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Application of CMOS charge-sensitive preamplifier in triple-GEM detector

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Abstract Among the various micro-pattern gas detectors (MPGD) that are available, the gas electron multiplier (GEM) detector is an attractive gas detector that has been used in particle physics experiments. However, the GEM detector usually needs thousands of preamplifier units for its large number of micro-pattern readout strips or pads, which leads to considerable difficulties and complexities for front end electronics (FEE). Nowadays, by making use of complementary metal-oxide semiconductor (CMOS)-based application specific integrated circuit (ASIC), it is feasible to integrate hundreds of preamplifier units and other signal process circuits in a small-sized chip, which can be bound to the readout strips or pads of a micro-pattern particle detector (MPPD). Therefore, CMOS ASIC may provide an ideal solution to the readout problem of MPPD. In this article, a triple GEM detector is constructed and one of its readout strips is connected to a CMOS charge-sensitive preamplifier chip. The chip was exposed to an ^{55}Fe source of 5.9 keV X-ray, and the amplitude spectrum of the chip was tested, and it was found that the energy resolution was approximately 27%, which indicates that the chip can be used in triple GEM detectors.

Key words GEM detector, CMOS ASIC, Charge-sensitive preamplifier, Energy resolution

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1 Introduction

With novel materials and advanced technique of printed circuit board (PCB) and micro-electronics being used in MPGD, over the past two decades, great progress has been made in MPGD[1], and as a new type of MPGD, the GEM[2] detector was developed during the late 1990s. Standard GEM from CERN is a thin, two-side copper-coated Kapton foil, perforated with a high density of holes etched using a photolithographic process. The diameter of these holes is about 70 μm (external) or 50 μm (internal) with a pitch of 140 μm [3]. By applying a suitable potential difference between upper and lower electrodes, a strong electric field as high as 100 kV/(cm·atm) can be produced inside those holes[4]. Therefore, electrons generated above GEM can be drawn into these holes and be multiplied. A GEM detector can be constructed using a single or several stacked GEM foils with a drift electrode and readout plane. Compared with the traditional position-sensitive gas detector, i.e. multiwire proportional chamber (MWPC) [5], the GEM detector possesses high rate limit, good position resolution, and other advantages.

Thanks to the relative separation from GEM electrodes, the readout modes of GEM detector can be very flexible and various, and as a promising MPGD, GEM detector has been used in particle physics ex-

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periments and also exhibits a great potential in medical and biological imaging systems. However, until now the best means to obtain an excellent position resolution in GEM detector has been by reducing the size of readout strips or pads of readout plane to the order of a micro-pattern, which markedly increases the number of readout units, and accordingly, large numbers of these readout units require large numbers of FEE units. Consequently, it results in considerable difficulties and complexities in a GEM detector and in other MPPD. At present, the size of integrated circuit (IC) has already reached the order of sub-microns and deep sub-microns and by adoption of CMOS, more than two million transistors can be integrated in an ASIC chip smaller than 0.5 cm^2 [6]. The unique features of high integration, lower cost, and lower power consumption of CMOS ASIC[6] offers an ideal means to solve the readout problem of MPPD caused by large numbers of micro-pattern strips of pads. In contrast to the traditional preamplifiers, CMOS-based ASIC chip has three advantages: high integration density, lower cost, and lower power consumption, and thereby can meet the requirements of FEE in GEM detectors and may also provide an ideal solution to the readout of other MPPD such as micro-strip gas chamber (MSGC)[7] and silicon micro-strip detector (SMSD)[8].

Considering the application of CMOS ASIC in MPPD, a triple GEM detector has been constructed by the authors of this study and one of its readout strips has been connected to a channel of a three-channel charge-sensitive preamplifier chip based on CMOS ASIC designed by Nuclear Electronics Laboratory of Department of Engineering Physics, Tsinghua University[9]. The chip was exposed to an ^{55}Fe source of 5.9keV X-ray, and the amplitude spectrum of the chip was tested and its energy resolution was found to be approximately 27%, which indicates that the chip can be used in triple GEM detectors.

2 Experimental setup

2.1 Triple GEM detector

A triple GEM detector is built by CERN standard $10\,cm\times10\,cm$ GEM foils to detect low-energy X-rays. As shown in Fig.1, three GEM foils are stacked one above another at a distance of 1 mm (transfer gaps) and were positioned 1 mm above the readout board (induction gap). On top of the stack, a cathode plane with 80 μm-thick mylar film defines a 4.5 mm-thick drift gap. The readout board with 3 mm wide anode strips at 0.5-mm pitch is made of print circuit board (PCB). The frame of the chamber is made of 6 mm-thick copper, and the chamber is operated with gas mixture of “Ar (70%)+CO_2 (30%)” at atmospheric pressure.

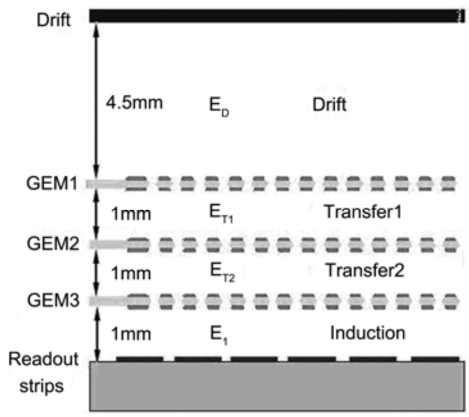

Fig. 1 Structure of the triple GEM detector.

The main amplifier connected to the CMOS preamplifier is ORTEC Model 572 and the multi-channel plus height analyzer is ORTEC Model 919E. To simplify the high-voltage division circuit, the high voltages supplied by ORTEC Model 556 on GEM electrodes, transfer and induction regions are equal, and for comparison, the readout strip of the triple GEM detector is also connected to a commercial preamplifier of Canberra Model 2006. The main performance of these two preamplifiers is listed in Table 1.

Table 1 Main performance of preamplifiers Model 2006 and CMOS ASIC

Preamplifier	Equivalent noise charge (ENC) (electrons)	ENC slope (electrons/pF)	Rise time (10%-90%) / ns	Decay time constant / μs	Charge sensitivity / mV·pC^{-1}
Canberra Model 2006	<350	~1	<25	50	~294 or 1469
CMOS ASIC	<1377	43.7	49.8	<0.84	~1000

2.2 CMOS charge sensitive preamplifier (CMOS ASIC)

When designing the CMOS ASIC, it is assumed that leakage current I_d and inter-electrode capacitance C_d of a detector is 1nA and 1pF respectively. It is also determined that feedback capacitance C_f and feedback resistance R_f of the CMOS ASIC is 1pF and 1.4 MΩ respectively. As shown in Fig.2, the basic structure of the CMOS ASIC is common-source and common-gate with metal-oxide semiconductor field effect transistor (MOSFET) M_1 and M_3. Because in a chip it is very difficult to realize a resistance with MΩ order of magnitude directly, the R_f is realized by making a MOSFET M_f working in variable resistance region.

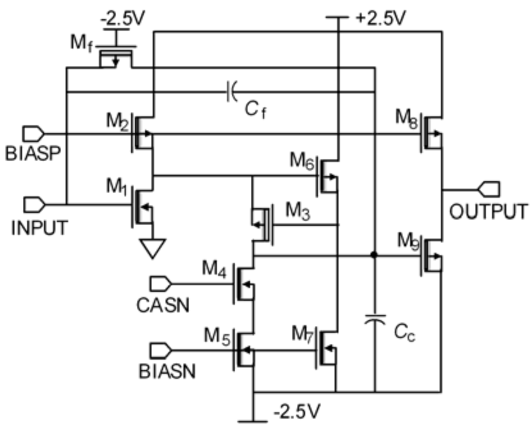

Fig. 2 The circuit schematic of the CMOS charge sensitive preamplifier.

Fig.3 shows the chip layout of the CMOS ASIC which consists of three channels and its upper-left corner is a circuit for supplying offset voltage. The total area of this chip is 260 μm×210 μm, so its integration density is higher than traditional preamplifiers by at least three orders of magnitude. Power consumption of this chip is 0.15mW and in input-stage MOSFET, it is adopted interdigitated structure to reduce the noise caused by passive resistance on gate.

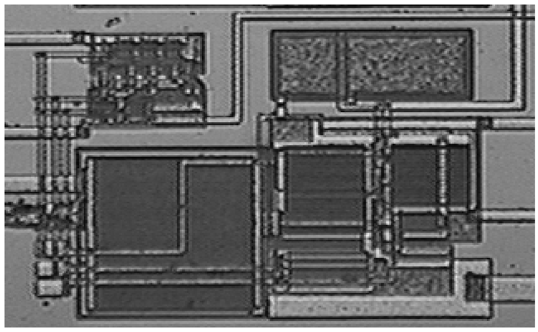

Fig. 3 The printing plate of the CMOS charge sensitive preamplifier.

3 Measurement and results

The output signal from CMOS ASIC is shown in Fig.4[9], in which rise time of the square-wave of input is 15ns. Fig.5 shows the amplitude spectrums of X-ray source ^{55}Fe measured with Canberra Model 2006 and CMOS ASIC under the condition that potential difference between GEM electrodes is 360V, electric field in transfer regions and induction region is 3.6kV/cm and effective gain of the triple GEM is 8×10^3. According to those two spectrums, the Ar escaping peak is clear. Although energy resolution of 5.9keV with Canberra Model 2006 (24%) is a little better than that with CMOS ASIC (27%), it should be noted that when measuring the spectrum with Canberra Model 2006, the source of ^{55}Fe was calibrated, while the source was not calibrated when the spectrum was measured with CMOS ASIC.

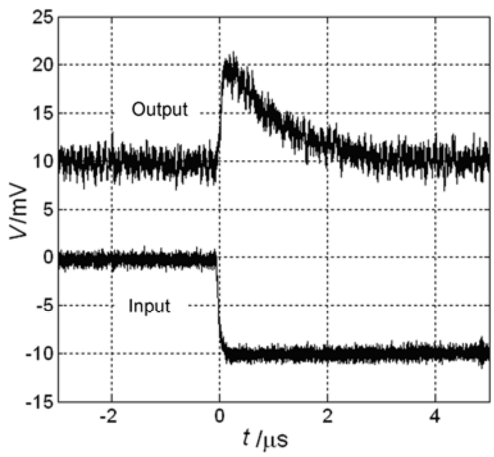

Fig. 4 Output signal from the CMOS amplifier.

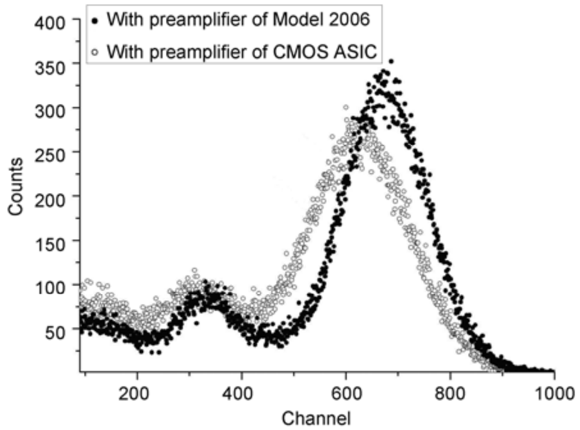

Fig. 5 Amplitude spectrums of ^{55}Fe with CMOS ASIC and Model 2006.

4 Conclusion and outlook

Indeed ENC of CMOS ASIC is larger than the commercial preamplifier (as listed in Table 1), but as for a triple GEM detector, at a normal gain around 10^4, much higher than other MPGD (only about several hundred), CMOS ASIC can be used as FEE in triple GEM detector. We have constructed a triple GEM detector and by making use of CMOS ASIC, tested its amplitude with ^{55}Fe. It indicates that energy resolution of 5.9keV X-ray with CMOS ASIC can be comparable with the result of Canberra Model 2006. Furthermore by its high integration density, at about $10^4/cm^2$, a small sized CMOS ASIC chip can accommodate hundreds of FEE units for micro-pattern readout strips or pads of GEM detector in a limited area, which can solve the difficulty of readout of GEM detector easily.

Further studies of this technique applied in GEM detector, e.g. 128 units of a CMOS ASIC chip connected to micro-pattern strips or pads of a triple GEM detector, crosstalk in a chip will be carry out in the next work.

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