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GAIN PREDICTION THEORY OF SINGLE FOIL GAS ELECTRON MULTIPLIER DETECTOR

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Abstract. *Gain prediction theory of single foil Gas Electron Multiplier detector was developed. Gas electron multiplier (GEM) detector with single foil was developed. Soft X-ray spectra with an energy of 5.9 keV emitted by the isotope Fe-55 were measured. On this basis, the dependence of gain and energy resolution from the detector voltage was determined. The simple theory of gain dependence on various detector parameters was developed. Preliminary results of the study confirmed the potential usefulness of the GEM detector as a substitute for the multiwire proportional chamber.*

Keywords: Gas Electron Multiplier, ionizing radiation detector

TEORIA WZMOCNIENIA JEDNOFOLIOWEGO DETEKTORA Z GAZOWYM POWIELANIEM ELEKTRONÓW

Streszczenie*. Opracowano teorię wzmocnienia jednofoliowego detektora z gazowym powielaniem elektronów. Opracowano detektor z gazowym powielaniem elektronów z pojedynczą folią. Zmierzono widmo miękkiego promieniowania X, o energii 5,9 keV, emitowanego przez izotop Fe-55. Na tej podstawie wyznaczono zależność wzmocnienia i energetycznej zdolności rozdzielczej od napięcia zasilającego detektor. Opracowano prosta teorią zależności wzmocnienia od różnych parametrów detektora. Wstępne rezultaty badań potwierdzają potencjalną przydatność detektora GEM jako substytutu wielodrutowej komory proporcjonalnej.*

Słowa kluczowe: detektor z gazowym powielaniem elektronów, detektor promieniowania

Introduction

Gas Electron Multiplier is a gas detector composed of a thin polymer film with insulating properties, that is coated on both sides with a conductive layer [4]. GEM film is composed from a plurality of small channels arranged regularly on the surface and passing through all the layers. Applying a potential difference of upper and lower conductive layer gives rise to a strong electric field inside the channels, causing the acceleration of the movement of electrons and their multiplication. Typical film thickness is about 50 microns Kapton and the thickness of the copper layer is 5 µm. The holes typically have an outer diameter of 70 µm, while the inner 50 microns. Typical spacing between the holes is 140 µm. External dimensions of the copper box with holes are in range from 100×100 mm to 300×300 mm. GEM detectors can be used as a substitute for position sensitive multiwire proportional chambers in high energy physics experiments [2].

1. Methods

The dependence of the gas gain in function of the electric field is described by the formula [3]

$$\log M = \int_a^b \alpha(s)ds \tag{1}$$

where α - first Townsend coefficient. The limits of integration (*a*, *b*) of the above integral include the area of the electrical field.

The formula (2) is derived assuming a constant electric field in the holes of the GEM film and first Townsend coefficient α dependence on the pressure of gas in the form [1]

$$\frac{\alpha}{p} = A \cdot \exp\left(-B\frac{p}{E}\right) \tag{2}$$

where *A*, *B* are constants depending on gas mixture, *p* - gas pressure in Torr, *E* – electric field.
For constant electric field on the distance *L* we obtain

$$M = exp\left[ApL\exp\left(-Bp/E\right)\right] \tag{3}$$

Assuming that total potential difference is located in a hole between both conductive layers of a GEM foil, the gas gain M is equal

$$M = \exp\left[A \cdot p \cdot L\left(-\frac{BpL}{U}\right)\right] \tag{4}$$

where L - foil thickness, U - supply voltage in Volts.
The formula (4) was derived from (3) assuming constant electric field $E = U/L$. Location of the peak is proportional to the gain of the gas detector, $m = S \times M$, where *S* is the coefficient of proportionality. The theoretical value of the coefficient can be obtained from the formula

$$S = \frac{k_u E q_e 2^n}{C_f U_{range} w} \tag{5}$$

where k_u – gain of the amplifier, *E* – energy of the quantum of radiation, q_e – elementary charge, *n* – number of the A/D converter bits in the multichannel amplitude analyser (MAA), *w* – ionization work, U_{range} - the voltage range of the MAA, C_f - capacitance in the feedback loop in the preamplifier.
The values of the parameters are the following: k_u = 80V/V, *E* = 5900 eV, *w* = 24 eV, *n* = 12, $q_e = 1.6\ 10^{-19}$ C, U_{range} = 10 V, C_f = 1 pF. The computed value of the coefficient is S = 2.58. The following values were assumed in the analysis: *L* = 0.005 cm, *p* = 760 Torr. The variance of the output signal was modeled by the formula

$$\sigma^2(m) = C + H \cdot m^2 \tag{6}$$

The formula (6) was developed assuming that there are two sources of variance in the measured signal: amplifier noise and fluctuation of electric charge in the detector. The amplifier noise is independent from the main peak position (particle energy). The fluctuation of the electric charge in the detector was assumed proportional to measured energy. It assumption neglects fluctuation in gas gain. Energy resolution R was calculated from the formula

$$R = \frac{FWHM}{m} = \frac{2.35 \cdot \sigma(m)}{m} = \frac{2.35 \cdot \sqrt{C + H \cdot m^2}}{m} \tag{7}$$

The built GEM detector uses film manufactured by Techtra using technology Micro-Chemical-Vias, consisting of chemical etching holes. GEM foil was placed in the housing of multiwire proportional chamber, which the anode wires has been removed from. The active area is 100×100 mm, and the window in which the film is placed is wider by about 3 mm on each side. The aim of pressing the film is to reduce the deflection of its center of gravity from a point on the plane defined by the edges to the minimum. In order to eliminate the interferences induced on fragments of wire without insulation (the entire structure is exposed and unprotected against external influence of the electromagnetic field), special design has been adapted from a male BNC connector, which covers part of the high voltage supply line to the system. Copper rims that were previously close to the anode wires and which were located about 4 cm from the active region of the film GEM have been connected to the ground potential, which does not lead to additional capacity to the system and not cause outflow of charge carriers in undesired directions. After initial assessments of the possibility to add the multiplicative GEM foil to the gas chamber, the polymer plate, that was a replacement for the disc with anode wires in the proportional chamber, was made. The disc has the same external dimensions as mounting plate with the anode wires, but instead of the wires it has a space for the placement of the GEM foil cap. The place was prepared to pass the copper strips, soldered to the terminals GEM foil, which were connected to the high voltage power supply. The image in Figure 1 shows the interior of the gas chamber and the positioning of the film GEM detector (ceramic polymer film with a centrally located, connected by leads to a crafted BNC). The GEM foil is shown in the foreground.

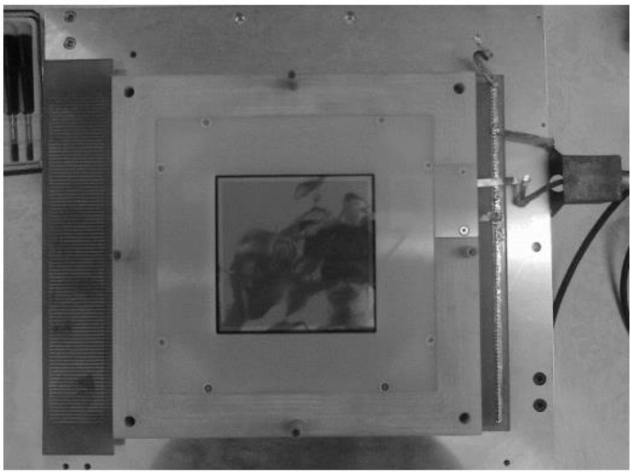

Fig. 1. Photo of the interior of the gas detector

Gas mixture that fills the detectors, was composed from Ar (90%) and CH_4 (10%). High voltage generated by the high-voltage power supply type ZWN-41 (manufactured by POLON Warsaw), was given by the resistor R value of 3 MΩ on top of the GEM foil cover and the lower cover was connected to ground (Figure 2).

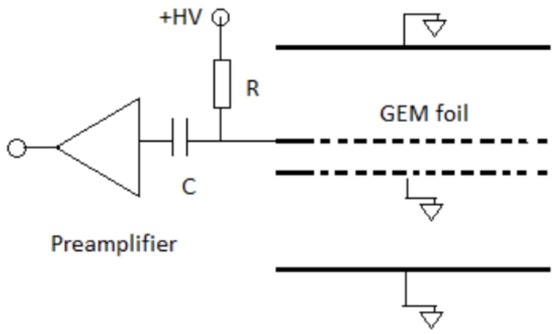

Fig. 2. Power connection diagram of the GEM foil

The signal from the top cover, after cutting the DC component off by the capacitor C with a capacity of 680 pF, is applied to the input of the charge sensitive preamplifier type 1002 (manufactured by POLON Warsaw). The signal from the preamplifier output was fed to the input of the shaping amplifier with adjustable gain type 1101 (POLON Warsaw). Shaped pulses from the output of the amplifier were fed to the input of multichannel amplitude analyser type Tukan-8k-USB.

2. Results

Sample spectrum of Fe-55 isotope measured in the system at 475V high voltage is shown in Figure 3. The main band of the spectrum contains in fact two superimposed bands: the main Kα energy 5.90 keV and lower energy Kβ 6.50 keV.

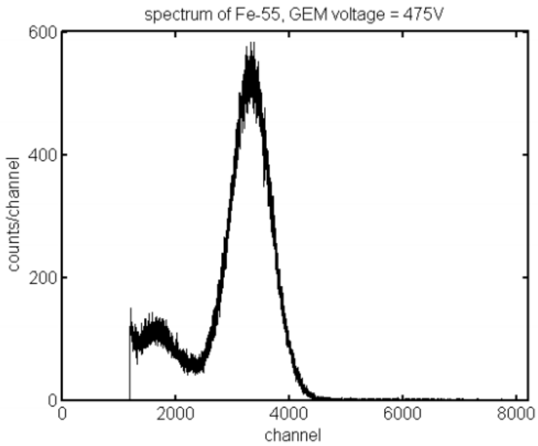

Fig. 3. Sample spectrum measured in the system Fe-55 475V voltage

The measurements were used to determine the spectrum according to strengthen the power supply voltage. To this end, for each spectrum collected at a given voltage, the position of the maximum absorption band was determined by fitting a Gaussian distribution function

$$\sigma^2(m) = C + H \cdot m^2 \qquad (8)$$

where *n* - channel number, *m* - peak channel number.

The dependence of the peak position in the function of the power supply voltage is shown in figure 4.

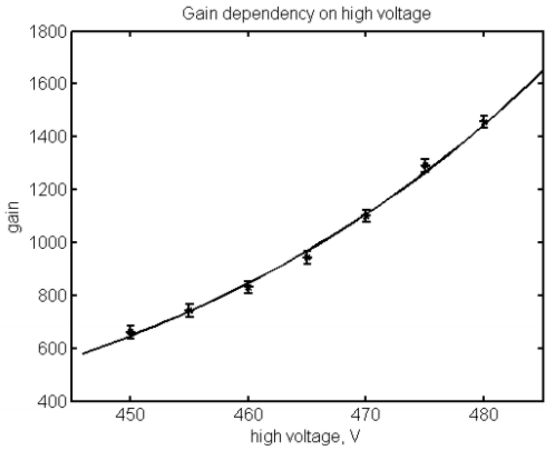

Fig. 4. Gain dependency on high voltage

The theoretical dependence of the gas gain M from the gas pressure, voltage and GEM film thickness was fitted to the measurement data, according to the formula (8). Experimental values of the constants A, B are the following: A = 10.9 ± 0.6 $Torr^{-1}cm^{-1}$, B = 220 ± 6 V $Torr^{-1}cm^{-1}$. Further measurements of FWHM (energy resolution expressed in band width at half height) in the dependence from the supply voltage and the position of the centre of the main peak were carried out. The measurements were carried out in the voltage range of 450 – 480 V. The graph in Figure 5 shows that the resolution improves with the supply voltage growth. The theoretical dependence of the standard deviation from the position of the main peak was fitted to the measurement data. The position of the main peak in turn depends on the voltage.

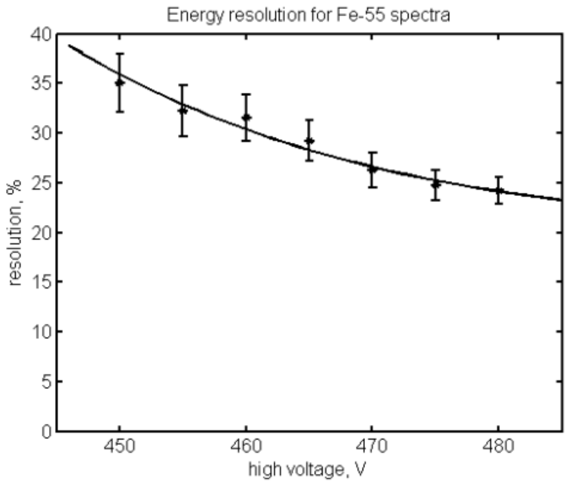

Fig. 5. Energy resolution dependence on the supply voltage

The H, C coefficients were found by least squares. Experimental values are the following H = 0.0073 ± 0.0014, $C = 4.46 \times 10^4 \pm 1.01 \times 10^4$. The dependence of the centre of the main peak of the power supply is fully in accordance with expectations. The voltage dependence of FWHM suggests that increasing the supply voltage will result in better energy resolution. However, it was not possible to measure the FWHM for higher voltages due to sparking, so one cannot say where is the optimum operation point. Only voltage 475 V and 480 V allowed to observe escape peak Kα band with energies of 2.68 keV extracting from the noise.

3. Conclusion

Built GEM detector was used to measure the spectra of Fe-55. Measured gas gain and energy resolution are in accordance with expectations. The simple theory of gain dependence on various detector parameters was developed and confirmed by experiments. Preliminary results of the study confirmed the potential usefulness of the GEM detector as a substitute for the multiwire proportional chamber.

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