

GEMpix detector: a new diagnostic for Laser Produced Plasmas monitoring

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Introduction

A common characteristic of Laser produced plasmas (LPPs) is their intense emission in the X-ray spectral region, in short time scale. These plasmas can reach electron temperatures of several keV, electron density up to 10^{23} electrons/cm³ and therefore they can be considered as pulsed sources of X-rays. They can be considered for several applications. Inertial Confinement Fusion (ICF) is one of the most relevant. In this case, X-rays play a role not only as a diagnostic mean of the physical properties of the plasma, but also to drive the implosion, in case of indirect scheme. In addition laser plasma could be used also as X-rays sources in many technological applications like X-ray microscopy, nano-lithography, dynamic studies of mechanical properties of materials, X-ray time resolved radiography. For these reasons the development of new X-ray imaging devices is relevant even beyond the field of laser produced plasmas. X-ray imaging diagnostics from LPPs are realized so far mainly by X-ray CCDs, Micro Channel Plates and Imaging Plates. This paper presents a new detector in the soft X-ray range, the “GEMpix”, which can have several advantages compared to the conventional imaging devices. It is a gas detector based on the GEM technology [1,2] with a quad-medipix chip as read-out electronics. Its potential as LPP imaging diagnostic has been preliminary demonstrated through some measurements performed on the ABC facility (ENEA, Frascati) [3,4].

The GEMpix detector

The GEMpix detector [5] is a micro-pattern gas detector based on Gas Electron Multiplier technology (GEM). It has been realized like a chamber with a cathode, an anode and three GEM foils. The cathode is made by an thin aluminate mylar foil (12 μ m) and defines also the detector window. The active volume is represented by the gas layer between the cathode and the first GEM foil. Triple-GEM structure allows a gain from 1 to 10^4 without discharge problems. The anode is a quad-medipix chip that has 512 x 512 pixels, each one with an area of 55 x 55 μ m². It is based on a C-MOS technology and consists of four medipix chips hold together without the silicon layer which, in this case, is substituted by the triple-GEM gas

chamber. It can work both in counting mode and in Time over Threshold (ToT) mode. In the second case, each pixel is used in a Wilkinson type ADC, so that the registered digital counts are proportional to time in which the signal is above the threshold, which in turn is proportional to the charge collected by the pixel.

This charge can be originated by a single photon interaction when the particle flux is not very high. An estimate of this flux limit (few tens of MHz) results mainly by the front-end-electronics and the electron drift velocity, giving an intrinsic time resolution of about 100 ns. Charge collected at higher fluxes implies the contemporary detection of many photons, whose signals are overlapped, corresponding to a charge integration mode. In both cases the gain provided by GEMs can be properly set in order to evaluate the released charge without saturation of the read-out electronics. Then GEMpix is able to work on a wide dynamic range: the estimated value is four orders of magnitude higher respect to the medipix detector which uses a silicon layer as active material. Dynamic range has been studied in the New Imaging X-ray Techniques (NIXT) Laboratory (ENEA) using mono-energetic photons of three different energies (fig. 2): 3.7 keV (Ca), 6.4 keV (Fe) and 8.0 keV (Cu), in the regime of single photon detection.

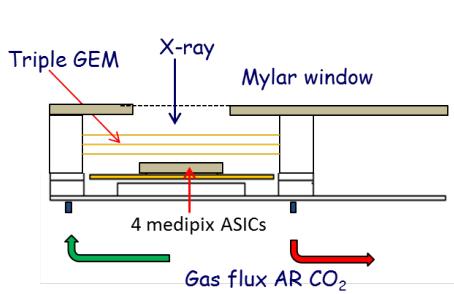


Figure 1: schematic layout of a GEMpix detector; it is evidenced the detector window, the triple-GEM and the quad-medipix chip. In and out gas connectors are also evidenced.

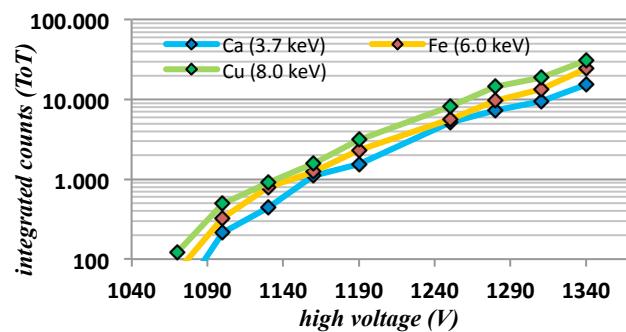


Figure 2: Integrated counts per incident photon from three different X-ray sources (Ca, Fe and Cu) when the gain voltage is varied from 1070 to 1340 V for ArCO₂CF₄ (45/15/40) gas mixture.

It is clear from the plot that when the gain voltage is increased, there is a corresponding increase of the total charge collected on the pixels and then digitized in counts. The transverse size of the electron cloud collected on the pixels depends on the GEM gain. The detected photon appears as a blob whose diameter is greater and greater when the applied voltage is increased (fig. 3). Then working at low gain voltages, smaller blobs are observed and photon interacting on different points of the active area can be distinguished, if the photon fluence is low, according to the observations made before. Since the time resolution of GEMpix is about 100 ns, as previously mentioned, counting mode can be used up to a few MHz, while charge integration mode (ToT configuration) will be used for detecting X-rays burst, like in the case

of LPPs, whose time width is of the order of few ns, or even shorter, if femtosecond lasers are used. As a result, charge is produced by more than one photon. Characterization in laboratory in regime of single photon detection has been done, in particular to study the intensity response and the spatial resolution (blob size). In order to check the imaging capabilities of this detector, experiments have been done with real laser produced plasmas. Some preliminary tests have been then performed on the ABC test facility (ENEA, Frascati).

ABC tests

ABC laser facility is dedicated to the study of Inertial Confined Fusion (ICF) and is equipped with two beam lasers which can deliver up to 100 J in pulses few nanoseconds long with a wavelength of 1.054 μm . Interaction of laser with target happens in a high vacuum spherical tank. A test measurement with GEMpix was conducted during two experimental campaigns. In both cases, laser pulse had time duration of 3 ns and the experiments consisted in the interaction of a single laser beam with a thin plane target made of different materials. In the first one, a beryllium window 5 mm in diameter and 50 μm in thickness was mounted on a tank port, without any pinhole. This was a very preliminary measurement aimed to test the GEMpix on the X-ray coming from this type of plasmas. Fig. 4 shows the result obtained on a target of lithium 6 Fluoride (${}^6\text{LiF}$) having a thickness of 334 nm on a substrate of C28 of 127 μm . The acquired image is uniform, as expected, and the transverse size is equal to the Be window diameter.

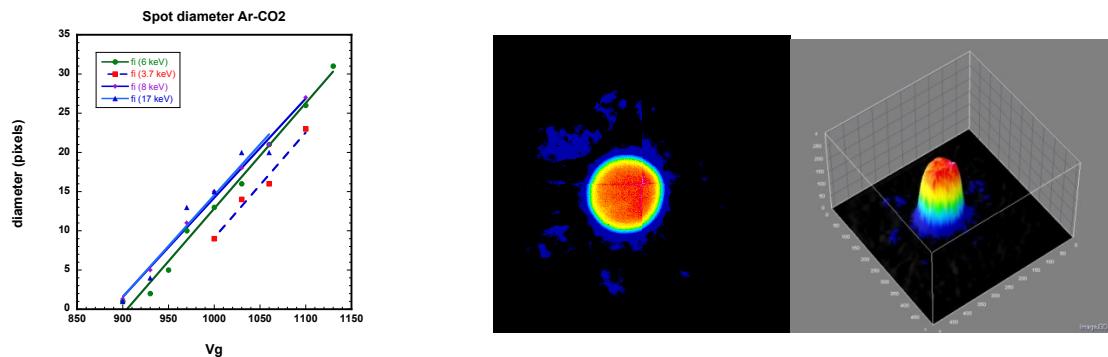


Figure 3: Blob mean diameter per incident photon from four different X-ray sources (Ca, Fe, Cu and Mo) when the gain voltage is varied from 900 to 1140 V for ArCO₂ (70/30) gas mixture.

Figure 4: X-ray spot coming from a beryllium window 5 mm in diameter and 50 μm in thickness when the ABC laser interacted with a ${}^6\text{LiF}$ target (334 μm) on a C28 substrate (127 μm). An ArCO₂ (70/30) gas mixture was used with a gain of about 440.

The result of this measurement has demonstrated that GEMpix can work well in ToT mode with high photon fluence and good uniformity is observed, taking into account that the spatial resolution is about 50 μm . In this case the GEM voltage was 900 V with a gain about 400. The following step was the addition of a pin-hole, inside the vacuum chamber, between the plasma and the window, giving a magnification of 1.5 in order to make an X-ray imaging of the

plasma plume coming from the target after laser interaction. The pin-hole was located almost at a right angle respect to the incident laser direction. Results are shown in fig. 5 in the case of an aluminum target (7 μm thick).

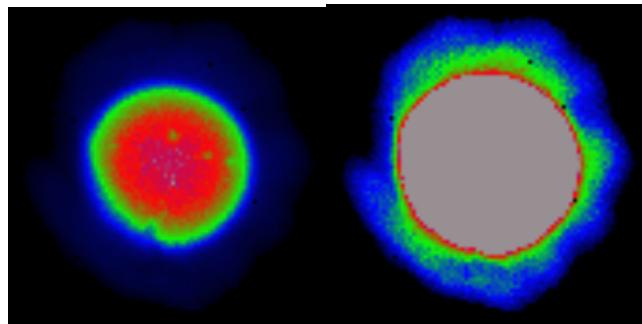


Figure 1: X-ray image of the plasma plume seen through a pinhole with 1.5 of magnitude when the ABC laser interacted with a Al target (7 μm). An ArCO₂ (70/30) gas mixture was used with a gain of about 440.

Image on the left gives information on the integrated charge due to all the incident photons. On the right, instead, intensity scale (colors) has been selected to saturate the core, but showing the presence of a corona around the plasma core. This corona exhibits clearly poloidal modulations, imaged with a spatial resolution of about 50 μm . On one side it is possible to observe a cut, which identifies the target.

Conclusions

GEMpix detector has been proposed as soft X-ray imaging detector for laser produced plasmas and the preliminary results obtained from ABC Frascati laser facility has been discussed and they appear promising. In fact the adjustable sensitivity of the detector allowed to obtain physical response without signal saturation, while electronic noise is practically absent. Imaging capabilities have been demonstrated, in a pinhole configuration, showing the shaping of the core emissions and the poloidal modulations of the corona, with good spatial resolution. Based on these results, suited configurations could be defined in order to assess the spectral distribution of the detected X-rays, thanks to the proportionality with the photon energy. Further calibrations and characterization will be done at the ultra-short laser facility Eclipse (Bordeaux) in July 2015.

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