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Development of digital imaging device based on the gas electron multiplier

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Abstract

We fabricated a gas electron multiplier (GEM) for application to digital imaging devices such as X-ray or γ-ray detectors. Sixty-four square (3×3 mm) copper pads were used to collect avalanched electron charge clusters from the GEM chamber. A 128-channel charge sensitive preamplifier, which also includes sample/hold amplifiers and a multiplexer, was used as the front end electronics of the readout circuits for data acquisition. With this system, we successfully took a two-dimensional digital image under the irradiation of the ^{55}Fe radiation source.

Keywords: GEM; Radiation detector; Digital imaging device; Readout electronics; Multichannel readout

1. Introduction

The gas electron multiplier (GEM) (Sauli, 1997) was developed to enhance the performance of traditional gas detectors (Büttner et al., 1998; Benlloch et al., 1998; Chechik et al., 1998; Bressan et al., 1999a,b) such as a multi-wire proportional chamber (Charpak et al., 1968) or micro-strip gas chamber (Oed, 1988), which have limited bias voltage levels due to the discharge between the electrodes. GEM devices have been used mostly to detect the trajectory of charged particles or to identify particles with spectroscopy in high energy physics. Furthermore, its various advantages, such as robustness, ease of manufacture and capability in the fabrication of large active area detectors, have opened up new possibilities in other applications.

Bressan et al. (1999c) and Bachmann et al. (2001) demonstrated a two-dimensional X-ray imaging system by using a GEM detector with a specially designed readout board. Their results showed the GEM detector's possible application in high resolution medical imaging systems. However, they used an external trigger signal, which was generated from the bottom electrode of the GEM foil, as the timing signal for the AD conversion. In this study, we used a multi-channel charge sensitive preamplifier (CSP) as the front end readout amplifier, which can integrate the charge signal from the readout board. The integration function allows us to take data with no external trigger signal, which makes the system simple and compact.

2. Fabrication of GEM chamber

The GEM foils (3M) used in this experiment as the dielectric layer are 50 μm thick(polyimide) and both sides of the dielectric layer were clad with a 5 μm copper film, which are used as the bias electrodes. Holes 55 μm in diameter were perforated at 140 μm of pitch. Two GEM foils were used in series to get sufficient signal intensity. As Fig. 1 shows, the thicknesses of the drift, transfer and induction regions' layers are 5, 3 and 1 mm, respectively. A single resistor network was used to provide the GEM chamber with high voltage. Each resistor R_p shown in Fig. 1 is for safe discharge between the electrodes, and 10 MΩ was used for each. The voltages provided to each individual electrode can be controlled by selecting appropriate values for resistors R_1–R_5.

The chamber was filled with a mixture of Ar and CO_2 at a mixing ratio of $Ar:CO_2 = 80:20$ (Bressan et al., 1999d; Bachmann et al., 2002). In this mixture Ar is the counting gas, which is the main source of the electron avalanche; and CO_2 is the quencher gas, which suppresses unwanted free electron generation from the recombination process of ionized positive ions on the cathode. Another important role of the quenching gas is the absorption of free electrons' energy in the clusters

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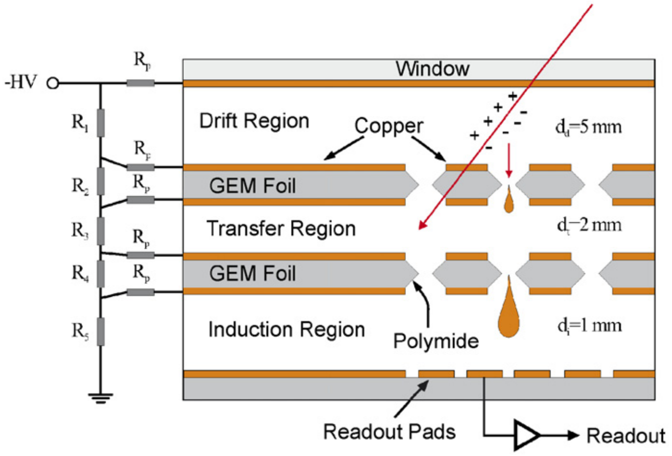

Fig. 1. Schematic of GEM chamber.

preventing thus an excessive ionization rate leading to high discharge probability. It also reduces the spatial dispersion of the electron clusters allowing us to achieve better spatial resolution. We can find a detailed discussion on quenchers and their properties in (Sauli, 1977). We operated the chamber in an open gas system because the mixed gas is nontoxic. The mixed gas flowed at a rate of 100 ml/min, and we assumed the pressure inside the chamber to be approximately atmospheric pressure.

3. Multi-channel readout electronics

So far, several kinds of readout structures for GEM detectors have been developed. For two-dimensional information readout, rectangular strips (or a Cartesian board) can be used (Bressan et al., 1999c). This method is very useful because it allows us to reconstruct very high resolution pixel information from the low density input channels. However, this method needs an additional calculation to find the coordinate where the electron cluster hits the readout board. Furthermore, an ambiguity may arise when more than two clusters hit the same strip simultaneously. In order to overcome these difficulties, a hexagonal pad structure with three coordinate axes was developed (Bachmann et al., 2001), but it still has the ambiguity problem when too many clusters hit the same axis.

Though it is difficult to achieve very high resolution readout due to the limitations of current fabrication technology, a pixel readout structure is the best way to avoid the ambiguity problem. When we use a pixel type readout board, each pixel pad is directly connected to a corresponding input channel of the preamplifier. Thus we can easily locate the position electron cluster hits from the number of channel where the signal comes, because we know the exact position of each pixel on the readout board. We fabricated an 8 × 8 pixel type readout board as the input channels of the CSP. The readout board was fabricated with ordinary PCB manufacturing technology. Each pad is 3 × 3 mm square and the pads' pitch is 4 mm. Sixty-four pads are arranged in a square and their numbers are indicated in Fig. 2. The charge signals from the readout pads are connected to the CSP's input via FPCB (Flexible Printed Circuit Board) cables. We used 8 cm long FPCB cables. However, we found that using a long cable as a CSP's input connector is undesirable because the longer the cable is, the higher the noise level is. Thus, we are now designing a new readout board which will be composed of readout pads and the CSP on the same PCB, on which the readout pads and the CSP are connected directly through the pattern on the PCB.

Fig. 3 shows the whole readout scheme. Because the signals generated on the readout pads are charge clusters, they should be transformed into voltage signals so as to be amplified and filtered in the circuits they follow. The CSP is the device that can convert the charge signal into voltage which is proportional to the amount of input charge. We used a CSP (VA_SCM2, IDEAS) which has 128 input channels. One of the merits of this chip is its function of integration on input charge. This integration function is particularly useful in the application of digital imaging devices. We can just integrate the input charge by opening the amplifier's input gate, with no external time trigger to indicate that the signal has arrived.

Because the VA_SCM2 is provided as a bare die chip, we should make a wire bond between the chip's input electrode and the corresponding readout pad on the PCB board. The pitch between neighbor input pads of the VA_SCM2 is 100 μm. On the other hand, both the track width and the space between tracks on the PCB are limited to 100 μm by the PCB fabrication technology's limitations. This means that we have to secure at least 200 μm of track pitch on the readout PCB, which made the wire bonding difficult. Thus, we decided to skip every even number of the chip's input channels. That is why we are using only 64 channels instead of all 128 channels in this experiment. Now we are finding a way to use all the input channels; one solution is to make an adapter between the input pads and the tracks on the PCB.

VA_SCM2 is composed of CSPs, sample/hold amplifiers (S/H) and a multiplexer. The CSP converts the charge signal into voltage and the S/H holds the input pulse's maximum value for a while so that the multiplexer can transfer the held signals to the analog to digital converter (ADC) in series. All these functions can be performed by providing appropriate timing signals. Five important timing signals are Amp_reset, Sample, Select, Shift_in and Ck (refer to Fig. 4). The chip can be reset by the Amp_rest, and can prepare integration of the input charge on CSP. The CSP's output is held during the Sample period and the held signal is connected to the multiplexer input by switching the Select signal, where all the signals on 128 channels are output in series by clocking the Ck signal. We can convert the multiplexer's analog outputs to digital values on an external ADC whose conversion timing is synchronized to the Ck signal.

The converted digital values are transferred to a PC to be analyzed, displayed and saved on storage devices. For rapid data transfer from the readout circuits to the PC, we used direct memory access (DMA) technology, which transfers the data from onboard FIFO memory to the system memory on the data acquisition (DAQ) PC directly, with no CPU intervention. This makes the transfer speed very high and decreases the possibility