit. The applied pulsed voltage, V_{appl}, is capacitively divided between the MCP and the gap.

each of the outputs. The triggering of this unit is a 5 V trigger-in, and the shot-to-shot jitter between the trigger-in and the HV pulse is $\sim 2\,$ns for voltages that are close to the maximal charging voltage (13 kV), where the jitter is larger for lower charging voltages. Additional information can be found in reference [6].

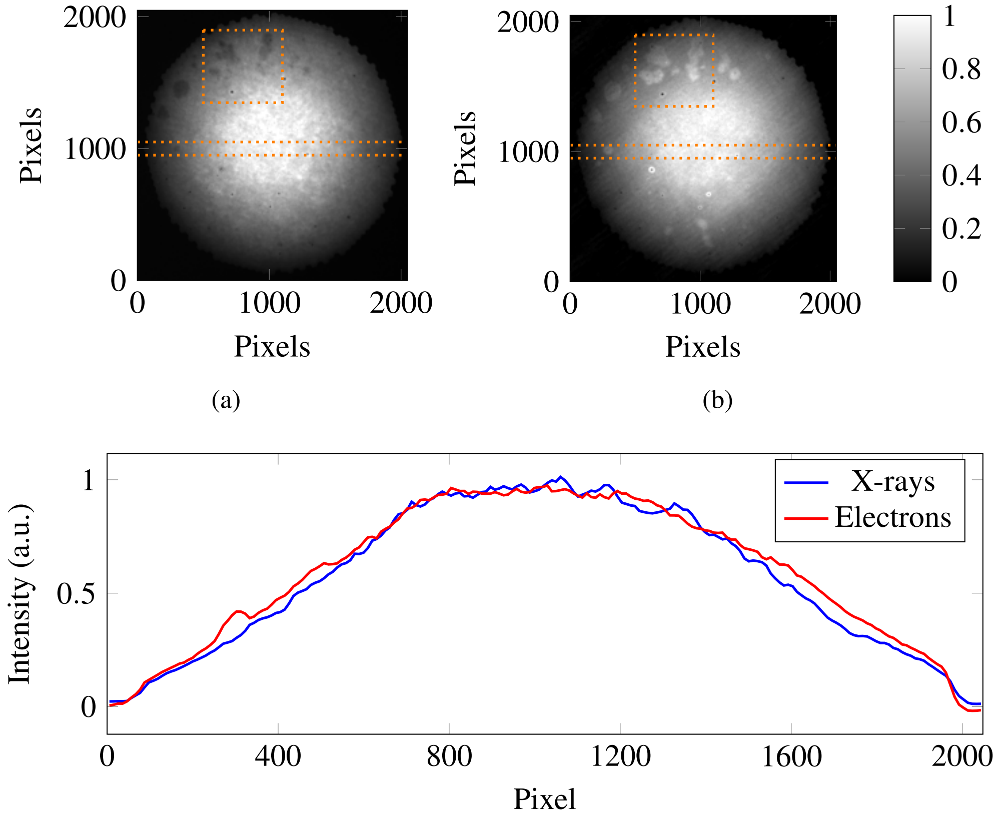
Obviously, using a single pulser to trigger both the source and the MCP allows one to obtain minimal jitter. Two out of the four outputs of the pulser are used along with a cable-delay system, taking into consideration the time-of-flight of the electrons across the vacuum chamber. Since the output pulse of the pulser is positive, an invert-polarity connector is used on the coax line between the pulser and the electron brush in order to allow for the electron emission.

The LPP x-ray source uses a 170 ps, 0.25 J Nd:YAG laser operating at 532 nm, focused onto a $\sim 50\,\mu$m spot on a Cu target. As a result of the laser-target interaction, a highly ionized plasma is produced with electron temperature and density of 200÷400 eV and $\sim 10^{21}\,\text{cm}^{-3}$, respectively. The hot-dense plasma emits a short x-ray pulse of $\sim 200\,$ps duration. Since the laser damages the target at the laser focus, the target is made to slowly spiral during operation, so that each laser shot is focused on an undamaged position on the target. In order to protect the MCP and to filter out the visible-light and UV emission from the LPP, a 10 μm-thick Beryllium filter is placed between the target and the MCP.

In a preliminary measurement, an x-ray film was positioned as a detector instead of the MCP, using the same Be window. The recorded image was seen to be uniform to within ±3% across an area of the same size as the MCP, confirming the spatial uniformity of the incoming radiation.

The x-rays emitted by the LPP source hit the MCP surface uniformly, and by correctly timing the high-voltage pulse, the MCP intensification occurs as the x-ray photons hit the MCP surface.

These measurements allowed for obtaining spatial calibration of x-ray spectra emitted by our Z-pinch generator, where the same configuration of the MCP and CCD camera was used for the



(a)

(b)

(c)

Figure 3: CCD images (intensity-normalized) of the MCP output from a single shot of the LPP x-ray source (a), and from 20 shots of the electron-gun source (b). The orange dotted lines show the area the average intensity of which is shown in (c), and the orange dotted rectangles show the zoom area displayed in the next figure. The mean of rows 950:1050 of the two results is presented in (c), for the LPP (blue) and for the electron-gun (red) experiments, showing very good agreement between the two methods.

measurement. We note that this method enables measuring the total response of the MCP and CCD apparatus, arising from the MCP spatial uniformity, the vignetting caused by the optical system, and the CCD response.

3 Results and discussion

The LPP source is strong enough to allow good signal-to-noise ratio (SNR) in a single shot, while the electron-gun source requires multiple shots to be recorded during a single CCD exposure to obtain a similar SNR. A comparison between the results of the two methods is presented in figure 3. The images are brightest at the center and increasingly dim at points closer to the edge, an effect which originates from intense vignetting caused by the use of two lenses in a tandem configuration. The similarity between the two images, coupled with the proven spatial intensity-uniformity of the photons from the LPP system, reaffirms the spatial uniformity of the impinging electrons as well.

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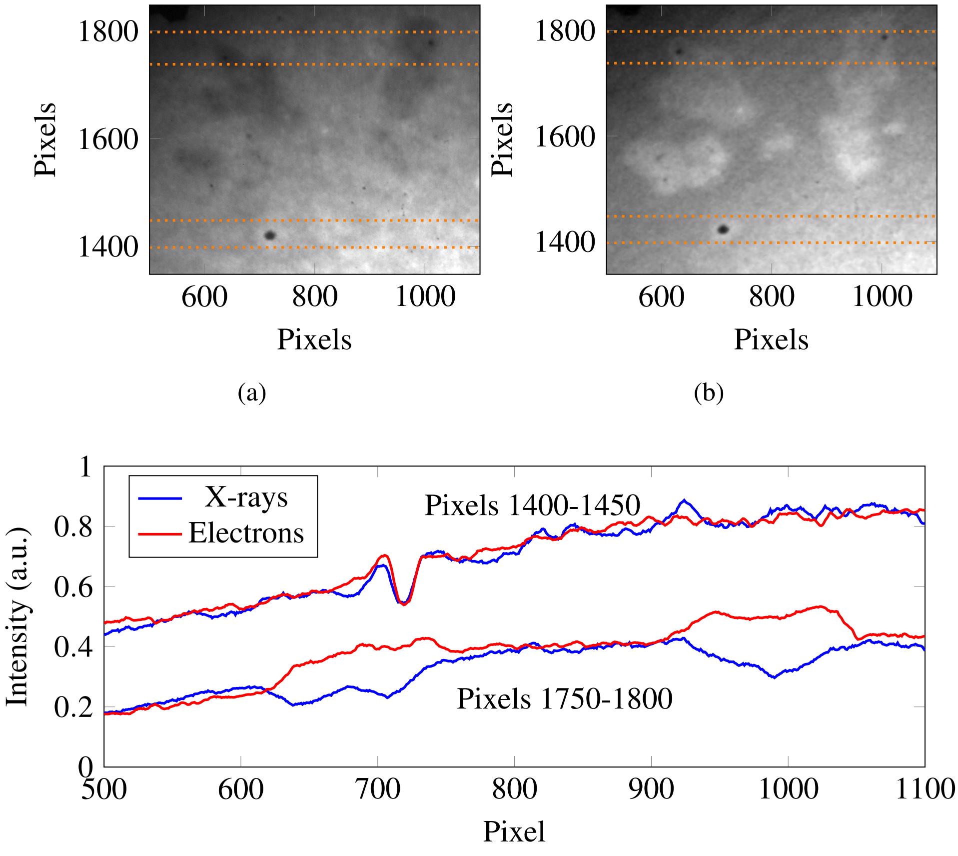

(a)

(b)

(c)

Figure 4: A zoom-view on a portion of the MCP, for the LPP (a) and electron-gun (b) experiments. In (c), the mean of two sets of 50 rows, indicated by the dotted orange lines in (a) and (b), is given for the LPP (blue) and electron-gun (red) experiments.

A closer examination of some of the features of the defects is presented in figure 4. The small blind-spot on the lower part is clearly seen in both images, with very good agreement between them. However, the larger spots at the upper part are seen to affect the two measurements differently: while the x-rays produce less light on the spots (see darker parts in figure 4a and lower intensity values in 4c), the electron-gun results show higher readings (see bright spots in figure 4b and higher intensity values in 4c).

When examining the similarities and differences between the MCP response to the two types of radiation, we note that the interaction between the Au photocathode and either the $\sim 1.5\,\mathrm{keV}$ photons or the $\lesssim 6\,\mathrm{keV}$ electrons is similar with respect to the interaction length: the attenuation length of the photons in solid-density Au is $\sim 0.2\,\mu\mathrm{m}$, and the penetration depth of the electrons is $\sim 0.1\,\mu\mathrm{m}$. It is noteworthy that the thickness of the Au photocathode is of the same order of magnitude as the interaction depths, i.e. of a few 1000s of Å.

There are two possible sources for image defects, namely: non-homogeneous photocathode coating and non-homogeneous aluminum coating of the phosphor. Areas at the front side of the MCP which are either poorly covered with Au-photocathode material or feature no cover at all, will display low or non-detectable conversion of the impinging radiation into secondary electrons. Areas with poor aluminum coating on the phosphor, or with no coating at all, cause deficient proximity-focusing of the electron bunches exiting the MCP channels. These defects consequently produce areas of poor light-emission intensity.

Since the latter source is insensitive to the type of radiation striking the photocathode, the differences between the images acquired using electrons and x-rays probably arise from a non-homogeneous photocathode coating, that cause differences between emission of secondary electrons from the two types of impinging particles.

The source of the differences between the response to photons and energetic electrons is a subject for further investigations. Regardless, the similarity between the two images shown here demonstrates the reliability of the method for examining the uniformity of the response of an MCP detector, as well as for flaws detection.

Acknowledgments

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