A proposed new microstructure for gas radiation detectors: The microhole and strip plate

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A new type of microstructure device for a gas radiation detector is proposed. This microstructure, the microhole and strip plate structure, merges the structures of a gas electron multiplier and a microstrip plate in one single plate. This design allows two-multiplication stages and a separation of the sensitive and the detection regions, with full optical positive feedback suppression. Simulations for gas gain and electron transparency of the microstructure are presented. Different applications are discussed. © *2000 American Institute of Physics.* [S0034-6748(00)04606-2]

I. INTRODUCTION

After the introduction of the microstrip gas chamber (MSGC)[1] several gas detectors based on microstructure devices produced by photolithography processes have been developed. The different microstructured plates are produced by etching single or several layers deposited on a substrate. Recently, a new microstructure, the gas electron multiplier (GEM),[2] uses a thin polymer substrate covered on both sides by a metallic film with multiple micrometer size circular holes produced by etching across both metal film and polymer substrate.

While the microstructured plates are used as gas radiation detectors with electron multiplication with direct charge collection, the GEM structure is used as an electron multiplication stage and as an interface between different detector regions without direct charge collection.[3] The GEM is generally combined with a separated amplification/charge collection device, usually a microstrip plate (MSP).

The development of these microstructures resulted from the requirements of tracking systems for the next generation of high-luminosity colliders, but applications in such diverse fields as medicine,[4] high-energy physics,[5,6] x-ray astronomy,[7] energy-dispersive x-ray fluorescence analysis,[8] and photosensors[9,10] have been successfully implemented. A comparison of the characteristics of different micropatterns and of combinations of micropatterns, in cascade, is presented in Ref. 11. A recent review of the different microstructures and their applications can be found in Refs. 12 and 13.

In this work a new microstructure device, the microhole and strip plate (MHSP), which merges the MSP and the GEM characteristics in a single plate, is presented. Although involving similar physical processes as GEM and other microstructures like microstrip,[1] microgap,[14] CAT,[15] well,[16] and microgroove[17] plates and CsI MSP photosensor,[18] this microstructure presents two independent charge multiplication stages and optically detaches the charge multiplication and collection region from the electron drift region, characteristics that could not be met using only one of the above mentioned structures. Like other microstructures, its application can be important in areas such as high-energy physics and astrophysics.

The proposed microstructure is intrinsically simple and is based on printed circuit technologies. Its fabrication is being negotiated[19] for prototype development and testing. The description of this structure and an overall review of its potential applications will be described.

II. DESCRIPTION AND APPLICATIONS

This device can be fabricated using a polymer film metal coated on both sides. Using microlithographic-etching techniques, a microstrip structure is produced on one of the sides (the microstrip one), being the cathode strips perforated through the plate (Fig. 1). The holes can be made either slotted or circular. The other side is a metallic film with perforated holes made along the cathode strips, i.e., it is an unstructured grid. With a suitable difference of potential applied between the grid side and the cathode strips, electrons coming from the region above the grid side (the drift region) will be focused toward the holes crossing the MHSP. The electric field inside the holes can be high enough to allow charge multiplication. With a suitable difference of potential applied between the cathode and anode strips, the electrons emerging from the holes are deflected toward the microstrip anodes where a second multiplication occurs. Where position information is needed the grid electrode of the MHSP can be structured to have the second position coordinate, as depicted in Fig. 2. In this application circular holes are preferably used.

A possible application of the MHSP as an x-ray detector is depicted in Fig. 3. The x ray interacts in the sensitive volume, between the radiation window and the MHSP grid plane. The resulting primary electron cloud drifts toward the MHSP structure suffering charge multiplication both in the hole region and in the microstrip region. Two multiplication stages are thus available and a high gain is achieved. This allows reducing the MHSP microstrip voltage to values safely below sparking thresholds as in the case of the GEM with separated MSGC device.[11,13]

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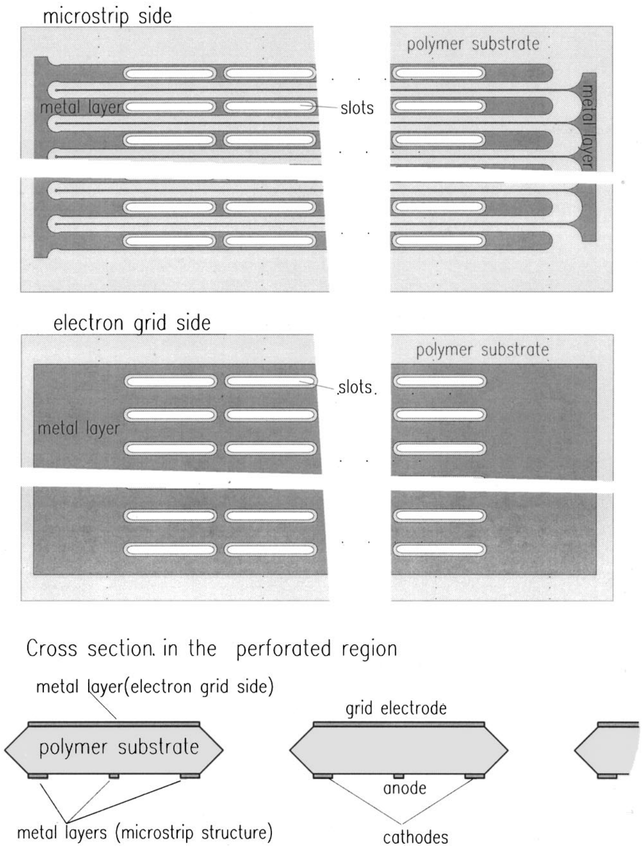

FIG. 1. Schematics of the new MHSP microstructure proposed in this work with slotted holes.

Another possible application, depicted in Fig. 4, results from the capability of having the MHSP operating as an ultraviolet (UV) photosensor with full optical positive feedback suppression. This optical feedback is usually mediated through the photons emitted in the electron multiplication processes. Two different operation modes are presented which use a reflective or a semitransparent photocathode. For the UV photosensor operating in the reflective mode a photocathode material, like CsI, is evaporated onto the MHSP grid electrode.[20] The electric field in the photocathode surface should be such as to allow the extraction of the produced photoelectrons as well as its drifting toward the hole region. For this design [Fig. 4(a)] the use of the two multiplication stages is possible since neither of them is seen by the photocathode. However, for the semitransparent photocathode design [Fig. 4(b)] the full feedback suppression can only be obtained without the first multiplication stage since otherwise the photocathode would see the photons emitted in this stage.

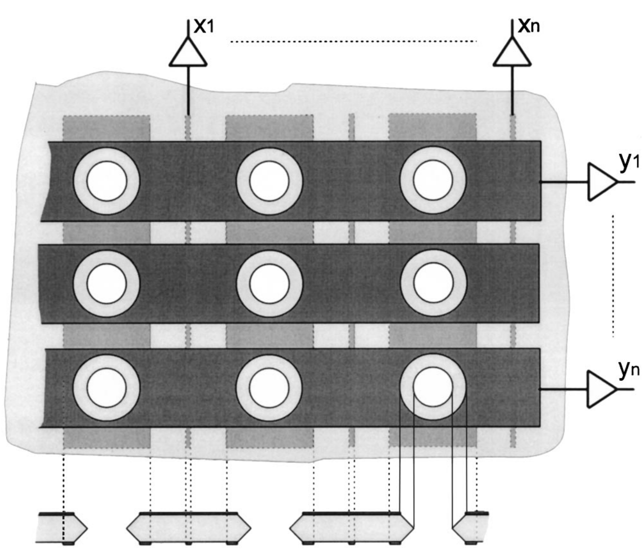

FIG. 2. Schematics of a MHSP as in Fig. 1 but with circular holes, structured for 2D position sensitive applications.

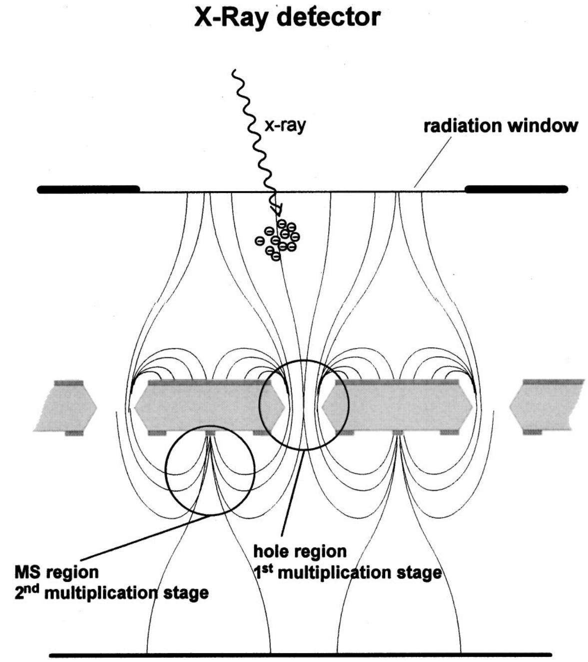

FIG. 3. Proposed x-ray gas detector using the MHSP.

The operation of the photosensor in the reflective mode can be used as a windowless photosensor, integrated directly in the scintillation gas. The development of integrated photosensors without optical positive feedback is very important for applications such as fast RICH detectors[2] and gas proportional scintillation counters.[18]

III. SIMULATION

To evaluate the electron transmission and gain of the MHSP working under different conditions a two-dimensional (2D) electric field simulator[21] was used. The electric field lines and the gas gain G_A achieved by the electrons drifting along these lines were calculated with a special software program (FLO2)[22] by numerical integration of the expression

$$\ln G_A = \int_{s_0}^{s_a} \alpha(E)\,ds,$$

where $\alpha(E)$ is the first Townsend coefficient for the filling gas which depends on the electric field intensity E and the curvilinear integral is calculated along the electric field line coordinate s from the starting electron position s_0 until ending in the microstrip anode s_a. This program uses E_x and E_y, the electric field components given by the 2D field simu-

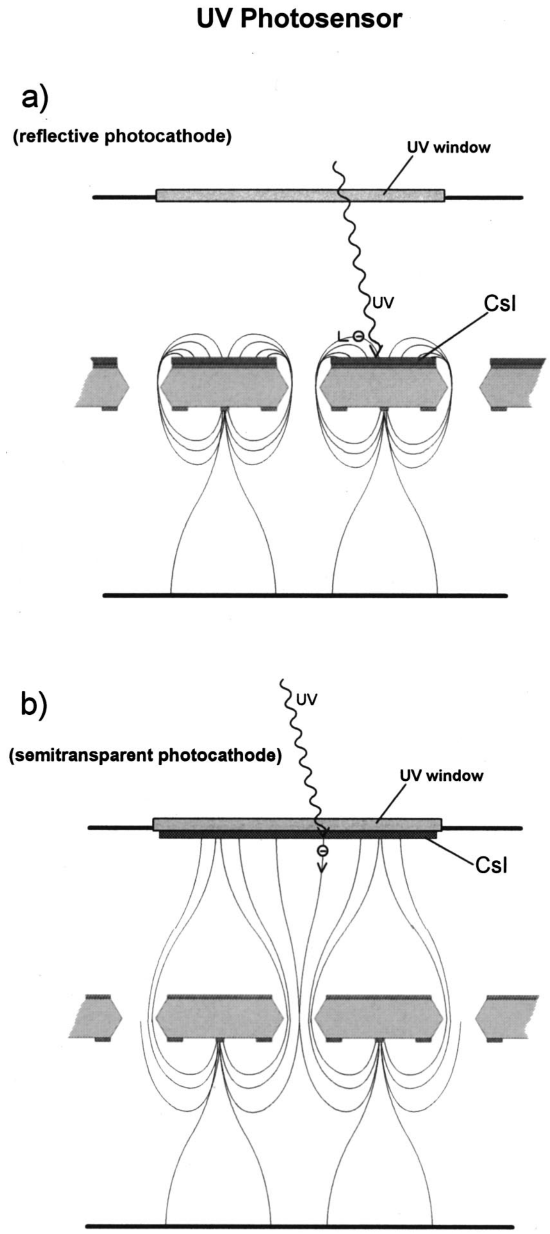

FIG. 4. Proposed UV photosensors using the MHSP in two different operation modes: (a) with reflective and (b) with semitransparent photocathode.

lator. Due to the 2D nature of the program only the slotted holes version of the MHSP was simulated.

For the simulation model the considered dimensions of the MHSP were chosen, taking into account the technical characteristics of a standard flexible printed circuit:[19] a 50 μm Kapton film with 5 μm thick copper layers on both sides, a 320 μm pitch, 40 μm wide anode, 150 μm wide cathode with slots with a wedge cross section 110 μm wide in the top and 80 μm wide in the neck (Fig. 1). Electric field intensities of 0.8 and 2 kV/cm were considered for the drift regions above and below the MHSP, respectively. The gas assumed to fill the chamber was pure xenon at atmospheric pressure and the data for $\alpha(E)$ was taken from Ref. 23. A set of 30 electrons uniformly distributed starting at 240 μm above the MHSP grid plane and 20 starting at a position 1 μm above the MHSP grid plane were followed in their path until they were collected (Fig. 5).

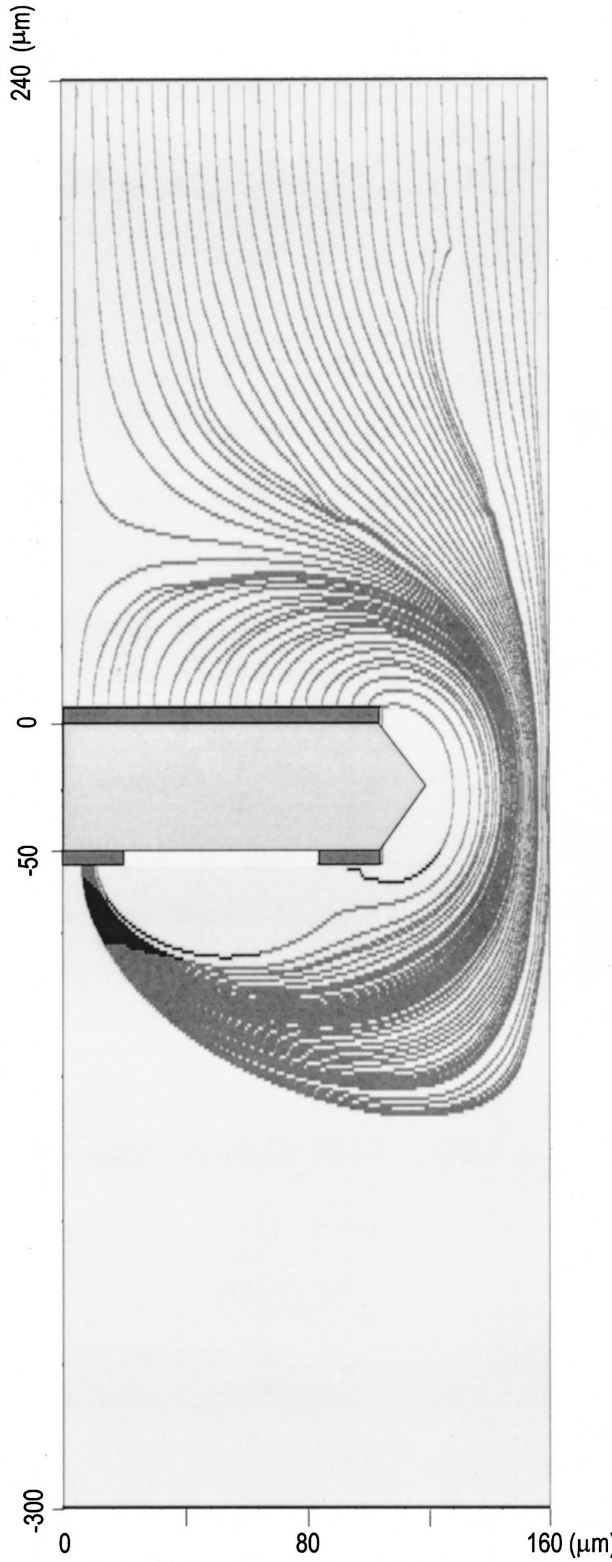

FIG. 5. Calculated electron paths for the MHSP for $V_g = -350$ V, $V_a = 500$ V, and for electric field intensities of 0.8 and 2 kV/cm for the regions above and below the MHSP, respectively.

In Fig. 6 we present the calculated results for the absolute gain G_A and anode electron collection efficiency ϵ_{ec} (number of starting electrons/number of single electron avalanches collected in the microstrip anode) as a function of

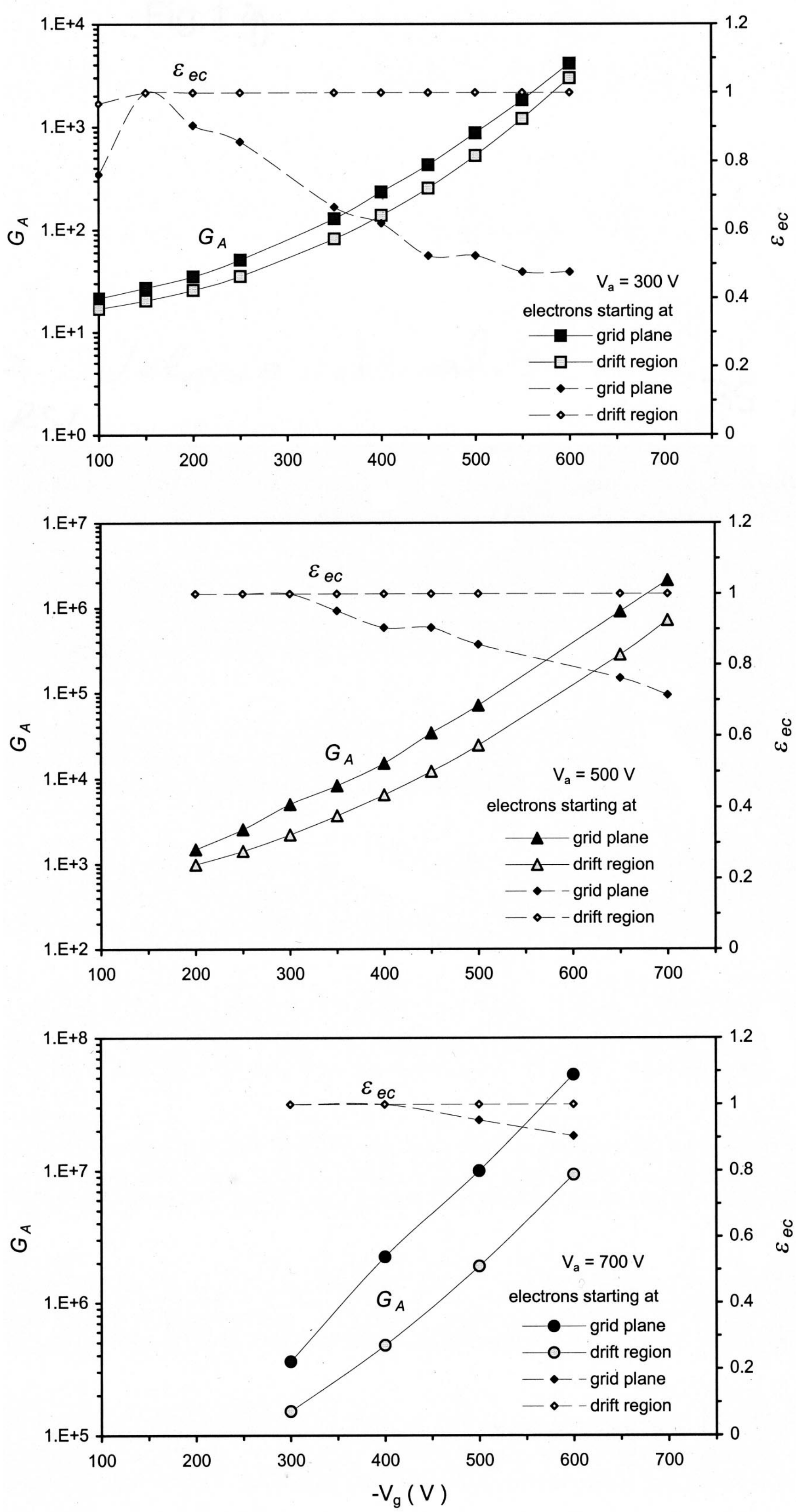

FIG. 6. Calculated results for the absolute gain G_A and anode electron collection efficiency ϵ_{ec} as a function of the difference of potential between the slotted grid and the cathode electrodes V_g and for anode to cathode voltage differences V_a of 300, 500, and 700 V, assuming electrons start either in the drift region or else 1 μm above the grid plane.

the difference of potential between the grid and cathode electrodes V_g, and for anode to cathode voltages V_a of 300, 500, and 700 V. In Fig. 7 the gain and the anode electron collection efficiency are calculated as a function of V_a for $V_g = -350$ V. Results for both electrons starting at the drift region and electrons starting close to the grid electrode surface are presented in Figs. 6 and 7.

The calculated results show the potential of a MHSP operating in the proposed modes, as an x-ray detector and as an UV photosensor. For x-ray detector operation mode the

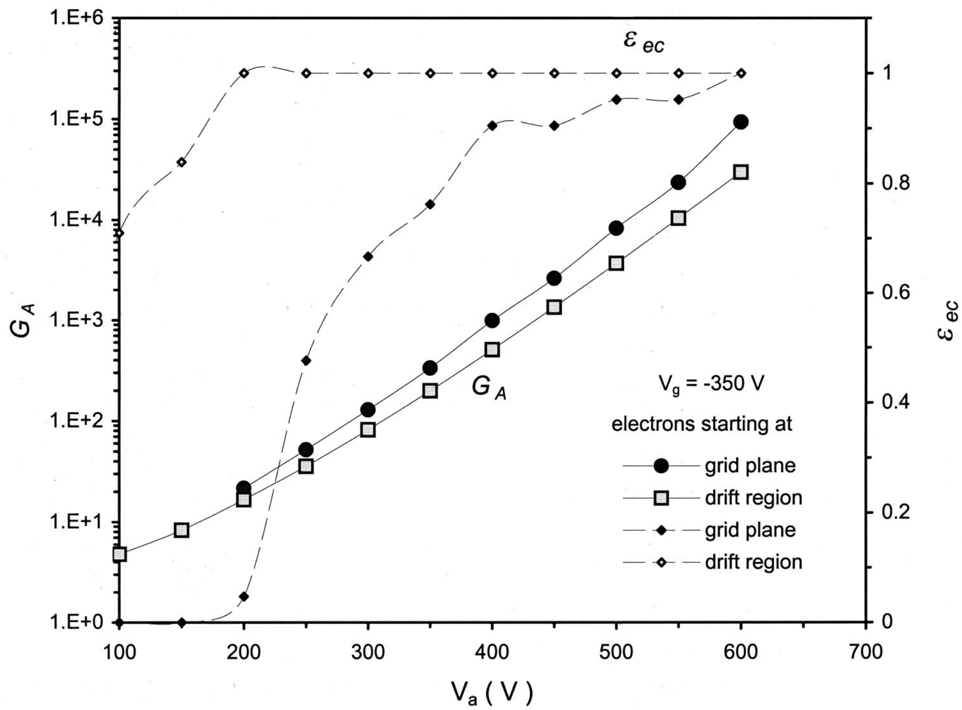

FIG. 7. Calculated results for the absolute gain G_A and anode electron collection efficiency ϵ_{ec} as a function of the anode to cathode voltage differences V_a and for a difference of potential between the slotted grid and the cathode electrodes V_g of -350 V, assuming electrons start either in the drift region or else 1 μm above the grid plane.

anode collection efficiency reaches 100% for the studied V_a and V_g voltages. As shown in Figs. 6 and 7, for voltages typically used in other microstructures (GEMs and MSPs) gains above 10^4 can be easily reached. For the reflective UV photosensor mode, anode collection efficiencies approaching 100% are possible with gains above 10^4. Higher gains should be achievable using thinner anode strips and narrower holes provided the manufacturing technology is available.

The calculated gain for electrons starting at the grid plane is higher when compared to the gain obtained for electrons starting in the drift region, since in the latter case electrons drift under weaker electric fields.

As the distance between electrodes is about 100 μm the clearing time of electrons and ions is about 1 μs. Count rate capabilities above $10^5\ \mathrm{Hz\,mm^{-2}}$ have been demonstrated for the GEM+MSP combination.[3,24]

IV. DISCUSSION

A new type of microstructure for gaseous detectors, based on advanced printed circuit board technology, was presented. Operating simulations show that gains above 10^4 with charge collection efficiencies approaching 100% are possible.

Along with the simulations described in this work, the extensive experimental results obtained with the previous microstructures[12–17] denote the functional capabilities of this microstructure. The implementation of such structure and the experimental study of its performance for the different applications are demanding. Extensive experimental tests are planned.

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