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The Principal Limitations of High-Rate Micro-Pattern Gas Detectors

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Abstract

In this work the results are presented from study of breakdown in gaseous detectors recently chosen as candidates for high-luminosity experiments. The analysis of Raether limit empirically defining a size of total electron multiplication before occurrence of breakdown is performed. The necessary and sufficient conditions of the origination of SQS-mode as a precursor before of spark breakdown are deduced owing to experimental data. The new attempt is given for qualitative explanation of the low-studied phenomenon of a breakdown in gas detectors.

Introduction

Now wide application was found by a new class of position sensitive devices or Micropattern Gaz Detectors (MPGD) such as MSGD, GEM,RPC,MICROMEGAS ,etc. [1]. Possessing high spatial and time resolution, these devices were quickly adapted as a coordinate detector in many large-scale physical works, especially in neutrino and astrophysical tasks. Nevertheless there are always objective reasons limiting the applicability of the invented devices. In this paper the main limit factor in the application is considered as the reduction of the efficiency of ionized particle coordinate registration in the study of physical processes in high-rate beams and in presence of a large alpha particles background due to appearance of the spontaneous streamers, decreasing the sensitive volume of detectors.

In papers [2.3] was showed the results of systematic studies of the gas gain behavior and high-rate characteristics of some types MPGD at different gas mixture pressures in a wide range of X-ray intensity flux to individual cells and the entire area of the detector. It was established, that at low rate of irradiation (<1 Hz/mm^2) the maximum electron charge (MAC) in Townsend's avalanche at which the breakdown has place in a gas mixture one can reach limiting value according to well known as Raether limit [4]:

$$MAC=A \cdot n_0 \leq 10^8 \text{ electrons},$$

where

A-coefficient of gas gain,

n_0 - number of initial electrons

At carry out of the physical tasks to provide a small probability of the breakdown it is necessary to operate with value of A on one-two order less that it follow from [1]. Also it should be noted that Raether limit is reached in case of tests of those detectors in which designs cathodes and anodes are divided by gas gap, for example, in RPC, MICROMEGAS, GEM, TGEM. In that cases when electrodes settle down on one plane, as it performed in MSGD, limit value of MAC didn't to be reached at any design decisions. It was compelled to enter the concept of "surface" streamer for an explanation of this phenomenon though it nature reminds the Geiger discharge mode with transition to the spark rather.

It is necessary to consider the value n_0 as a value, which plays an essential role in the evidence of gas multiplication transition from avalanche to streamer or spark. Experience shows that MAC is reached at $n_0 > N$ crit., which approximately equally in 10^3 electrons. Therefore, in order to reach the Raether limit, which offers the highest possible gains at low rates, one should optimize not only detector design, but also the composition of gas mixtures. Contrary at $n_0 < N$ crit. transit may be occurs from Townsend avalanche modes to spark directly without intermediate streamer mode. In such cases MAC is a strong dependence on the structure of gas mixtures. Remarkable there is the fact that MAC accepts the maximum value in gas mixtures with buffer components as neon or helium instead argon. The explanation apparently should be looked for in the nature of primary ionization in these gases when couple electron-ion creation is needed significantly more energy and, secondly, high level of the metastable states of atoms of neon and helium considerably reduce probability of emergence of free electrons for initiation of secondary avalanches and formation of the prebreakdown streamers.

Factors, defining the limited high-rate characteristics of MPGD.

From physic of the avalanche processes taking place at MPGD is known that different stages of gas multiplication accompanied with transits to area of limited proportionality, a streamer mode or Geiger discharge, also as the plasma state and spark breakdown are defined by external conditions. Namely pressure and composition of gas mixtures, design of electrodes, beam and background rate, etc. are main factors, from which depend of the behavior of the gaseous devices. For example, the transition from area of limited proportionality can be ended as Geiger discharge mode, if gas mixture has not components, absorbing a rigid ultraviolet radiation. The other way is appearance of the self-quenched streamer mode when gas mixture has the corresponding extinguishing components. This way is most attractive for MPGD, operating at high-rate beam conditions. We consider this position more detail. As it follows from paper [5] the origination of streamer discharge mode is defined by two factors: necessary and sufficient conditions. The first condition follows according to a formula [1] which is empirically introduced for the case of formation of a limit total charge in the result of avalanche reproduction in gases. The other condition also can be presented thanks to experimental data according to the similarity low, existing in the physic of gas discharge which assumes the precursor pulse existence before the transit to another mode of discharge. Therefore in the operation with MPGD it is possible to present the next sequence of events. After passing of primary bunch of ionizing particles in a gas-discharge gap there are pulses of a proportional mode with rather not large amplitude about some mV and time duration not more than several tens nsec. To increase the operating voltage a pulses-precursors may be originate in some gas mixtures with an uncertain delay on time and amplitudes at one-two orders more than amplitudes of a proportional mode. Time delay of the pulses-precursors is in the range from several hundred nanoseconds to several hundred milliseconds. Time duration of these pulses is in range of several hundred nanoseconds.

From results of the experiment studies made with various gas mixtures and different n_0 it is possible to claim that the emergence of the streamer with amplitude in some hundred of mV is always connected with existence of pulse-precursor. With increase of the operate voltage on electrodes of MPGD the frequency of emergence of streamer pulses grows and it can reach the same value, as well as the frequency of initially proportional pulses. From here the conclusion follows that maximum efficiency of streamer registration number in relation to total number of proportional and streamer pulses shouldn't exceed of 50%.

Proceeding from the above the sufficient condition of the transit to a streamer mode can be defined as the probability of formation of secondary or inoculating electrons in the impact s of atoms and molecules of the second sort according to conclusions from paper [6]. As time of life of the exit and metastable atoms in gases can be rather long up to several sec. the reason of a delay of emergence of an pulse-precursor can be explained with this fact. In this connection it is possible to consider justified term "memory" introduction for the description of streamer model formation in accordance of the date in paper [2].

At n_0 > N crit. and considerable background from alpha particles the probability of the secondary Townsend's avalanches increases initiated by an inoculating electrons in a local summary electric field from a drifting to cathode spatial positive charge and an external electrostatic field in the gas gap of MPGD. The ionization wave has resulted secondary process of reproduction of electrons reaches a cathode surface and releases the induced negative from previous ionization processes. After that a space between two opposite charge areas is shorted by means of a narrow shinning plasma cord or streamer.

As the emergence of a streamer is always connected with a formation of a so-called «dead» zone of registration of passable ionizing particles there is clear a reason of deterioration of the detector coordinate efficiency at increase in speed of a flux of the falling radiation and a background from alpha particles.

Conclusion.

From physic of the gas discharge follows that any type of a breakdown in an interelectrode gap can be a consequence of the various reasons. It is necessary to consider as main of them the mechanisms of positive feedback at the expense of rigid ultra-violet radiation especially in the final stages of Townsend's multiplication and ionic bombing of a cathode surface with the origination of a free electron. Apparently both of these processes play a basic role in formation of MAC and they should be point out by consideration of necessary and sufficient conditions for transition to the breakdown phenomena according to Raether limit. Nevertheless such picture is most characteristic for Geiger discharge mode when gas pressure in the detector is significantly less atmospheric.

In the case of MPGD application as coordinate or time detectors pressure and structure of gas mixtures differ from gas filling in Geiger counters. Photon and ionic positive feedback is almost completely suppressed in MPGD from point of view of knocking–out of electrons from a surface of electrodes if the gas contain the corresponding extinguishing admixtures as freons or hydrocarbons.

The necessary condition for development of the prebreakdown in the form of a streamer is the performance of Raether limit as it shows in the systematic studies. Nature of this phenomenon certainly is much more difficult than only Geiger's discharge mode. It is enough to tell that it includes characteristic features of a plasma state and has to be fully researched [7].

The sufficient condition of the emergence of a streamer in this case is considered as a probability for free electrons to originate in the gas volume of the detector by a different ways. Such phenomena in gases as metastable and non-metastable Penning effects and other inelastic impacts of the 2-nd sorts can be the reasons of the emergence of free electrons. These processes are especially actuality when the high-luminosity experiments carried out in the presence of the breakdown from alpha particles.

Introduction of both these conditions can to explain many factors connected with appearance of streamer as a precursor of a breakdown for different values of A and n_0. For example, a falling of the efficiency of events registration at high-rate beams and background from alpha particles is presented as the next. At choice of the any value of n_0 the value of A should be correspond to formula (1) to protect our device from breakdown i.e. to perform the necessary condition. From experimental data it is known that in gas devices even for a small values of A there is a high probability of appearance of free electrons for occurrence of the secondary avalanche or precursor in the total electric field from a positive space charge of the previous avalanche and an external field of the detector. As a result of this process there is an ionization wave which extends to a cathode and shortly closes space between it and place of emergence of the precursor. This moment is the base from point of view of the streamer formation and it is logical to accept it as a sufficient condition of the emergence of a prebreakdown in gas detectors. Short circuit between two opposite areas as a result of passing of an ionization wave can be lead to formation of the narrow cord or streamer which was shone in presence of the recombination.

It should be noted that there is a deep interrelation between necessary and sufficient conditions of the transition to a prebreakdown or streamer discharge mode according to Raether limit formula. Both factors, A and n_0, in this or that quality participate in a complex dynamic plasma process, including such lines , as stopping of electrons, electroneutralization of charges, electrostatic fluctuations of an ionic branch, etc.

Further transition of a streamer to a spark in MPGD can be caused by the various reasons. One from them is increase of operate voltage, when the size of MAC starts accepting values above of that limit which is defined by a formula (1). Thus the sequence of events including passing of primary proportional pulse, secondary a precursor pulse and also a streamer pulse is defined by the value of coefficient A. In case of excess of a MAC limit and existence of induced negative charge on the cathode there is a new injection of a charge to the residual streamer channel and fast development of spark breakdown.

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