Property of LCP-GEM in pure dimethyl ether at low pressures[†]

Y. Takeuchi,[*1,*2] T. Tamagawa,[*1,*2] T. Kitaguchi,[*1] S. Yamada,[*1] W. Iwakiri,[*1] F. Asami,[*1,*2] A.Yoshikawa,[*1,*2] K. Kaneko,[*1,*2] T. Enoto,[*1,*3] A. Hayato,[*1] T.Kohmura,[*4] and the GEMS/XACT team

We developed a photoelectric X-ray polarimeter onboard X-ray advanced concepts testbed (XACT) sounding rocket, the first dedicated NASA rocket mission for high sensitivity observation of cosmic X-ray polarization.[1,2] The polarimeter uses a time projection chamber technique to obtain the distribution of photoelectron emissions from which the polarization of the incident X-rays can be measured. A key device of the polarimeter is a 100-μm-thick gas electron multiplier (GEM) foil with a copper-clad liquid crystal polymer insulator (LCP-GEM),[3,4] which amplifies the signal that keeps the track image of photoelectrons. The required gain of the LCP-GEM for the polarimeter is 3,000 without discharge. Fine photoelectron track images are essential for a highly sensitive measurement of X-ray polarization. By extending the track length using a low-pressure gas, high-resolution photoelectron track images can be obtained. On the other hand, the low-pressure gas decreases the X-ray detection efficiency of the polarimeter. We anticipate that the optimum gas pressure of pure dimethyl ether (DME) is 50−150 Torr by considering the trade-off between the detected count rate and the modulation factor.[1] However, LCP-GEMs have never been operated below 190 Torr in DME gas. Under such low gas pressures, discharge is one of the most significant risks to the successful operation of GEMs. To explore this unknown regime, we performed a systematic investigation of the gain properties of a 100-μm-thick LCP-GEM in DME at low pressures for the first time.

We developed a prototype gas-chamber detector, which possesses the same geometry as the flight model of XACT. By irradiating the chamber with 6.4 keV X-rays, we obtained the spectrum from the readout pad and fitted it with a Gaussian model. An energy resolution of approximately 20% at the FWHM was achieved. The highest gain under stable operation at 190 Torr was 2×10^4 at dV_{GEM}= 560 V, while that at 20 Torr was approximately 300 at dV_{GEM}= 470 V. Above 50 Torr, the highest gain exceeded 3000, which meets our requirements for the XACT polarimeter. The gain curves could be reproduced by exponential functions; however, a change of slope with pressure was observed. In addition, we determined the real GEM gain derived from the sum of charge amounts induced in the readout pad and GEM anode using the same data set. The real gain represents the amplification degree of electron drifting in the GEM hole, while the effective gain is the real gain multiplied by the amplified electron collection efficiency of the readout pad.[5] The real gain is approximately twice the effective one because the charge amount of the GEM anode is almost the same as that of the readout pad.[6] The highest gain at 190 Torr is 4×10^4, while that at 20 Torr is around 600. These real gain curves also show deviation from an exponential function.

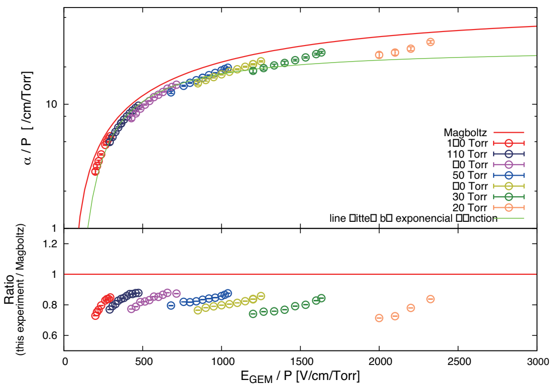

Fig. 1. Top: Comparison between the measured α and the α simulated by Magboltz[7] with 1σ errorbars.Bottom: Ratio of α obtained in this experiment to that obtained with Magboltz calculation.

To comprehensively characterize the gain variations with different gas pressures and GEM voltages, we derived the first Townsend coefficient, α. Fig. 1 shows the observed α as a function of E_{GEM}/P superposed with the results of Magboltz calculations.[7] E_{GEM} is the electric field applied to the GEM. The data points can be roughly reproduced by an exponential function, although they show deviation from it in the higher E_{GEM}/P range. This is because the DME ions gain sufficient kinetic energy from such a strong electric field to ionize the DME gas and emit additional electrons that are amplified in the GEM hole. The measured α values were approximately 80% of ones derived from Magboltz calculations, which suggests that the length over which the number of electrons were amplified in the GEM hole was different from the GEM thickness but close to 80 μm.

References
1) K. Gendreau et al.: Proc. SPIE, **8443** 84434V-1 (2012)
2) J.K. Black et al.: NIM, **A581** 755 (2007)
3) T. Tamagawa et al.: NIM, **A560** 418 (2006)
4) T. Tamagawa et al.: NIM, **A608** 390 (2009)
5) J. Benlloch et al.: NIM, **A419** 410 (1998)
6) Y. Takeuchi et al.: JINST, **7 C03042** (2012)
7) S.F. Biagi: NIM, **A421** 234 (1999)

† Condensed from the article in JINST 9 C01002 (2014)
*1 RIKEN Nishina Center
*2 Department of Physics, Tokyo University of Science
*3 NASA/GSFC
*4 Department of Mechanical Engineering, Kogakuin University