Ways of development of the MPGD techniques

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Abstract

The results and prospects of research work in the field of MPGD carried out within the framework of the RD-51 CERN group from the INR RAS are proposed for discussion. The aim of the work is to significantly increase the hardness and temporal stability of modern detecting devices to electrical breakdowns arising in gas-discharge gaps. Until now, this circumstance has existed as the main limiting factor in the mass production of MPGD.

Outline

- **Thesis 1.** Interpretation of the electric field strength in the region of limited proportionality of a gas discharge.
- **Thesis 2.** The calculation of the magnitude of the electric field in the region of the anode wire in multiwire proportional chambers designed by G. Charpak.
- **Thesis 3.** Parameters of current characteristics in various modes of a gas discharge.
- **Thesis 4.** Brief information about the corona mode of a gas discharge.
- **Thesis 5.** A few words about the streamer mode of a gas discharge.
- **Thesis 6.** On the effect of dielectric material on breakdowns in MPGD design.
- **Thesis 7.** Brief conclusions from the experience of testing the characteristics of thick gas electron multipliers.
- **Thesis 8.** Ways to improve the performance of MPGD. Conclusion.

Thesis 1. Interpretation of the electric field strength in the region of the limited proportionality of a gas discharge

To understand the essence of the problem, we turn to the well-known formula:

$$2^{20} \approx 10^{6} \qquad (1)$$

From mathematical identity (1) it follows that the Townsend coefficient of avalanche electron multiplication in gases A1, equal to 10^6 in the region of limited proportionality in gas-discharge detectors of various types, can be achieved after the electrons have passed 20 mean free paths with s = 1 µm at a voltage of 30 eV due to inelastic collisions of the first kind.

In terms of conventional designations, the electric field strength is as E1 = 30 V/µm = 30 kV/mm = 300 kV/cm.

Thesis 2. The calculation of the magnitude of the electric field in the region of the anode wire in multiwire proportional chambers designed by G. Charpak

$$E_{max} = \frac{V_{max}}{\frac{d}{2}\left[\pi \frac{l}{s} - \ln\left(\frac{\pi d}{s}\right)\right]} \qquad (2)$$

From formula (2) it follows, that : at **d = 20 μm, l = 3 mm, s = 2 mm, Vmax = 2.4 kV** for the gas mixture **Ar + 20% CO_2**

E_{max} = 2.94 × 10^5 V / cm = 29.4 kV / mm = 294 kV / cm,

that practically coincides with the value **E1** shown in **thesis 1** and gives reason to consider the value **A1 = 10^6**, which is typical for the mode of limited proportionality in a gas discharge for the any gaseous detectors.

Thesis 3. Parameters of current characteristics in various modes of a gas discharge

Electrical phenomena in vacuum and in gases are accompanied by the passage of a discharge current, the magnitude of which is determined by the design of the detector and the operating voltage applied to its electrodes. In Table 1 is showed the types or modes of the discharge and the ranges of variation of the current value corresponding to this mode of discharge:

Table 1

Discharge Type	Discharge Current
1. The ionization mode	pA ----- nA
2. Proportional mode	nA ----- µA
3. The limited proportional mode	µA ----- mA
4. Corona mode	0.1 mA ----- 10 mA
5. Streamer mode	0.1 mA ----- 10 mA
6. Spark mode	100 mA ----- 10 A

These data are obtained from the methodology for training of multiwire proportional gas chambers of various types in air, carried out at the INR RAS, at normal atmospheric pressure and room temperature.

It should be noted that the measurement limits of the discharge current in the corona and streamer modes are almost the same, which may indicate to the independent nature of their origin.

Thesis 4. Brief information about the corona mode of a gas discharge

The corona mode of an independent gas discharge, as one of the precursors of breakdown phenomena, when the voltage between the electrodes of the gas detector is increased. It is the characteristic of structures with a small radius of curvature electrodes.

According to the Peak formula (3), which he empirically derived, it is possible to determine the initial or critical value of the electric field strength at which a corona discharge begins in the air under ordinary conditions in devices with a flat geometry of electrodes:

$$E_{crit} = 3.1 \cdot 10^4 \cdot \delta \left[1 + \frac{0.308}{\sqrt{\delta \cdot r_0}} \right] \qquad (3)$$

where r_0 - radius of the corona electrode,

δ - air density referred to air density at P = 760 mm Hg and t = 0^0 C.

Table 2

r_0, μm	2	5	10	25	50	100	200	400	500	700	800
E_{crit}, kV/cm	798	420	300	182	128	115	89	70	66	60	58

Table 2 shows the results of calculations of the critical electric field strength by the formula (3) depending on the radius of curvature of the corona electrode.

It is important to note that:

a) the calculation results do not depend on the distance between the electrodes;

b) when **r_0 = 2 μm, 5 μm, 10 μm**, the value of **E_{crit}** greater than or equal to E1 = 300 kV/cm, given in **thesis 1**. ***This means that an independent corona discharge can occur before a limited proportional discharge appears in a gas detector of any design.***

Thesis 5. A few words about the streamer mode of a gas discharge

Another initiator of breakdown phenomena in gas detectors can be an independent streamer mode of a gas discharge. It occurs as a result of the electrostatic interaction between a positive charge moving from the anode electrode and a negative charge induced on the cathode electrode, which is in full compliance with the breakdown condition **(4)**, deduced by Rather:

$$A_{total} = n_0 \cdot A \geq 10^8 , \qquad (4)$$

where:

n_0 - the number of electrons of primary ionization,

A - the value of the coefficient of the Townsend avalanche electron multiplication.

The process of propagation of an ionization wave from such an interaction inside a gas volume has a duration of the order of several nanoseconds. After it passes through a gas detector, a luminous column or cord is observed due to photons with an energy of the order of 1.5 eV, which arise as a result of the recombination of positive and negative ions.

The probability of a streamer mode of a gas discharge transforming into a spark breakdown can be significantly reduced by using a gas mixture with electronegative additives and circular resistive electrodes with a diameter of 50 ÷ 80 μm and

$\rho = 10^5\ \Omega$ / cm.

Thesis 6. On the effect of dielectric material on breakdowns in MPGD design

Dielectric materials or spacer substrates often serve as insulators between electrodes in MPGD designs. However, during prolonged flow of discharge current and leakage current, they undergo heating, which leads to a significant change in their structure,
as well as the formation of induction zones or domains.

Such formations can be sources of explosive ionization, which worsen the insulating properties of the insulator with the transition to a spark breakdown.

This process has been little studied in comparison with the action of the corona or streamer modes, but it is also a source of negative effects on MPGD during long-term operation of devices in conditions of high beam loads.

Thesis 7. Brief conclusions from the experience of testing the characteristics of thick gas electron multipliers

The INR RAS has accumulated significant experience in the design and testing of thick gas multipliers. Some of the results of this research work in the form of TGEM, RETGEM, wire TGEM designs were shown at previous meetings of the RD-51 collaboration. At present, it is possible to draw brief conclusions from the experience of testing the characteristics of TGEM manufactured at the INR RAS:

1. In a single-stage TGEM design with fiberglass electrodes with holes made by mechanical drilling, it is not possible to obtain an electron multiplication coefficient above $A \leq 10^2$ due to the corona discharge over the surface of the hole.
2. The electron multiplication coefficient **$A \leq 10^4$** is achieved in a single-stage TGEM design with round wire electrodes having a radius $R \geq 20$ µm without the use of dielectric spacers.
3. In the RETGEM design with strips of conductive paint with $\rho = 2$ kΩ / cm applied to a polyvinyl chloride base, coefficient **$A \leq 10^4$** was achieved. The limitation of the electron multiplication process was also associated with the development of streamers.

Metal MPGD

4. A similar result with an electron multiplication coefficient **A ≤ 10^4** was obtained in a single-stage TGEM design with 50 µm thick beryllium bronze grid electrodes (Fig. 1, fig.2, fig.3) without a dielectric spacer. The nets were made by chemical etching at an electric vacuum plant. A higher value of A could not be achieved due to the appearance of streamer phenomena.

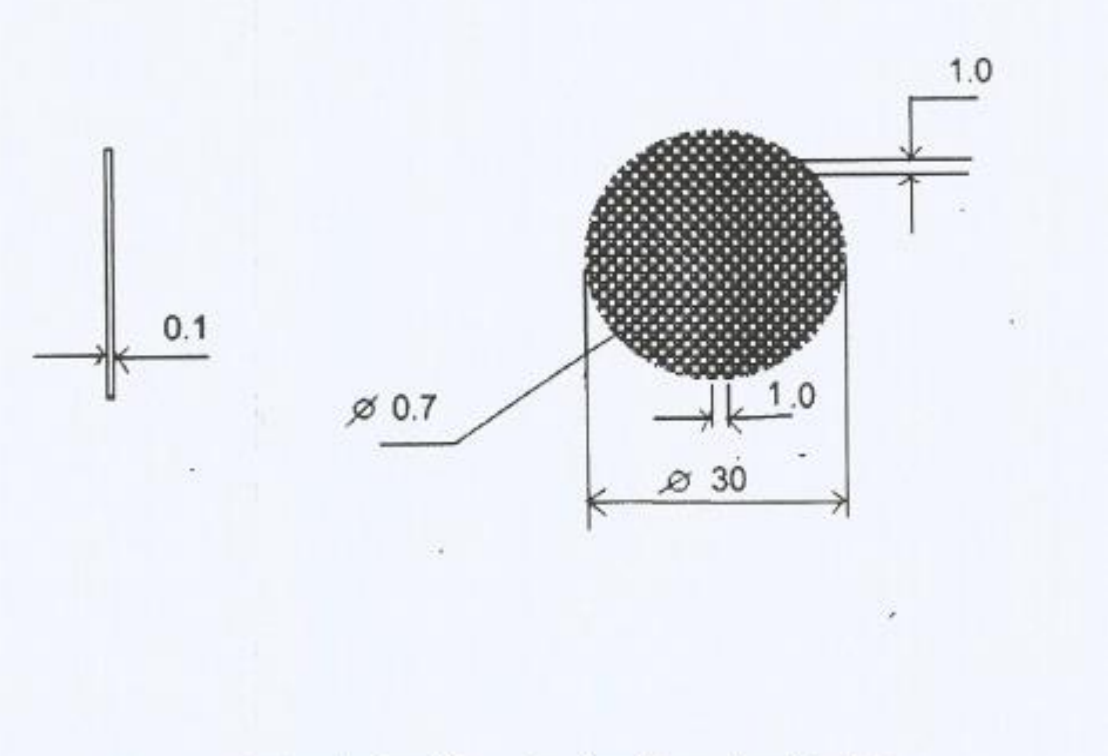

Fig.1 Metal electrode with perforation from circuit holes

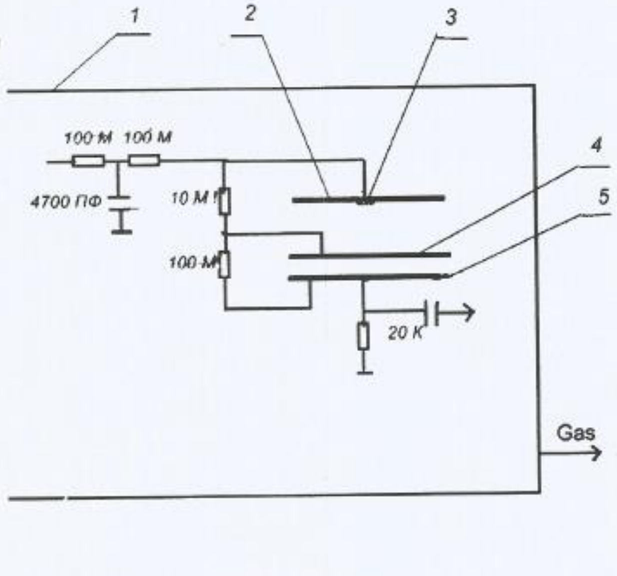

Fig.2 Layout of new MGEM electrodes

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

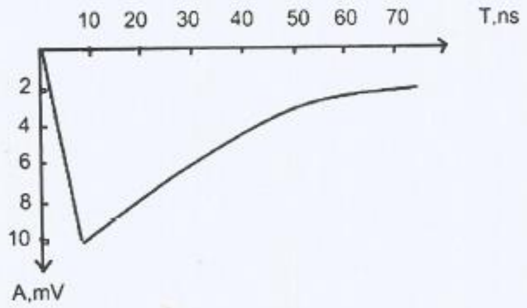

Fig.3 Waveform of anode pulse

Thesis 8. Ways to improve the performance of MPGD

Based on the foregoing, we can determine the following steps to improve the characteristics of MPGD from the point of view of expanding the scale of industrial production of detectors of this type:

1. **The resistance to breakdown and leakage of charges in flat microstrip gas detectors of the MSGD type can be significantly increased by applying round substrates of stainless steel or copper with a radius R = 20-30 μm along the entire length of the strip on the edges of the strips.**
2. **The probability of a corona discharge in hole microstructure gas detectors type of GEM, TGEM, MICROMEGAS and others can be minimized by using circular metal mesh structures with R ≥ 20 μm.**
3. **The streamer mode of the discharge, as well as the spontaneous surge of the discharge current due to the draining of the charge from the dielectric domains, can be significantly limited by using resistive round electrodes with R ≥ 20 μm and ρ ≥ 50 kΩ / cm.**
4. **The use of dielectric materials in gas-discharge gaps as spacers should be minimized due to the possibilities of the sufficient tension by using of the grid electrodes.**

Conclusion

It can be seen that in the framework of R&D-51 a large amount of researches will have to be performed, as well as tests in air and gases in laboratory conditions, as well as in charged particle beams.

Thank you very much!