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NUCLEAR EXPERIMENTAL TECHNIQUES

Development of the Active Element for Detectors Based on Thick Gas Electron Multipliers

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Abstract—A thick gaseous electron multiplier is used as an active element in designing radiation-resistant fast-response detectors (hadron calorimeters, tracking detectors, etc.). Design and technological efforts have been made in order to optimize the structure of the element. Results of measurements and the nearest plans are presented.

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INTRODUCTION

In view of the scheduled tenfold increase in the LHC luminosity [1], the necessity arises of upgrading the active elements of the CMS end cap hadron calorimeters designed and produced at the Institute for High Energy Physics (IHEP) [2]. In this paper, we analyze the requirements for the active elements of the hadron calorimeters operating at high radiation counting rates, propose a version of detectors, and present results of measurements and plans of future development.

A high radiation hardness (~60 Mrad) and a high counting rate capability are the main requirements for detectors operating under heavy radiation conditions and at high counting rates. In addition, the detectors must be easy to produce (cheap), reliable (the access to equipment is limited on colliders), and robust. A thick gaseous electron multiplier (THGEM) meets these requirements to the greatest extent [3]. Numerous works have been performed lately, in which, apart from studying the basic problems, the THGEM characteristics have been analyzed as functions of a set of various parameters. Therefore, our investigations are based on these results and have a purely practical character: optimizing the chamber design aimed at simplifying the production technology and attaining the maximum gain.

DESIGN

The structure of a single-electrode THGEM is shown in Fig. 1a. It differs from the design of a gaseous electron multiplier (GEM)—predecessor of the THGEM—in the characteristic dimensions of the electrode, which are an order of magnitude greater than those of the GEM (the diameter of holes, the pitch, and the electrode thickness). This allows one to use ordinary glass-cloth laminate and standard printed-circuit board production technique in THGEM manufacture.

A fragment of the THGEM electrode used in this study is shown in Fig. 2a. There are rims around the holes that increase the breakdown voltage. The hole diameter is approximately equal to the plate thickness. The spacing between the holes is 800 μm. The electrodes were produced by the IHEP (Protvino). The rims around the holes were formed using the technology proposed by CERN. Finished holes were cleaned by the hydroabrasive method; afterward, the electrode was washed in an ultrasonic bath and dried.

All measurements were performed with electrodes made from 500-μm-thick cloth-cloth laminate with 35-μm-thick copper cladding. The hole diameter is 400 μm, the rim width is 120 μm, and the spacing between holes is 800 μm. The photograph of the electrode under a microscope is shown in Fig. 3.

The technology used to manufacture electrodes guarantees a high quality and a good accuracy of the etched rims around holes, which are the factors determining in the final analysis the value of the breakdown voltage (i.e., the maximum gain).

The chamber schematically shown in Fig. 1 was used in the measurements. The chamber was blown with an Ar + 30%CO_2 mixture at atmospheric pressure. According to numerous publications, such a design ensures a gain of as high as 10^5. In many cases, this is inadequate. Further increase in the gain can be attained by cascading the electrodes, as is shown in Fig. 4. Physically, this design is more intricate than the single-electrode chamber.

To get around these obstacles (i.e., to eliminate the gap between the electrodes), the construction shown in Fig. 2b was produced. The three-layer electrode was produced by the same technology as the double-layer

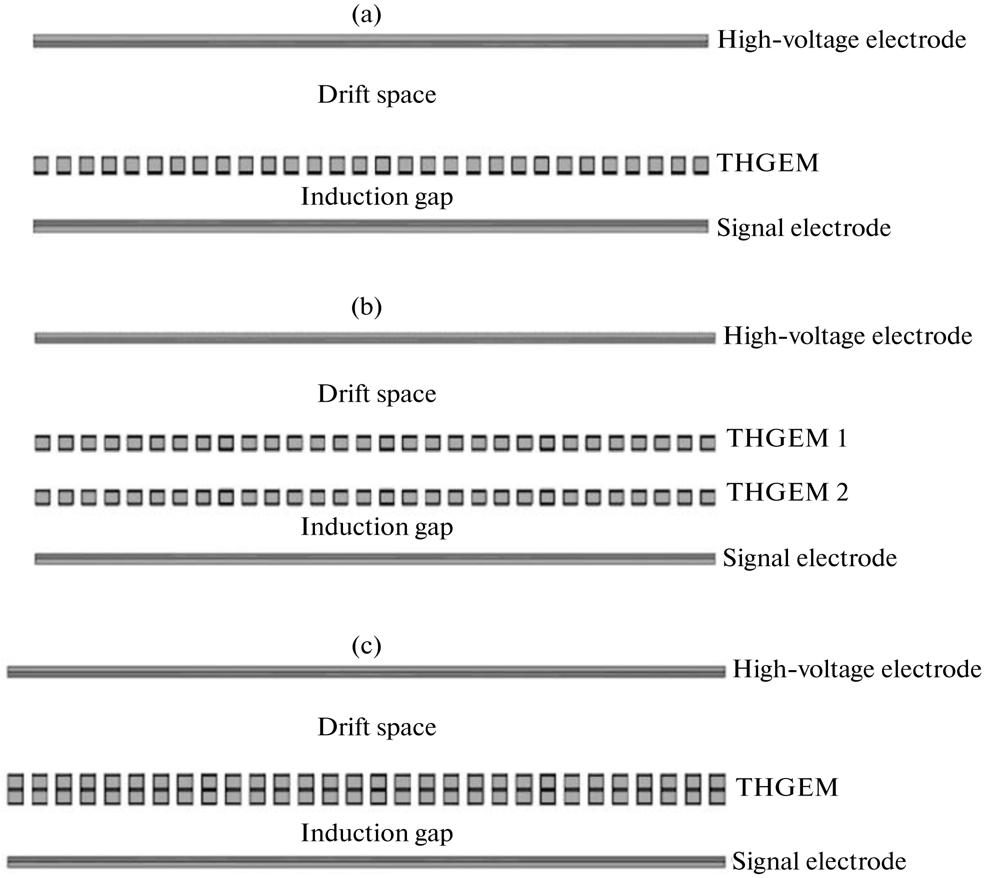

Fig. 1. Structure of the THGEM (a) with a single, (b) two, and (c) three electrodes. The typical dimensions of the drift and induction gas gaps are 3 and 1 mm, respectively.

one; i.e., the stages of drilling and etching of the plate were executed only once. The rim of the middle electrode was similar to those of the outer ones.

The electrode was inserted between the high-voltage and signal electrodes, as is shown in Fig. 1c.

The operating conditions of this chamber and the previous one were identical. The voltage was applied to each electrode from its own source via a 10-mΩ resistor. The electrode was 1 mm thick. With high-voltage and signal electrodes each 1 mm in thickness (to combine the function of the protective layer), the total thickness of the chamber will be 7 mm, which will allow easy insertion of it into the available absorber of the CMS end cap hadron calorimeters.

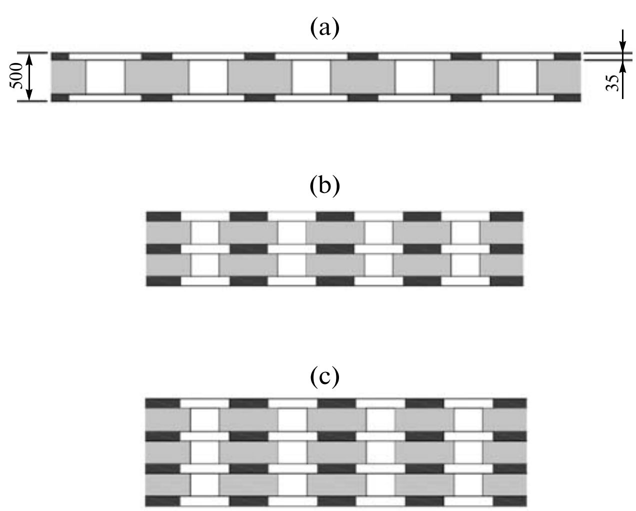

Fig. 2. (a) Cross section of the fragment of the THGEM electrode (glass-cloth laminate 500 μm thick, clad with copper 35 μm on both sides), (b) fragment of the three-layer THGEM electrode, and (c) fragment of the four-layer electrode.

RESULTS OF MEASUREMENTS

The chamber was irradiated by a collimated radioactive source (^{90}Sr). When the double-layer electrode (Fig. 2a) was used, the signal amplitude at $V_1 = 2.6$ kV, $V_2 = 2.3$ kV, and $V_3 = 0.4$ kV was ~1 mV into a load of 50 Ω. An increase in voltage V_2 initiated discharges; variations in V_1 and V_3 affected the gain only slightly.

Figure 4 shows the signal from the three-layer THGEM at V_{drift} = 600 V, V_{THGEM1} = 1.9 kV,

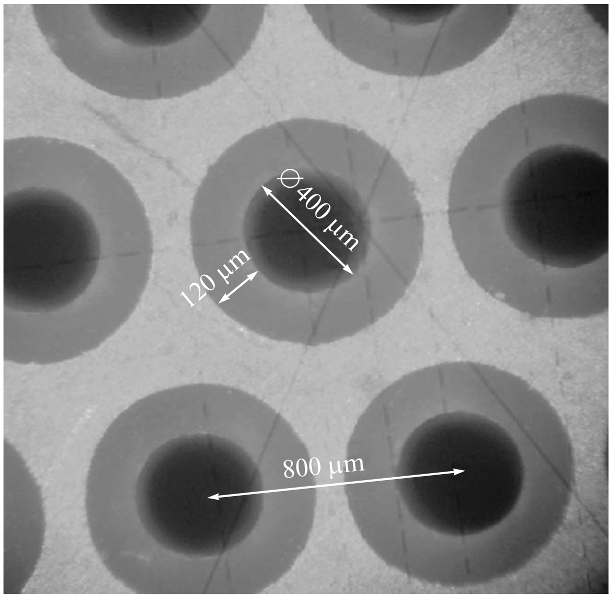

Fig. 3. Photograph of the THGEM electrode under a microscope.

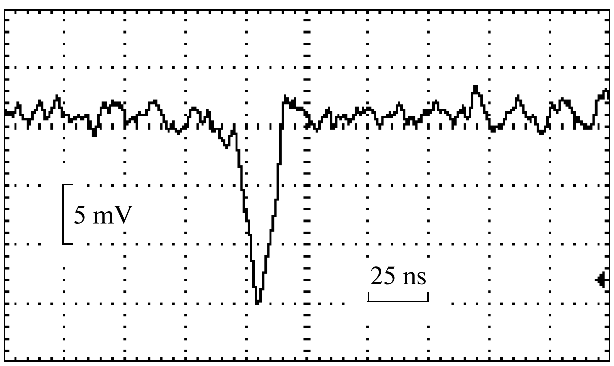

Fig. 4. Signal from the chamber with a three-layer electrode.

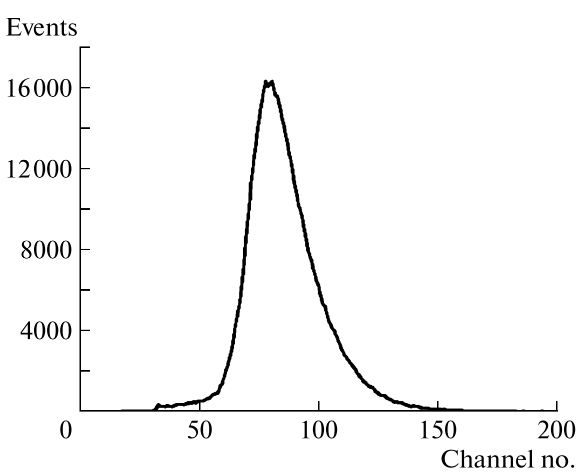

Fig. 5. Amplitude spectrum of signals from the three-layer electrode irradiated by a ^{90}Sr radioactive source.

V_{THGEM2} = 1.5 kV, and V_{induc} = 200 V. The voltage picked off the signal electrode was fed through the amplifier to a multichannel analyzer.

The amplitude spectrum of signals from the three-layer electrode chamber exposed to ^{90}Sr without selection of events by scintillation counters is presented in Fig. 5. Such a distribution is expected to be produced by a minimum ionizing particle (a muon). The number of primary electrons estimated from the analysis of the amplitude distribution is ~13.

A four-layer electrode shown in Fig. 2c was also produced. The gain increased by an order of magnitude with respect to a three-layer electrode. The increase of ~2000 V in the high voltage applied to the chamber is considered to be the main drawback of such a design. A gain such as this may be required when designing detectors for certain types of tasks. The maximum achievable avalanche charge in a plane-parallel gaseous detector is known to be determined by the so-called Raether limit [4]

$$An_0 < 10^8 \text{ electrons},$$

where A is the gain, and n_0 is the number of primary electrons. To ensure stable performance of the detector, the avalanche charge must be factors of 10–100 lower.

CONCLUSIONS

Our study has allowed us to optimize the design solutions used in production of the first chamber samples for prototypes of the coordinate detectors and active elements of the calorimeters. We intend to carry out investigations of the prototype performance in late 2009. It has also been proposed that small chambers be placed at the entrance into the magnet of the FODS setup [5] for studying the long-term stability of operation in a high-power magnetic field and at high counting rates. To assess the radiation hardness of THGEMs, an identical chamber will be irradiated to a dose of 60 Mrad.

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