We are developing GEM-based time projection chambers (GEM-TPCs) under an inter-group collaboration in CNS, aiming at the measurement of nuclear reactions of short-lived nuclei at RIBF and the measurement of heavy ion collision at ALICE. In general, process of electron multiplication in GEM (and other so-called micro-pattern gas detectors) is quick relative to the multiplication process around wire. Thanks to the quick response, high-rate particle measurement can be realized. If the beam particles are impinged into an active area of GEM-TPC, nuclear reactions can occur in the active area. The TPC used in such an operation is called active target, which enables us to measure low-energy recoils and reaction vertex precisely. Within our collaboration, two active targets based on the GEM-TPC, called GEM-MSTPC and CAT-S [1] are developed and used for the missing mass spectroscopy of short-lived nuclei at RIBF. By using CAT-S, the first forward-angle measurement of deuteron inelastic scattering off $^{132}$Sn has been done in 2016, aiming at revealing isospin dependence of nuclear matter equation of state [2]. In the fiscal year of 2017, a new active target CAT-M was developed aiming at the measurements of giant resonances in $A \sim 100$ unstable nuclei. In this report, the structure of CAT-M and its commissioning experiment are described.

The CAT-M is designed to have the thicker effective target and the larger acceptance than those of the CAT-M. The expected statistics will become 10 times larger with keeping the resolutions for excitation energy and scattering angle in the center-of-mass frame. Figure 1 shows the picture of the CAT-M. The CAT-M consists of time projection chamber (TPC) and silicon detectors.

The field cage of the TPC is of cubic shape and the volume of the field is of dimension of 400-mm in width and depth and 200-mm in height with two layers of 4-mm pitch wires. Each wire in one layer is connected with 1-MΩ resistor. The wire diameter is 50 µm. The uniform drift field is formed in an active area of $304 \times 280$ defined by the aperture of anode plate of the field cage. A mesh grid is glued on the anode to maintain the uniform drift field. The wire diameter and the aperture of the mesh grid are 30 µm and 224 µm, respectively. The field cage is placed on the bottom plate of the chamber. A dual-gain multi-layer thick gas electron multiplier (DG-M-THGEM) is designed by ourselves and produced by REPIC, based on the design of M-THGEM [3]. The DG-M-THGEM has four electrode layers and three insulator layers, which are placed alternately. Total thickness of DG-M-THGEM is about 1.3 mm. The hole size and pitch is 300 µm and 700 µm, respectively. Specification of the DG-M-THGEM is summarized in Table 1. The performance evaluation of prototype DG-M-THGEM is summarized in Ref. [4]. Three electrode layers are three-fold segmented along the beam axis, in order to control the gains at beam (center) and recoil (side) regions, independently. The multiplied electrons are collected in readout pads. Each readout pad is of regular triangle shape with 7-mm side. The total number of readout pads is 4048.

Table 1. Specification of DG-M-THGEM

<table>
<thead>
<tr>
<th>Dimension</th>
<th>300 × 360 × 1.3 mm$^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrode</td>
<td>15-µ Au coated 18-µ Cu</td>
</tr>
<tr>
<td>Insulator</td>
<td>FR4 (400, 380, and 400 µm)</td>
</tr>
<tr>
<td>Hole</td>
<td>300 µm in diameter with 700 µm pitch</td>
</tr>
<tr>
<td>Beam region</td>
<td>29.4 × 308 mm</td>
</tr>
<tr>
<td>Recoil region</td>
<td>132.5 × 308 mm</td>
</tr>
</tbody>
</table>
Two arrays of silicon detectors are placed on the both sides of the TPC. Each array consists of six single sided strip silicon detectors with $10 \times 10$-cm$^2$ area and about 500-$\mu$m thickness (products of Hamamatsu). The signals from the strips are read out.

The same readout scheme is used both for the TPC and the silicon detector arrays. The signal is transferred by using flexible printed circuit (FPC) cable with 67 lines. The 32 lines are used for signal and the rest are connected to ground. At the border of chamber, a printed circuit board (PCB) with FPC connectors at the both sides used as feedthrough in order to seal the gas. The signals are processed and acquired by using general electronics for TPC’s (GET) consisting of AsAd, COBO and Mutant. The transferred charge is input into a digitization board with programmable pre-amplifier and shaping amplifier called AsAd through protection circuit board called ZAP. In our ZAP board diodes are mounted to protect the pre-amplifier from unexpected large amount of charges. The AsAd board has a function to produce the multiplicity signal of hits. One AsAd board can treats 256 signals and four AsAd boards can be connected to one COBO. The COBO collects the multiplicity signal from the AsAd board and produce the trigger output to be used for the external trigger. The COBO accepts the external trigger and distributes it to the AsAd boards, then the AsAd board buffers the digitized samples and sends them to the COBO. The data is read out directly from each COBO via 10-Gbps optical link connected to a data storage server. The Mutant synthesize the clocks among the COBO’s and the AsAd’s, while the Mutant has other intelligent functions such as the multiplicity assembling, high-level trigger production and so on. The whole system of GET is managed by using a software Narval.

The CAT-M was constructed and commissioned in December, 2017. The commissioning was performed in HIMAC under the experiment program 15H307. The CAT-M was operated with 0.3-atm hydrogen to measure the proton inelastic scattering off $^{136}$Xe. The bias voltage values for the cathode and the anode of the field cage were -9 kV and -6 kV to form the drift field having the strength of 1 kV/cm/atm, with which the drift velocity was about 1 cm/µs. The typical bias voltages for the electrodes of the DG-TH-GEM are -1600 V, -1120 V, -640 V, -160 V for the recoil region and are -1600 V, -1146 V, -815 V, -361 V for beam region. The $^{136}$Xe beam accelerated by a synchrotron up to 200 MeV/u bombarded the CAT-M. The typical intensity was $10^6$ particles per pulse (ppp) with typical extraction time of 1.2 sec. The thresholds to produce the trigger from the hits in readout pad of the TPC should be high enough to discriminate the delta rays. However, these threshold values are commonly used to determine if the hits are recorded or not. If the thresholds for all the readout pads are high, the singles from the high energy recoils reaching at silicon detectors cannot be recorded. In order to overcome this problem, we decided to divide the recoil region into two regions. In one region the threshold value is high enough to create the trigger for the events where the recoil particles stops inside the active area in TPC and in the other region the threshold values are as low as possible to record all the pulses. The external trigger was the logical OR of the hit signals of readout pads in TPC and ones of the silicon detectors.

The CAT-M worked with $10^6$-ppp beam injection during about 20-hours measurement. The recoil events were successfully recorded with the TPC triggers. Typical hit pattern in the TPC is displayed in Fig. 2. Beam particles traveled from bottom to top and a particle was recoiled at around $Z = 20$ horizontally. But the number of silicon triggers was larger than expected and the external trigger was produced by using only TPC triggers. One possible reason for the background in the silicon trigger is light particle production during the transportation of beam and it is strongly depend on the experimental condition. We will find the source of the background in the next experiment in HIMAC. Analysis for the performance evaluation is ongoing.

![Figure 2. Hit pattern for one event triggered by TPC](image.png)

References