Universal Journal of Physics and Application 2(7): 321-324, 2014 http://www.hrpub.org
DOI: 10.13189/ujpa.2014.020701

Metal Gas Electron Multiplier

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Abstract This paper presents a modification of the metal gas electron multiplier (MGEM), free from one of the main drawback of this type of detectors namely the surface dielectric breakdown in the gap between the metal electrodes with holes. The high gas gain (104-105) with simple gas mixture or air offers the measurement for traces of alpha particles or high energy x-ray photon. It factor is very attractive for using of MGEM as background monitor of alpha particles or therapeutic beam counter.

Keywords Gaseous Detectors, Micropattern Gaseous Detectors (GEM, TGEM, RETGEM, WGEM, MGEM)

1. Introduction

Widely using of gas electron multiplier (GEM) in nuclear physics and many applications are due to a several number of attractive features such as high spatial and time resolution, the ability to work in a more intense beams compared with wire devices [1,2]. It should be also note the possibility of mass industrial production for GEM or MGEM based on the last achievements in the micro electronics. The principle of avalanche electron multiplication is the basis for work of GEM in holes of small diameter of (0.3-1.0) mm. in space between two flat metal hole electrodes divided by a dielectric layer by thickness (0.1-1.0) mm.

When given a high voltage the electric field with value of (104-105) V/cm it is performed a necessary condition of avalanche electron gain in the gas with factor about 103 without formation of the sparks. Further increase of voltage on electrodes of GEM leads, as a rule, to emergence of micro discharge processes along a surface of a dielectric layer.

Results with TGEM

In our laboratory the first experiments on research of characteristics of GEM was carried out by means of development and to test of a so-called thick decision (TGEM) [3-5]. This decision was accepted with that this design could be reproduced in usual conditions with expenses of not big efforts in the machine equipment, fig1:

The model sample represented a composition from drift gap, a two-side metalized plate from 1.6 mm fiberglass and a signal induction gap,fig.2:

The sensitive area consisted of the 1 mm holes located in chessboard order with a 1.5 mm step. The area of 15×15 mm^2 was under radiation of alpha source. After drilling of holes by machine way the plate is exposed to polishing and check on breakdown in the air environment, fig3:

Primary electrons which have been given rise by an alpha source over top electrode of TGEM drift to the holes under the influence of a focusing field. Giving potential difference between top and bottom TGEM electrodes the Townsend avalanche was occurred. The amplification factor had a value order 10^3 in simple Ar+20%CO_2 gas mixture. In this case can to say that every hole worked as independent proportional counter,fig.4:

The main advantage of such device is absent of influence of volume positive charge and photon feedback on gas avalanche process in the neighbor holes as it has place in the wire detectors.

Experience with RETGEM

Due to the high degree of granulation of cells that are sensitive to ionizing radiation, the spatial resolution of detectors type GEM or TGEM reach values not exceeding several tens of microns. At the same time the fine structure of the above mention devices has little protection from the spark breakdown. Streamers and sparks are almost inevitable when working with a high coefficient of the electron multiplication for long periods of operating time ,thus accumulating the static charge on the details of detector construction. It follows therefore that the question of choice of the electrode material for such devices is of fundamental importance.

Studies have shown[6,7] that the resistive electrodes made from fiberglass, glass, teflon, kapton, and others materials with high ohmic resistance in the range from 10^{12} to 10^{15} Ω provide reliable protection of the detectors and the input electronics. However, the loading capacity of the position sensitive detectors with high –resistive electrodes is very limited and it often does not satisfy the conditions of the experiment.

From this fact the authors of the paper [8] applied the method of deposition of the resistive layer of chromium oxide with a surface resistance of (0.3 -10) GΩ on the substrate made of kapton. Test of this type of Resistive

Electrode Thick GEM (RETGEM) have shown that random discharges occurring at high gas gain had the view of streamers rather than sparks without causing a distort on the inner surface of electrodes and the input electronics [9,10].

Analysis of the causes of accidental discharges and breakdowns in the detector showed that the main source is the residual dust and shaving after drilling of holes in material of electrode. In order to avoid such problems special techniques have been developed. It is noted that the performance of this element in mass production conditions may be a strong limited factor.

The aim of our task was to create and test characteristics of the prototype of RETGEM with electrodes making from polyvinylchloride plastic (PVC) [11]. This material is widely used in the manufacturing of gas discharge detectors such as streamer tubes due to relatively low cost, the possibility of using the extrusion process and the absence dust during machining. The resistive coating in our case was performed in a usual way applying the graphite paint GRAPHIT 33. The surface resistance varied in the range 50kΩ-1 MΩ depending on the max flux of particles [11].As the discharge current in our RETGEM did not exceed the value of 15 μA, the cases of distortion of acquisition electronics and the inner surface of the detector were not seen.

The standard PVC of 1 mm. thickness was used. This material is widely used in the mass production of the streamer tubes. The surface resistivity of this material may vary (50-1000) kΩ by means of graphite coating paint of 5-10 μm thickness providing a full spark protection. The holes were drilled by machine as it was made as for the case with TGEM in workshop without any metallization and etching of the area around holes. The holes were made with 1 mm in diameter and a step of 2 mm.

The operation principle of this detector was the same as for the case of TGEM. When a HV is applied to the graphite electrodes the electrostatic field is formed in the holes as in the case of TGEM with metallic electrodes.

Most of the tests were performed by using Ar+20% CO_2 or Ar+20% CH_4 gas mixtures under pressure of 760 Torr. The gas ionization was produced either by α-source Ra^{226} with energy 4.7 Mev or β-source with energy 67 keV. The signal was measured by oscilloscope without any amplifier, fig.5:

The amplitude of the signal for the case of the α-source with intensity I=I04 1/sec is not large. It can be explained by reaching of the Rather limit [12]:

$$N_o \cdot A \geq 10^8 \quad (1)$$

where

N_0 number of initial electrons,

A-amplification factor

Under these conditions limited proportional mode or streamer mode are occurred. The measurements showed that current of the RETGEM was not more (15-20) μA. Thus ,the sparks current was eliminated in this device.

In case of β-source the gain as a function of difference voltage applied to the RETGEM electrodes close 10^5 (it corresponds to the amplitude of the signal of about 10 mV) was achieved, fig.6:

It is interesting to note, that there was a kind of saturation in the amplitude of signal with the value of the gain about 10^6 without breakdown.

It was observed that s a single –layer RETGEM with electrodes made of PVC was fully spark-protected. The achieved gain is sufficient for many applications that require safe and high rate operation. Also the RETGEM is a very robust device. It does not require special cleanliness of inner surfaces and can to work with poorly quenching gases.

From the point of view of wide of PVC in mass production of the streamer tubes the proposed RETGEM also has good perspectives for being very useful in many applications such as RICH, TPC detectors, neutron position-sensitive detectors,etc. [13].

Wire GEM detector

GEM detectors have good position resolution on x-,y-,coordinates and may provide high resolution on z-coordinate also owing to extraction of electron components of avalanches[13].The other advantage of GEM is a high suppression of secondary avalanche production on electrodes of a chamber by photons from avalanches in GEM holes. For example, for Penning mixture the secondary avalanches are produced after primary avalanches. The primary avalanches are produced by ionization electrons from detected event and the secondary avalanches are produced by photons from primary avalanches on component of gas mixture with low ionization potential [14].Tails of secondary avalanches have continuous character and exceed considerably the primary avalanches in duration so they can be removed easily by differentiation.

Considerable shortcoming of GEM with plastic electrodes is the static charges accumulation on the walls of GEM holes leading to instability of GEM operation.

The wire GEM design is realized on electron multiplication between square holes in two meshes operated as electrodes of GEM. Because there is not plastic material between GEM electrodes the accidental discharges do not damage GEM electrodes and static charge is not accumulated on surface of electrodes. WGEM electrodes were winded with Be bronze wires diameter of 0.1 mm [15].The gap between electrodes is equal to 1 mm. The holes in such meshes have dimensions 0.5×0.5 mm^2. The WGEM sensitive area is equal to 2 cm. in diameter,fig.7:

The signal from anode of induction gap are fed to oscilloscope DS-1080C. The chamber was filled with Ar+20%CO_2 mixture under atmospheric pressure. The drift gap was irradiated by α-particles having energy 4.869MeV (Ra^{226}), fig.8:

The gain factor as a function of H.V.is increased in range 2.3-3.0 kV up to 5×10^4 and thereafter become saturated .The saturation effect is caused by appearance of streamer discharges in holes of WGEM because α particles produces in one channel or hole $Q_e=3\times10^3$ of ionization electrons and it have the effect of Raether with threshold for which the streamers are appeared .The streamers restrict the operating voltage of WGEM but does damage it. The operation of WGEM is restored completely after the H.V.is decreased below threshold for streamer appearance, fig.9:

The WGEM can be used in experimental physic , medicine, and many other fields of applications.

As the alternative decision authors of paper [15] developed and tested a design of the metal gas electron multiplier or MGEM without dielectric layers. In this case the phase of going of current on a dielectric surface is absent. Avalanche multiplication of electrons and the flow of electric current is only in the volume of the holes along electric field lines.

Test runs have shown that in the detector of this type is possible to have the gas gain order 10^4 and higher with the gas mixture of conventional type, for example, Ar +20%CO_2 .without sparks and charge leakage along the inner surface of holes.

Hole metal electrodes was performed by the method of laying of wires in the staggered groups consist from 10 pieces with 1mm steps.

In order to adapt the technology of manufacturing of these type detectors to the capabilities of modern electronics and to optimize the electric field inside holes this paper proposes the new solution or MGEM performed from two metal copper electrodes with a thickness of 50 μm. The perforation in form of circular holes is showed in fig.10

Sensitive area is equaled to 700 mm^2.The diameter of holes consists a value of 0.7 mm. Staggered disposition of the holes are performed with step of 1mm.

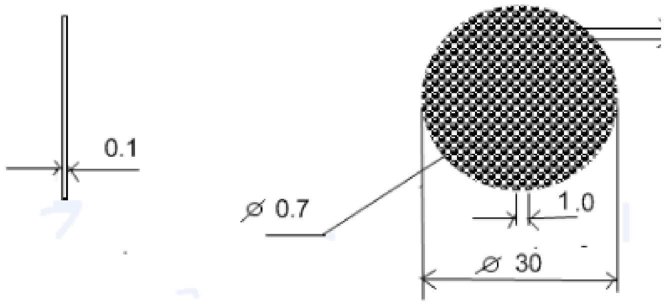
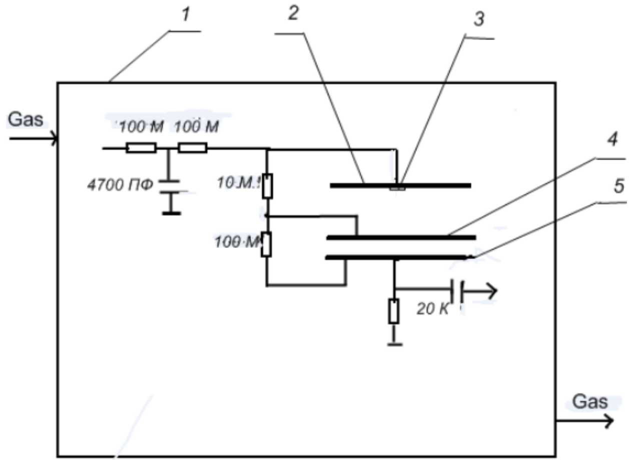


Figure 10. Metal Electrode with Perforation from Circuit Holes

2. New Design of MGEM

The arrangement of the elements of the new MGEM is showed in fig11.

Open or close body 1 is purged by gas mixtures. The drift electrode 2 is situated over cathode electrode 4 by a distance of 3 mm. The source of alpha particles 3 Ra226 with intensity 104 1/sec and energy 4.8 MeV is located over cathode electrode. Negative high voltage is supplied to the electrodes after T-shaped filter. The gap between of cathode 4 and anode 5 is adjusted via spacer located in the outer isolate part of electrodes. Value of the gap can be changed within interval of (0.2-1.5) mm. In this solution the gap between metal electrodes consists of value 1±0.02 mm. The accuracy of the axial alignment of holes was not worse than 0.005 mm. The absence of dielectric substrate on metal electrodes 4 and 5 of this structure in comparison with the design of GEM is the main property. The new design of MGEM eliminates the flow of discharge current on the inner dielectric surface .As a result the formation of domains with different values of electrification is not occurred. Given this fact the probability of spark discharge is significantly reduced allowing reach a large gas gain (104 and more) during registration of minimum ionizing particles.



1-body
2-drift electrode
3-alpha particle source
4-cathode electrode
5-anode electrod

Figure 11. Layout of new MGEM electrodes

3. Discussions

Fig.12 shows the waveform of signal obtained from anode electrode of MGEM. A volume of detector is purged gas mixture Ar+ 10%CH4+1.5 % SF6.Anode signal was taken through the high voltage capacitor with C=2200nF on load R=20 k. Cathode signal fed to high impedance input of the oscilloscope. Point of view the results of measurement of the drift velocity in gas mixture like type it can be taken in this case as Vdrift=5 cm/μs or 20ns/mm. It means that with gap between electrodes equal 1mm. the front end of negative anode pulse in dependence of the electron drift should not exceed of 20 ns. The shape of the anode pulse is same as the pulse shape, produced in ionization pulse chamber. The back front of pulse is defined by positive ion drift .It has a duration of more than 1000 times in accordance with the relation electron and ion masses. At results it has duty within a few tens of microseconds. The same consideration is related to form of positive cathode pulse. The front end is determined by the arrival time of the first positive ions on the cathode and the back end depends from t=RC of the cathode outer circuit.

Evaluation of the gas gain and pulse amplitude can be make from the next initial data: intensity alpha source Ra226 is not more than 104 p/s; gap or drift length consists of 1mm;

capacity of MGEM is evaluated as capacity of plane capacitor with an area of 700 mm2.

Under these assumptions the gas amplification factor had a value about 104-105.The amplitude of the signal from anode is measured in the range (3-30) mV.

Note the sparks or other cases of micro discharges inside holes and surface of electrodes were not marked in the long time of testing of MGEM.

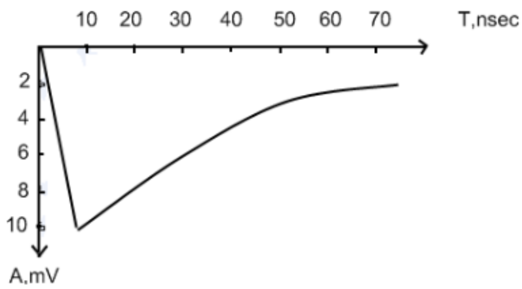


Figure 12. Waveform of Anode Pulse

4. Conclusions

Design of metallic gas multiplier, presented in this paper, eliminates surface micro discharges during flow of positive ions current from compare to GEM with dielectric substrate. In MGEM the flow of discharge current is occurred along the lines of the hole electrostatic field without formation of local regions which are responded for streamer or spark discharges.

Tests of MGEM have showed their greater reliability and sensitive to traces of radioactivity compared to devices of the same type. This design of MGEM can be recommended for mass production in modern conditions of the rapid development of micro electronics.

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