Dual Gain Multi-layer Thick GEM with high-intensity heavy-ion beams in low-pressure hydrogen gas

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We are developing a gaseous active target CAT-M based on a time projection chamber with using GEMs for the study of unstable nuclei using missing mass spectroscopy \cite{1}. CAT-M employ a GEM called dual-gain multi-layer thick GEM (DG-M-THGEM) \cite{2} which has two characteristic structures. First, electrodes of the GEM is separated to control the gain of each segment independently. The GEM is called dual-gain thick GEM (DG-THGEM). The DG-THGEM can reduce the number of secondary electrons by controlling the gain of a region which measure beams to be low even if high intensity beams is injected \cite{3}. An active target CAT-S have been operated successfully by using the DG-THGEMs in a physics experiment of a deuteron inelastic scattering with the high intensity \textsuperscript{132}Sn beam of several $10^5$ Hz \cite{4}. Second is a structure of alternating layers of electrodes and insulators which was developed by Cortesi as multi-layer thick GEM (M-THGEM) \cite{5}. Because the total thickness of the M-THGEM become thick, the structure is expected to result in a minimal amount of the bending even by mounting without tension and support. In this paper, performance of the prototype DG-M-THGEM with an active area of $10 \times 10$ cm$^2$ was investigated with a high intensity heavy ion beam up to $10^9$ Hz. Effect of space charges due to ion backflow from the GEM with the high intensity beam was also considered.

The performance evaluation of the prototype DG-M-THGEM with high intensity heavy-ion beams was performed by employing the active target CAT-S filled with hydrogen gas at the pressure of 40 kPa. A \textsuperscript{132}Xe beam with the energy of 185 MeV/u was impinged into CAT-S at a synchrotron accelerator facility HIMAC of National Institutes for Quantum and Radiological Science and Technology.

The effective gas gain for the beam was measured with the low-intensity beam of 5 k particle per pulse. The potential differences among the electrodes in the beam region were changed while those in the recoil region were fixed at the effective gain of about 2000. Figure 1 shows the result of the effective gas gain as a function of the reduced bias in the GEM holes. The effective gas gain $G_{\text{eff}}$ is defined as ratio of the amplified charges to the initial charge,

$$G_{\text{eff}} = \frac{Q}{\frac{\Delta E}{W}}$$

where $Q$ is the collected charges on the readout pad, $\Delta E$ is the energy deposit of the incident particles above the readout pad, $W = 36.5$ eV \cite{6} is the mean energy for ion-electron pair creation of the H$_2$ gas and $e$ is the elementary charge. The gain lower than 100 can be achieved in the beam region with any high voltage setting while the gain of the recoil region was kept the value of about 2000. According to comparison between the open squares and the solid circles, the effective gain measured during beam injection does not seem different from the one without the beam.

Charge resolutions were also measured by changing the setting of the potential differences of the DG-M-THGEM. In order to evaluate the charge resolution, groups consisting of 4 pads were defined as shown in Fig. 2 (a), where the axes of x and z are defined as the direction perpendicular and parallel with the beam axis, respectively. In the figure, 4 hatched red triangles, open green triangles, solid blue triangles are one group to sum up the collected charges defined as variables of $Q_{i-1}$, $Q_i$ and $Q_{i+1}$, respectively. The sum of the collected charges of a specific group is almost same with the average value of the collected charges of neighboring groups because the range of the beam is long enough and the energy deposit varies linearly in the active region. Thus a residual of the total charge of the specific group from the average of the total charge of neighboring groups should become almost zero. Here a charge resolution in each group was defined as the standard deviation of the residual distribution which is explained as following equation.

$$\epsilon = \frac{Q_i - \frac{(Q_{i-1} + Q_{i+1})}{2}}{\Delta E/W}$$

A dependence of the charge resolutions on the effective gas gain is shown in Fig. 2 (b). The charge resolutions significantly depend on the gain value regardless of the setting to supply voltage to the electrodes. The result indicates that the charge resolution mainly depends on the effective gas gain and independent of the electric field strength in individual region of the GEM.

Beam intensity dependence of the measured charges were studied by investigating position dependence of the energy deposit along the beam axis. Figure 3 shows the
Figure 1. The gain curve as a function of the reduced bias by using the $^{132}$Xe beam with the low-intensity of 5 k particles per pulse. Open circles, squares and triangles are the gain of the beam region measured with the beam. The open circles are the data that the ratio among the potential differences between $V_1$ and $V_2$, $V_2$ and $V_3$, and $V_3$ and $V_4$ was kept constant. Open squares are the data that the only potential difference between the electrode $V_3$ and $V_4$ was changed. Open inverted triangle is the data that the only potential difference between the electrode $V_2$ and $V_3$ was changed. Open triangle is the data that the only potential difference between the electrode $V_1$ and $V_2$ was changed. Cross mark is the gain of the recoil region measured with the alpha particles while the beam passed in the beam region which had the gain of about 100. Solid circles are the gain of the beam region measured with the alpha particles when the beam was off.

Figure 2. (a) The definition of the pad groups to evaluate the charge resolutions with the equation (2). 4 triangles are one group at each low to obtain the collected charges $Q_{i-1}$, $Q_i$, and $Q_{i+1}$, respectively. (b) The Charge resolution as a function of the effective gas gain. Legends are the same with figure 1.

Figure 3. Position dependence of the energy deposit along to the beam axis by changing the beam intensity.

References