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Characteristics of a Micro-pattern Gas Detector with Pixel Read-out for X-ray Imaging

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A micro-pattern gas detector (MPGD) with a pixel read out was evaluated for X-ray imaging. Our MPGD has one gas electron multiplier (GEM) with an active area of 5 × 5 cm^2 as a charge amplifying stage that is completely decoupled from the readout electrode, and we have used an advanced printed-circuit board (PCB) technique to fabricate the micro-pattern readout. A test chamber was fabricated for our experiment, and all components of our MPGD were assembled in a test chamber filled gas. We studied the charge signal by X-ray used for a medical diagnostic system in the pixel readout with a gas mixtures of Xe (90%)/CO_2 (10%) and the performance of our MPGD was examined with an X-ray energy and various applied voltages of the GEM and the drift plate.

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I. INTRODUCTION

In the last decade, X-ray imaging techniques have developed rapidly, as a result of which traditional films have began to be replaced by electronic device. Also X-ray imaging systems based on the gas proportional detector have been conceived and rapidly developed [1]. In general, gas-filled detectors consist of an electrode plane and a segmented electrode structure inside a sealed chamber, and nowadays, various designs of micro-pattern gas detectors (MPGDs) exist [2]. Especially, the gas electron multiplier (GEM) has been introduced by Fabio Sauli as a charge-amplifying stage, and micro-pattern gas detector can improve the reliability of the combined detector [3]. On this account, GEMs present good alternatives for hard X-ray detection applications, such as X-ray imaging and synchrotron radiation studies [4]. The micro-pattern gas detector has a readout line or a pixel with a pitch of small as a few hundred microns because of advanced photolithographic techniques; thus, very good localization accuracy and very high rate capability can be obtained [5]. Recently, a position sensitive gas detector was introduced, and this detector has small pixels manufactured by using procedures normally used to build multi-layer printed-circuit boards (PCBs) [6]. In this way, structuring the readout PCB in a multi-pixel pattern, a full 2D capability can be achieved. These MPGDs with GEM s coupled to small 2D pixels have wide applications; X-ray astronomy and plasma imaging, *etc.* [5].

We have developed an X-ray image sensor with complementary metal-oxide semiconductor (CMOS) or thin film transistor (TFT) pixel readout by using a gas filled detector. For design of these readouts, the characteristics of the X-ray signals at the pixel should be evaluated. In this paper, the characteristics of the X-ray signal of a MPGD with a pixel readout were evaluated for X-ray imaging. We used an advanced printed-circuit boards (PCB) technique to fabricate the micro-pattern readout. Our MPGD has a gas mixtures of Xe (90%)/CO_2 (10%), at atmospheric pressure, and the simulation results were compared to experiments done with gas mixture.

II. EXPERIMENTS AND DISCUSSION

The schematic setup of the micro pattern gas detector (MPGD) is shown in Fig. 1. Essentially, it contains a

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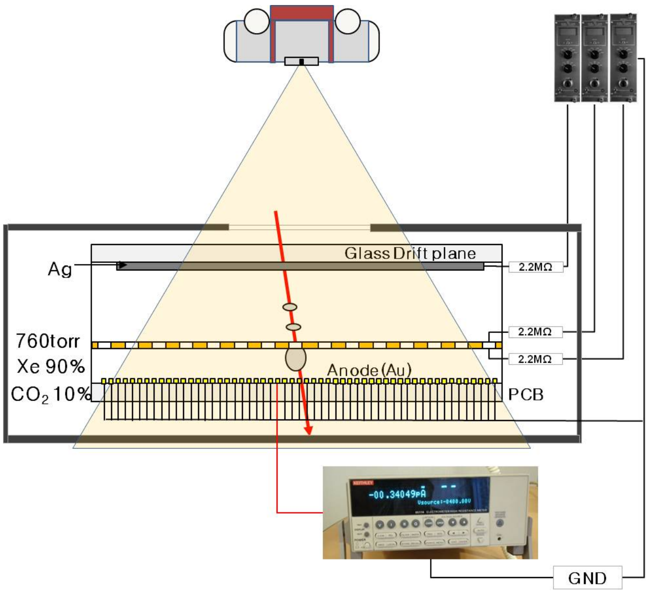

Fig. 1. (Color online) Schematic view of the experimental setup.

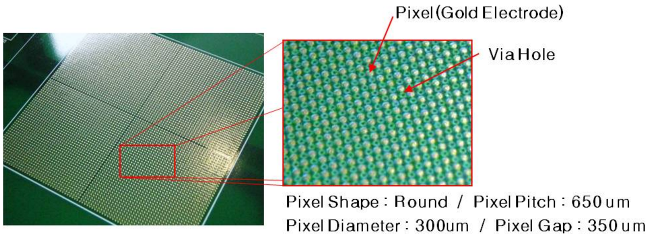

Fig. 2. (Color online) Multi-pixel readout.

test chamber, an X-ray tube, a drift plate, a GEM and a readout plate. We used single GEM with an active area of 50 × 50 mm^2, one of the standard type fabricated at CERN; the hole shape is a double cone with an inner diameter of about 45 μm and an outer diameter of about 70 μm. The hole pitch is 140 μm and the thickness of the GEM is about 60 μm, a 50 μm-thick kapton with 5 μm copper on each side. When a voltage is applied between the two conductive plates (copper), a strong electric field is generated inside the holes. We used glass substrates to fabricate the drift plate, and this drift plate was coated with silver. The drift plate was placed 4 mm from the top plate of the GEM, and the readout plate was placed 2 mm below the bottom plate of the GEM. The conversion gap and the collection gap were kept at 4 mm and 2 mm by using a spacer made of Teflon. The readout plate was fabricated by using the advanced printed-circuit boards (PCB) technique and has 76 × 76 pixels in 50 × 50 mm^2 areas. The pixels are round with a pixel diameter of 300 μm and a pitch of 650 μm. The pixel readout fabricated by using the PCB technique is shown Fig. 2. In the measurement, the drift plate, the GEM and the pixel readout were placed in the test chamber, and each electrode was connected to an individual ORTEC 556 high-voltage

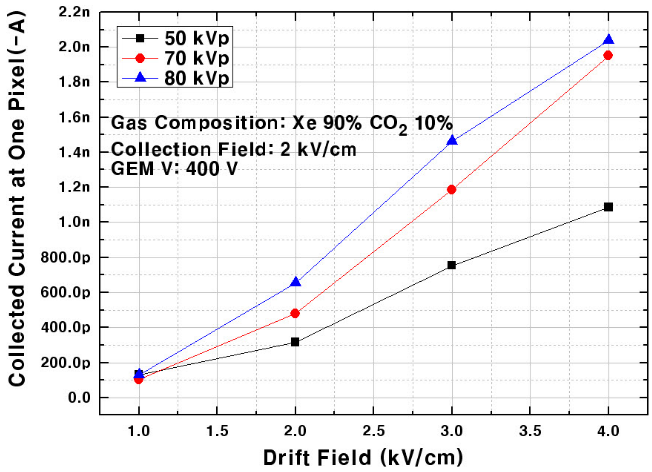

Fig. 3. (Color online) Measured current as a function of the drift field.

supply. We used a gas injection system and highly pure Xe (99.999% purity) and CO_2 (99.99% purity) with a mixing ratio of 9:1 to fill the chamber at atmospheric pressure. The current which were amplified by the GEM at the electrode pixels were measured through a Keithley 6517A electrometer. The signal was obtained at one pixel randomly randomly selected from all pixels, and we used the Labview program to control the data processor. The X-ray tube was placed 50 cm above the test chamber, and the X-ray tube has voltage range from 50 to 80 kVp, and the current was fixed at 15 mA. Our chamber measured the signal mainly for X-ray energies of 50 ∼ 80 kVp.

In order to check and evaluate the experimental results, we used the MCNPX code to simulate the interaction with X-rays in the gas mixture. The MCNPX code computes the rate of X-ray energy deposition in the detector geometry and various materials. For the energy deposition, the code tracked secondary electrons created by X-ray, and the ionization energy of the secondary particles was deposited uniformly along the track length. Therefore, we could estimate the energy deposited per unit track length. For every gas mixture, we used actual value for the 1 atm pressure, density, geometry, X-ray energy spectrum, and we used Maxwell program to simulation the electric field strength in the MPGD with a GEM. Maxwell is program computes the electric fields in the detector when the drift plate, the top and the bottom plate of the GEM have various applied voltages.

In a medium with perfect conductors and insulators, the current $i(t)$ induced by a moving charge q onto an electrode can be calculated by means of the Shockley-Ramo theorem:

$$i(t) = q\frac{\vec{v}_d(t) \cdot \vec{E}_w}{V_w}, \quad (1)$$

where $\vec{v}_d$, $\vec{E}_w$, and V_w are the charge drift velocity and weighting field and potential, respectively [7]. The cur-

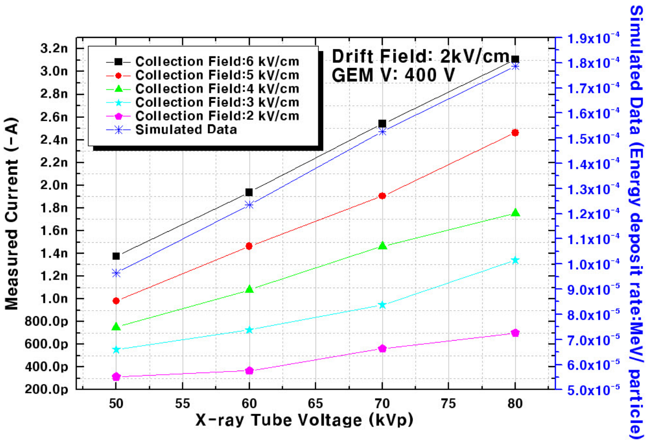

Fig. 4. (Color online) Measured current as function of the X-ray energy with various collection fields.

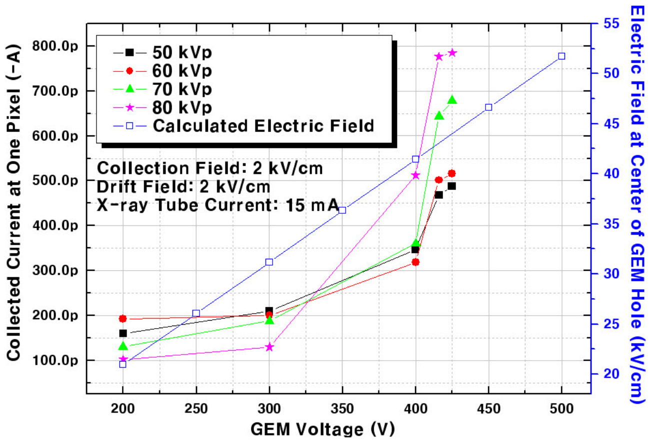

Fig. 5. (Color online) Measured current as function of the GEM voltage for various X-ray energies.

rent of the pixel readout electrode was investigated for a wide range of X-ray energies and compositions of the gas mixture. The current measured for Xe (90%)/CO_2 (10%) and various X-ray energies as function of the drift field is shown in Fig. 3. We also measured the current for drift fields less than 6 kV/cm, and the applied voltage difference between the GEM's top and bottom electrode was 400 V. The measured current increased with increasing drift field of the detector and increasing X-ray energy but at low drift fields (<1 kV/cm), we can see a similar value for X-ray energy of 50, 70, and 80 kVp. This occurs due to a defect in the charge collection efficiency, where the drift velocity of an electron in the gas mixture is reduced considerably at low fields (<1 kV/cm) [8]. Therefore, the current induced by a moving charge q onto an electrode decreases sharply at low drift fields and these values were similar for various X-ray energies. The measured current was about −1 nA for 50 kVp and about −2 nA for 80 kVp at a 4 kV/cm drift filed. The measured current and the simulated energy deposit rate for different collection fields as a function of the X-ray energy are shown in Fig. 4. The energy deposition was calculated by using MCNPX, and in the drift volume, which has gap as 4 mm between the drift plate and the top plate of the GEM, the calculated energy deposition is proportional to the X-ray energy and the Xe gas content. The number of primary electron-ion pairs (N_0) depends on the energy that the detected particle has deposited in the gas (ΔEnergy) and the average energy per ionization of the gas (W) [7]:

$$N_0 = \frac{\Delta \text{Energy}}{W}. \tag{2}$$

Therefore, it is possible to estimate the charge generated in the gas volume, but the simulated energy deposition results for one particle of an X-ray only, so we can't estimate an accurate result. We could only confirm the tendency of the energy deposition as a function of the X-ray energy and the gas composition. The calculated energy deposition decreased by about 7% when the Xe composition dropped to 5% for 80 kVp, and calculated energy deposition increased about 28%, 23%, and 17%, respectively, when the X-ray energy increase from 50 to 60 kVp, 60 to 70 kVp, and 70 to 80 kVp for the Xe (90%)/CO_2 (10%) gas mixture. These results were compared with the measured currents for different collection fields. The measured current increased about 40%, 31%, and 22 %, respectively, when the X-ray energy increased from 50 to 60 kVp, 60 to 70 kVp and 70 to 80 kVp for the Xe (90%)/CO_2 (10%) gas mixture at a 6 kV/cm collection field. The rate of increase for the measured current was inversely proportional to the X-ray energy and was larger than the calculated energy deposition rate, but the tendencies were similar. We also observed that the tendency of the rate of increase for the measured current with different X-ray energies disappeared at low collection fields. The larger the collection field, the more current collected, so the maximum measured current was shown at a 6 kV/cm collection field and this value was about −3 nA.

We obtained the collected current for various X-ray energies (50 – 80 kVp, tube current: 15 mA) as a function of the GEM voltage at 2 kV/cm collection and drift fields, and these results are shown in Fig. 5. We observe that the collected current was independent of the X-ray energy at low GEM voltage, and was proportional to X-ray energy at the GEM voltages above 350 V. The curves of the graph show a characteristic exponential avalanche growth. Above a GEM voltage of 400 V, the electric field at the center of GEM hole, calculated by using Maxwell was 41 kV/cm, and the currents were considerably increased. At GEM voltages >420 V, we could not measure current because a spark was generated.

Also, we observed that the measured current were linear in the incident dose, and this result is shown in Fig. 6. We used a dosimeter; DOSIMAX plus manufactured by iba dosimetry, and this dosimeter has the appropriate solid state detector and was used for the constancy test

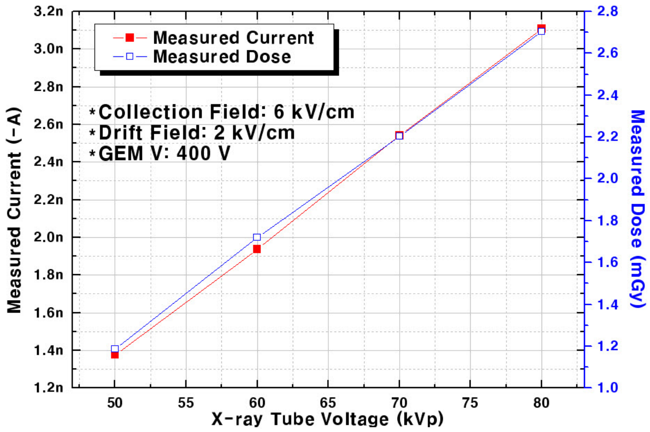

Fig. 6. (Color online) Measured linearity of the current in the incident dose.

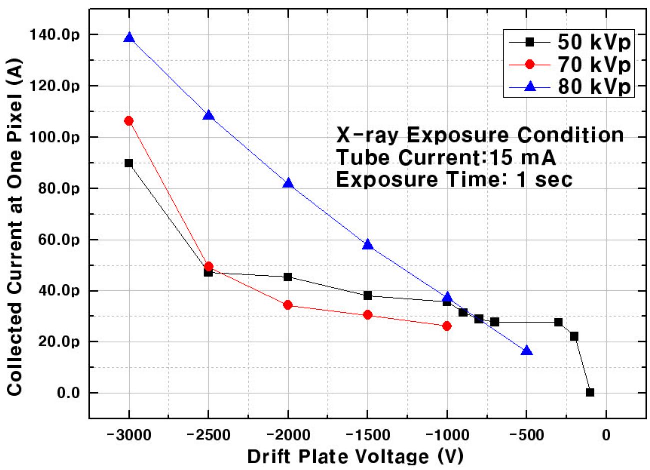

Fig. 7. (Color online) Measured current without GEM for various X-ray energies.

at the radiographic and fluoroscopic X-ray unit. The dosimeter was placed 50 cm below the X-ray tube where our gas chamber was located. The X-ray exposure time was 0.5 sec, and the X-ray tube current was 15 mA. The rate of increase of the measured current and incident dose were almost the same for different X-ray energies, and we confirmed that the measured current were linear in the incident dose.

We measured the current without the GEM and this result was compared to result with the GEM to investigate the effect of the GEM. The GEM was removed from the detector, and a drift plate was placed 6 mm from the readout electrode. A HV from −0 to −3000 V was applied to the drift plate and detector was exposed to 50, 70, and 80 kVp X-ray energies. We obtained the current collected at one pixel without the GEM, and this result is shown in Fig. 7. The measured maximum current was −140 pA when −3000 V was applied to the drift plate and the detector was exposed to an X-ray energy of 80 kVp. The maximum current measured was −3.2 nA with the GEM, so we confirmed the GEM effect and a rough gain for Xe (90%)/CO_2 (10%) was obtained. In experiments, our detector with the GEM had a signal as 20 times larger than that obtained without GEM.

III. CONCLUSION

We measured the current collected at one pixel in a MPGD filled with a Xe (90%)/CO_2 (10%) gas mixture for a single-GEM setup with a 4 mm drift gap and a 2 mm collection gap when a detector exposed to X-rays is used for a medical diagnostic system. We simulated the rate of energy deposition by X-rays and this result was used in order to check and evaluate the experimental result. The signals as currents were obtained and evaluated for various X-ray energies as a function of the drift and the collection fields and the GEM voltage. This result is important to optimize the design parameters of the CMOS or the TFT pixel readout for X-ray imaging by using a gas filled detector. Good choice of the drift and the collection field and the GEM voltage guarantee good image quality and stable operation. Besides, we confirmed that the measured current has linearity in the incident dose. The signal's linearity in the incident dose is important for obtaining an X-ray image. Finally, we observed the effect of the GEM plate on the signal collected at one pixel, and the signals were amplified 20 times.

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