

Operation of MHSP multipliers in high pressure noble-gas

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Abstract - We report on the performance of a Micro-Hole & Strip Plate (MHSP) electron multiplier operating in pure Xe, Kr, Ar and Ne at the pressure range of 1 to 6 bar and in Ar – Xe mixtures at pressures ranging from 1 to 7 bar. The maximal gains at 1 bar Xe and Kr are $5 \cdot 10^4$ and 105, respectively; they drop by about one order of magnitude at 2 bar and by almost another order of magnitude at 5-6 bar; they reach gains of 500 and 4000 at 5 bar in Xe and Kr, respectively. In Ar, the gain varies very little with pressure, from $3 \cdot 10^3$ to $9 \cdot 10^3$; in Ne the maximum attainable gain, about 105, is pressure independent above 2 bar. The results are compared with that of single- and triple-GEM multipliers operated in similar conditions. Potential applications are in hard X-ray imaging and in cryogenic radiation detectors. In the Ar - Xe mixture no significant reduction of the maximum achievable gain was measured. Absolute gains of $1\text{--}4 \cdot 10^3$ were reached in Ar/50 mbar Xe over this pressure range from 1 to 7 bar. Energy resolutions between 14% and 16% were reached for 6 keV X-rays.

I. INTRODUCTION

Gas electron multipliers operating in high pressure noble gases have been the subject of an intense study in the most recent years. These devices find applications on the fields of cryogenic detectors for neutrino physics, dark matter search and PET [1-4], gaseous photomultipliers [5] and X-ray and neutron imaging detectors [6,7].

The simple purification and low ageing under charge avalanche multiplication of the noble gases makes them suitable for the use on sealed gaseous detectors operating for long periods and with stable conditions. The major drawbacks on the use of pure noble gases at atmospheric pressure are related with photon and ion induced feedback that strongly limits the maximal gain achieved on this gases. The introduction of the Gas Electron Multiplier (GEM) and the confinement of the electron avalanches to the holes of the GEM allowed achieving higher gains on noble gases without the limitation placed by UV-photon feedback [8,9]. Detectors comprised of 3 cascaded GEM (triple-GEM) were developed for the operation at high pressures [9] aiming to increase the detection efficiency. However, a major drawback of these detectors is the fast decrease in the maximum gain achieved when increasing the pressure of the gas. Besides the limit on the maximum

applied voltage to the electrodes, common to other micropatterned detectors like MSGC and GEM, the decrease in the maximum gain in triple - GEM detectors is caused by other factors. The decrease in the charge extraction efficiency from each GEM and in the charge transfer efficiency from one GEM to the next with increasing pressure are causes of a decrease in the measured gain of the detector.

A specific drawback of detectors comprised by a cascade of GEM is the feedback caused by ions that, flowing from the last GEM to the previous, induce the emission of electrons from the electrodes of the GEM, therefore setting a limit to the maximum gain attainable [9].

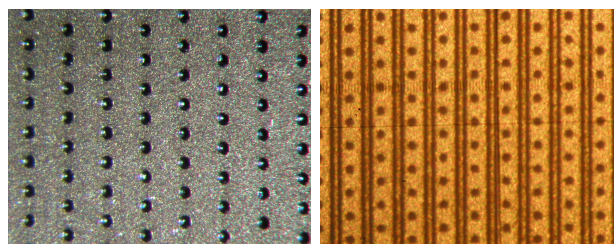


Fig. 1 – Micro photography of the top (left) and bottom (right) sides of the MHSP. On the bottom side the holes are centered with the cathode strips. The narrower anode strips run between the cathodes.

The recently introduced Micro Hole and Strip Plate (MHSP) [10] is presented as an alternative to the triple – GEM for the operation at high pressures. This micropatterned detector combines a GEM-like multiplication stage (holes) followed by a MSGC-like multiplying elements (strips) in one single structure, fig.1.

The MHSP presents 2 multiplication stages controlled by 2 independent voltage differences, between the Top electrode and the Cathode, V_{CT} , and between Cathode and Anode, V_{AC} . The normal operation mode of the MHSP, fig. 2, involves the focusing of the primary electrons in to the holes of the MHSP. These primary electrons are multiplied inside the holes and the charge produced is extracted and further multiplied between the cathode and anode strips, being collected on the latter ones. The 2 multiplication stages, separated by a distance of some microns, allow the MHSP to achieve high gains with a very efficient charge extraction and transfer between

multiplication stages. This features, combined with the good optical screening of avalanche photons and improved ion-blocking capability as compared to GEM [11], make the MSHP very suitable for the operation on high pressure noble gases.

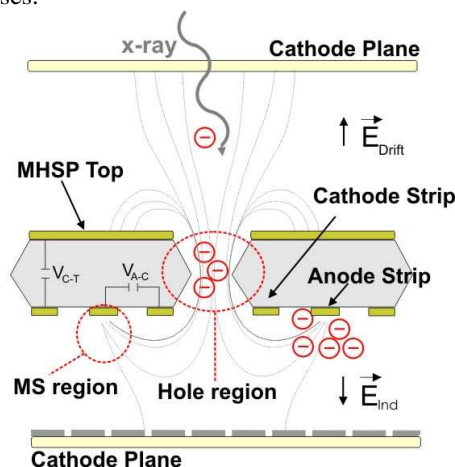


Fig. 2 – The primary electron produced on the drift region are focused in to the holes of the MHSP where they are multiplied. The resulting charge is extracted and further multiplied in the region close to the anode where the electrons are collected.

II. EXPERIMENTAL SET-UP

The detector used is composed of a stainless steel chamber, 10 cm in diameter. The radiation enters the detector by a 25 μm thickness aluminized Mylar window having 2 mm diameter. The MHSP was placed inside the body of detector and isolated from its walls by a MACOR holder. The voltages used to polarize the top, cathode and anode electrodes of the MHSP were supplied via metal feedthroughs isolated from the detector body by MACOR feedthroughs. The window and body of the detector were kept at ground potential. All the parts of the detector were glued with non conductive low pressure epoxy glue (Trac-Con 2116). The absorption/drift region and induction gap were, respectively, 5 and 3 mm wide. Prior to the filling of the detector it was pumped down to the pressure of 1×10^{-5} mbar. After the filling, the gas purity was maintained by non-evaporable getters SAES St707 heated at 150°C.

The MHSP, with an active area of $28 \times 28 \text{ mm}^2$ is made of a 50 μm Kapton foil, with 5 μm copper coating on both faces. The top surface of the MHSP, GEM like, is patterned with bi-conical holes of 40/70 μm diameter, placed in an asymmetrical hexagonal lattice of 140 and 200 μm pitch into the direction parallel and perpendicular to the strips placed on the bottom side. On this side the holes are centered within the cathodes, these ones, 100 μm wide, run between the anodes, 35 μm wide.

The signals from the anodes of the MHSP were fed through a Canberra 2006 preamplifier of 1.5 V/pC; for the measurements with Ne the sensitivity was reduced to 0.3 V/pC. The signals were further processed by a Tennelec TC243 amplifier (4 μs shaping time) and a Nucleus PCA2 1024 multichannel analyser. The electronic chain sensitivity was calibrated, for absolute gain determination, using a calibrated capacitor directly connected to the preamplifier input and to a precision pulse generator.

All the electrodes were independently polarized using CAEN N471A power supplies. The detector vessel, the radiation window and the induction backplane were connected to the ground. The voltage of the MHSP top electrode, V_{TOP} , determines the drift field; the voltage difference between this top electrode and the cathode strips, V_{CT} , determines the avalanche gain in the holes; the voltage difference between the anode and cathode strips, V_{AC} , determines the avalanche gain around the anode strips; and the voltages of the strips determine the induction field.

For the present studies, the detector was irradiated with 5.9 keV X-rays from a ^{55}Fe source with the 6.4 keV X-rays filtered by a chromium film.

III. HIGH PRESSURE PURE NOBLE GASES

For the measurements with the pure noble gases, Xe, Kr, Ar and Ne, the maximum voltages V_{CT} and V_{AC} were applied to the MHSP, in order to maximize the gain. Then, and prior to the onset of discharges, the voltage V_{AC} was reduced, while maintaining the V_{CT} voltage constant, in order to produce the gain curves presented on this paper. The 5.9 keV X-rays pulse height distributions were fitted to a Gaussian superimposed on a linear background and the peak centroid was monitored as function of V_{AC} and V_{CT} . For each gas, V_{TOP} was increased with pressure so that the reduced electric field in the drift region was only mildly decreased. Values in the range of 100-75 $\text{Vcm}^{-1}\text{bar}^{-1}$ were used for Xe, Kr and Ar fillings, and of 60-50 $\text{Vcm}^{-1}\text{bar}^{-1}$ for Ne fillings, respectively.

In Figure 3 a-d, we present the detector's total gain as function of the total voltage difference applied to the MHSP, $V_{Total} = V_{CT} + V_{AC}$, for pure Xe, Kr, Ar and Ne, respectively, and for the different gas pressures. The gain-curves exhibit the characteristic exponential avalanche growth, but at low V_{Total} values the pulse amplitudes drop faster than exponential, due to inefficient electron transport to the anode strips. The V_{CT} values used for each pressure, were increased with increasing pressure from 460 to 820V for Xe, from 430 to 740V for Kr and from 320 to 660V for Ar; for Ne we set values around 320V for all the pressures, except 260V set at 1 bar.

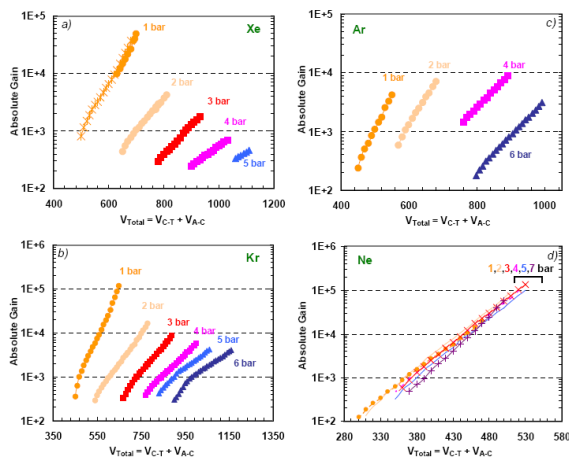


Fig. 3 – Absolute gain achieved with the MHSP in pure Xe, Ar, Kr and Ne as function of the total voltage.

Fig. 3 a,b, show an identical trend of the maximum gain dependence on pressure for pure Xe and Kr: a fast decrease of the maximum achievable gain from 1 to 2 bar and a slower decrease of this maximum for pressures above 2 bar. Nevertheless, the amplitude reduction with increasing pressure is much slower for Kr than for Xe. Gains about $5 \cdot 10^4$ and 10^5 were obtained at 1 bar for Xe and Kr, respectively, being reduced to $5 \cdot 10^3$ and $2 \cdot 10^4$ at 2 bar, and to 500 and $4 \cdot 10^3$ at 5 bar. On the other hand, the maximum gain obtained for Ar (Fig.3 c) presents only a small dependence on the pressure, increasing from $\sim 5 \cdot 10^3$ at 1 bar to a maximum of 10^4 at 4 bar and decreasing by a factor 3 at 6 bar. The maximum gain achieved in Ne is fairly constant for pressures above 1 bar, being $\sim 2 \cdot 10^4$ at 1 bar and $\sim 10^5$ for all the other gas pressures.

V. AR-XE MIXTURES

Throughout the measurements with Ar-Xe mixtures the drift field, determined by the MHSP upper electrode voltage, was kept at about 100 V/cm, and the anode to cathode voltage difference, V_{AC} , was kept at 250 V. In each set of measurements, the voltage difference across the holes, V_{CT} , was gradually increased. Both V_{CT} and V_{AC} were maintained below the onset of discharges.

At 1 bar, the best operating conditions, i.e. highest gains for relatively low applied voltages, were obtained with argon / 5% xenon mixtures [12]. Since the electron-impact cross-section is higher for Xe than for Ar, the Xe atoms play a more significant role in the charge avalanche processes. Thus, the increase of Ar content has a smaller effect on the mean-free-path for Xe ionisation, and a constant Xe partial-pressure content could, in principle, yield roughly the same maximum gains. In Fig. 4 we

depict the MHSP total gain as function of V_{CT} , for $V_{AC}=250V$, for Ar–Xe mixtures at pressures of 1–7 bar, with a constant 50 mbar Xe content. The maximum gain is almost constant up to filling pressures of 6 bar, varying between $2 \cdot 10^3$ and $4 \cdot 10^3$. Up to these pressures the increase in the V_{CT} voltage compensates the increasing energy loss in elastic collisions as the total pressure rises. However, for voltages above 500 V, the V_{CT} voltage cannot be increased since the electric strength of the microstructure is reaching its discharge limit. In consequence, the compensation can no longer be achieved and the gain drops above this pressure.

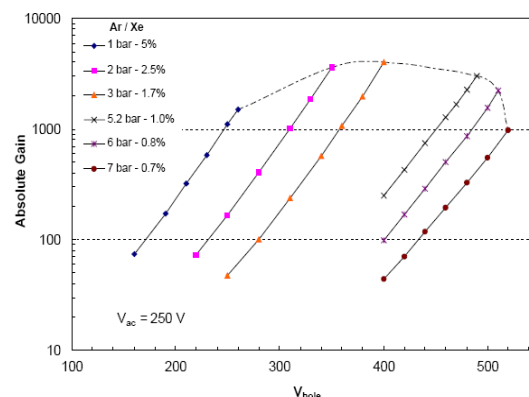


Fig. 4 – Absolute gain achieved with the MHSP in for mixture of Ar with 50 mbar of Xe at pressures from 1 to 7 bar.

V. CONCLUSIONS

In this work we presented the characteristics of a MHSP electron multiplier operated in Xe, Kr, Ar and Ne at pressures ranging from 1 to 6 bar. When compared with the operation of a triple-Gem detector for the same gases [9], this single-element multiplier has yielded higher gains. This could originate from the particular MHSP's geometry; the two amplification stages separated by only a few tens of microns, resulting in a more efficient electron transfer from stage to stage compared to that occurring in multi-GEM cascades [13].

The gas gain at 1 bar is about $5 \cdot 10^4$ for Xe, and higher than 10^5 for Kr. Xe and Kr show fast gain decay with pressure and the gains are reduced to about 500 and 4000, respectively, at 5 bar. For Ar, the gain variation with pressure is less marked; it varies between 3 and $9 \cdot 10^3$, with a maximum at 4 bar. In Ne, the maximum achievable gain increases from $2 \cdot 10^4$ at 1 bar to around 10^5 for pressures above 2 bar. At atmospheric pressure, the values reached with a MHSP are somewhat higher compared to a triple-GEM, except for Ar where the gains are lower by almost one order of magnitude [9]. For pressures above 4 bar the MHSP reaches about two orders of magnitude higher gains than the triple-GEM. In Ne, however, the gain

difference between the two multipliers is reduced with increasing pressure; it becomes similar above 5 bar. Compared to a single-GEM operated in pure Kr [14], the MHSP yields gains that are more than two orders of magnitude higher, at 1 bar; the MHSP's maximum gain decreases faster with increasing pressure, resulting in only one order of magnitude gain difference between the two at 6 bar.

The study of the operation of MHSP electron multiplier in argon–xenon mixtures, at pressures varying from 1 to 7 bar has proven that the MHSP can reach high gains on this mixtures. Gains between 2 and $4 \cdot 10^3$ were achieved in Ar/50 mbar Xe gas mixtures at pressures up to 6 bar. Above 6 bar, limitations on the maximum gain are imposed by the MHSP discharge limit. Nevertheless, gains are still above 10^3 at 7 bar. Energy resolutions of 14% FWHM were reached with 6 keV X-rays; they do not degrade significantly with increasing pressure.

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