Micromegas prototypes with thermo-bond film separators*

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Abstract: In this paper we report the results of Micromegas prototypes constructed by attaching micromesh to an anode using thermo-bond films. The excellent metal attaching ability and good dielectical property of this kind of film make it a promising material to be used as avalanche gap spacers. Several prototypes are successfully made. The electron transmission properties are first studied and then the gas gain is measured in argon-isobutane mixtures. The maximum gain of more than 10^4 is easily obtained. The energy resolutions for ^{55}Fe 5.9 keV K_α ray can be better than 20% over one magnitude in gain for different operational gas mixtures and the best energy resolution of 13.7% (FWHM) can be achieved with the gas mixture of 94% argon concentration. The preliminary test results of the prototypes with sensitive area of 45 mm×45 mm without internal support show good uniformity across the sensitive area.

Key words: Micromegas, thermo-bond film, separator, electron transmission, gain and energy resolution

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1 Introduction

The Micromegas detector developed at Saclay (France) in 1995 is a kind of micro pattern gaseous detector [1] with two asymmetry gaps separated by three parallel electrodes. The detailed working principle had been explained in Refs. [1, 2]. The key feature of Micromegas detectors is the presence of a micro-structural avalanche gap (typically a few hundred microns) with a very strong electric field which leads to quick ion collection and high gas amplification. It shows bright prospects of application in both high energy experiments and nuclear experiments for its high rate capability, good time resolution as well as the excellent spatial resolution if micro-strip readout pattern is employed [3–5].

The crucial step in Micromegas fabrication is the construction of the avalanche region. It is composed of a micromesh electrode, a readout pad and a separator. Micromesh used as avalanche electrode is supported by the spacer on top of the anode and the spacer should be insulating and have good mechanical properties. In view of this, several materials have been chosen. One is the etching plastic pillars accompanied by the development of "Bulk" technique [6] and another one is the finishing lines [7] as well as other suitable materials.

It is attractive to find new ways to build Micromegas detectors which could make the fabrication process easier and also reduce the costs without compromising the detector performance. This work reports a novel idea to build Micromegas chambers using thermo-bond films as avalanche gap separators. This kind of work makes it possible to build chambers without internal solid state support structure which meets the requirement of medical imaging that no dead-zone should be present in the sensitive area. The "easy-attaching" property and good mechanical strength of the film make it applicable for the design of large area detectors. Also, the excellent metal adhesive capability will assure the use of thermo-bond films to make multi-layer parallel mesh chambers

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such as PIM (Parallel Ionization Chamber Multiplier) [8]. Some basic properties of the prototypes which have one amplification gap are tested and will be reported in the following.

2 Thermo-bond film and Micromegas fabrication

2.1 Thermo-bond film

Thermo-bond film is a kind of adhesive bonding film which is flexible and insulating. The film is usually made of a substrate sandwiched by two bond lines or only two bond lines attached together side by side. Typically, it is few hundred microns thick and can be cut into various shapes. It is solid at room temperature but can melt and becomes adhesive if heat is applied. Temperatures for the film softening usually can extend from 120 ℃ to 200 ℃. This kind of film can be used to splice different materials together using different thermal attaching methods. The excellent adhesive ability exhibited while attaching metal substrates makes it a good candidate for the avalanche gap separator in Micromegas detectors.

2.2 Micromegas prototypes fabrication

Several Micromegas prototypes with thermo-bond film separated avalanche gaps were successfully made and the schematic view of the detector is illustrated in Fig. 1(a). The prototype fabrication processes are as follows:

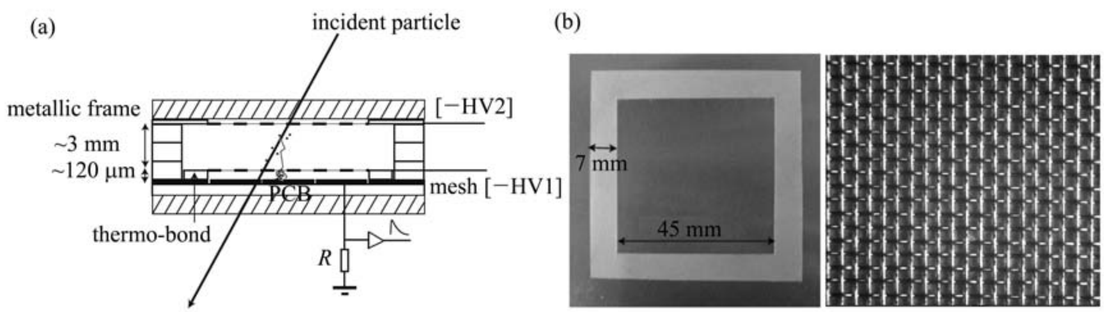

Fig. 1. (a) Schematic view of the Micromegas prototype and experimental setup; (b) Cut thermo-bond film frame (left) and 350LPI tabby woven wire mesh (right).

1) Preparation. Cut thermo-bond films into box frames (Fig. 1(b) left); cut two metal wire meshes into proper size and pull them taut; attach one mesh to an epoxy frame to form a drift electrode.

2) Thermal attachment. Put the anode PCB board on a flat electric platen; place the cut thermo-bond film and tightened mesh on top of the anode; heat the whole system to the temperature when the film starts to melt; use a laminator roll on top of the mesh and make them adhere firmly.

3) Assembly. Wait for the heated anode to cool down, weld the readout circuit and assemble the whole detector.

The meshes we used are 350LPI (line per inch) woven wire meshes (Fig. 1(b) right) which have 50 μm×50 μm square holes and pitch size of 70 μm when it is tightened. This kind of woven mesh is easy to fabricate and has been used by other groups [9, 10]. The thickness of the mesh after it is stretched is about 42 μm, almost the same compared with the original mesh. Thermo-bond film used as separator is 160 μm thick and the formatted avalanche gap after thermal adhesion is somewhat smaller. The readout PCBs for the prototypes each contain 9 copper pads which form a 3×3 array. Each pad is a 15 mm^2 square and is covered with gold on the face. All pads have separations of 300 μm between each other.

3 Experimental setup

The Micromegas prototypes are tested inside a metal vessel which has windows at the top lid. A gas mass flow controller is connected to the vessel and supplies argon and isobutane mixtures with controlled gas concentration. An electronic chain which contains an Ortec 142AH charge sensitive preamplifier, an Ortec Model 855 main amplifier and a Multi Channel Analyzer (MCA) is connected to the detector and the data are acquired from a computer linked to the MCA.

A ^{55}Fe radioactive source which provides 5.9 keV X-ray is used during the tests. X-rays can easily penetrate the 15 μm thin polyvinyl chloride foil window and enter the drift region. In order to reduce the electronic noise which is one of the most important influencing factors for low energy measurements, the whole system is aligned together and set at ground. Also the output signal line of the detector and the preamplifier are enclosed by aluminum foils.

4 Results

Several prototype chambers with sensitive area of 45 mm× 45 mm and frame width of 7 mm are constructed using the method stated above. The electron transmission across the wire mesh, the gas gain and the energy resolution are tested and studied.

4.1 Electron transparency

The electric fields of a Micromegas detector are uniform both inside the drift and the avalanche region. But the electric lines near the avalanche mesh behave like a "funnel" and those coming from the drift region are compressed towards the centers of the holes. The shape of the "funnel" is relative to the electric field ratio of the avalanche and drift region and will affect the transmission of electrons generated in the drift region by passing through particles. Due to their relatively low mass, the electrons will suffer diffusion in the gas and the trajectories will deviate from the electric lines. This leads to the electron transmission also being influenced by the geometry of the mesh, such as mesh thickness, wire diameter and the size of square hole. For those detectors with thin electroformed micromeshes (thickness ~5 μm), full electron transparency seems easy to obtain for certain field configuration and proper optical transparencies. However, previous study with woven wire mesh (thickness ~20 μm) shows that full electron transparency is hard to achieve for thick meshes [11]. So we have to study the electron transmission properties with our 350LPI mesh.

Since the gain for fixed avalanche electrode voltage is the same for different drift electrode voltage configurations, the variation of MCA channel corresponding to photoelectric-peak of 5.9 keV X-ray with the drift electrode voltage will reflect the change of electron transmission with the electric field. In our experiment, the voltages of the avalanche electrode are fixed first and then the drift electrode voltages are set to obtain different electric field ratios. Simulation of electron transmission using CERN developed software Garfield [12] also has been done. Simplified geometry which constructs the mesh by crossed columns is used in the 3D model to generate electric fields and the field data are then input to Garfield to perform Monte Carlo simulation. The experimental measurements of variations of the 5.9 keV X-ray photo-peak with field ratio are normalized to be compared with the simulations.

Comparisons of the two aspects are plotted in Fig. 2(left). The electron transparency shows no dependency on the avalanche mesh voltage, i.e. it does not depend on the gas gain as expected. The rough consistency of simulation and experiment also shows that full electron transparency can be obtained for such 350LPI mesh if the electric field ratio is sufficiently high. Tests results in other argon-isobutane mixtures are presented in Fig. 2(right). The maximum values of MCA channel correspond to the points where full electron transparencies are reached. Much higher field ratio is required for argon-rich gas mixture to reach the maximum. This can be explained by the influence of electron diffusion in the gas. Transverse diffusion of electrons is more significant in argon-rich gas mixture at electric field about several hundred to a few thousand V/cm; so much higher field ratio is needed to compress the electric line much tighter in the hole and to transport all drifting electrons generated in the drift region. The decline of the curve at high electric field ratio is the result of the recombination effect of electron-ion pairs at low drift electric field.

4.2 Gas gain and energy resolution

Gas gain properties of the prototypes are tested for various argon concentrations. A ^{55}Fe radioactive source is placed at the center of the metal vessel. Nine readout pads are connected in parallel. Then the induced signals are injected to the electronic chain and converted to MCA counts in different channels. Before the tests, the electronic chain is calibrated by known square waves. The relationship between MCA channel and input charge is derived and shows good linearity.

N_0, the number of electrons generated by the 5.9 keV X-ray in the drift region is calculated to be E/ε_0 and ε_0 is given by:

$$\varepsilon_0 = \frac{\varepsilon_{\rm Iso}\varepsilon_{\rm Ar}(Z'_{\rm Ar}P_{\rm Ar}+Z'_{\rm Iso}P_{\rm Iso})}{\varepsilon_{\rm Iso}Z'_{\rm Ar}P_{\rm Ar}+\varepsilon_{\rm Ar}Z'_{\rm Iso}P_{\rm Iso}}, \tag{1}$$

where $\varepsilon_{\rm Ar}$, $\varepsilon_{\rm Iso}$, $Z'_{\rm Ar}$, $Z'_{\rm Iso}$, $P_{\rm Ar}$, $P_{\rm Iso}$ are the average energy loss per produced ion pair, the effective atomic number and the partial pressure for argon and isobutane respectively.

The gas gain G is then determined by (assume electron transparency is 100% according to the above

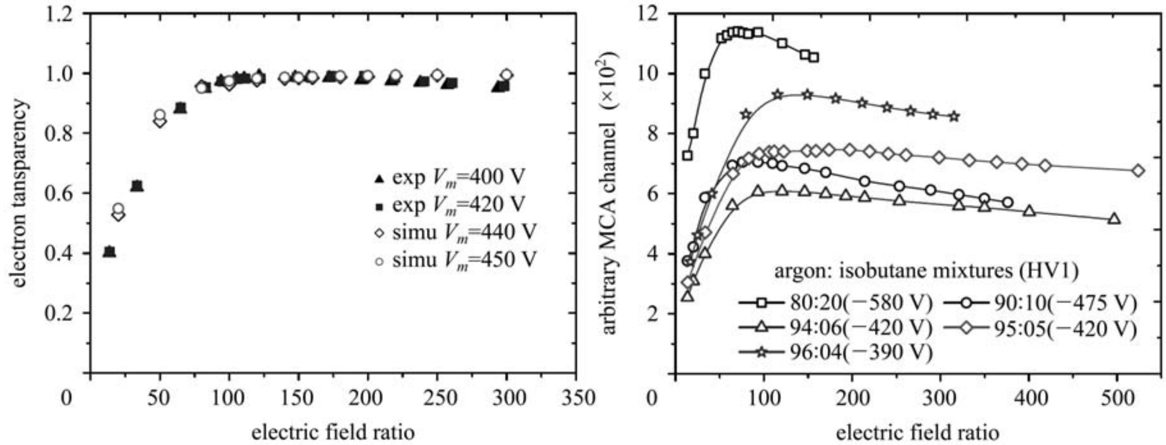

Fig. 2. Comparisons of simulation and experimental results of electron transparency variation with electric field ratio (gas mixture: Ar/iC_4H_{10} 95/5) (left); The photo peak positions of 5.9 keV X-ray as a function of electric field ratio (right).

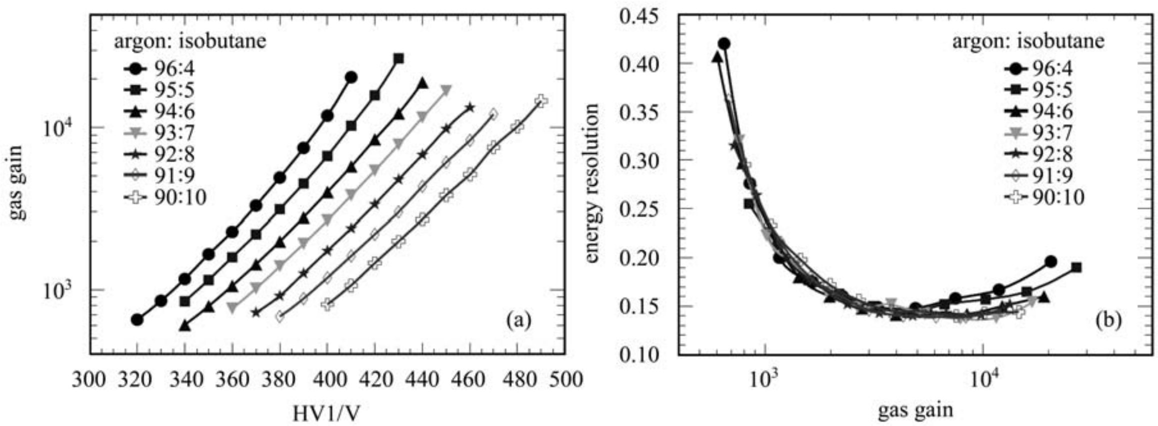

Fig. 3. (a) Gas gain versus applied avalanche electrode voltage (HV1); (b) Energy resolution as a function of gas gain.

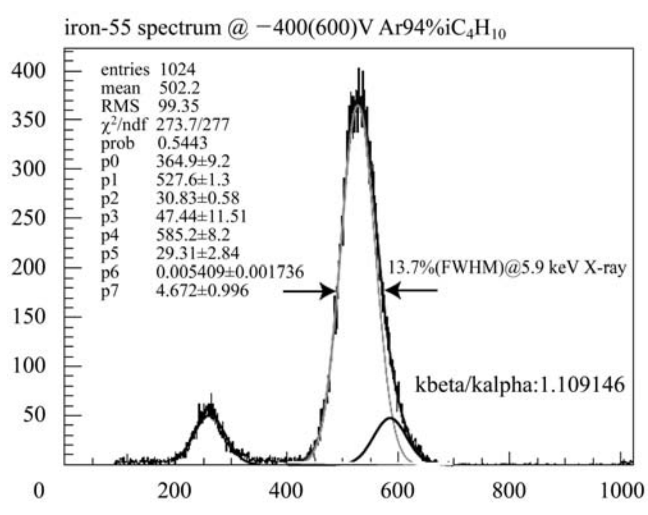

Fig. 4. The best energy resolution for 5.9 keV X-ray (obtained at 94% argon concentration).

discussion):

$$G = \frac{Q}{N_0 e}, \tag{2}$$

where Q is the charge deposited in the Microemgas and e is the charge of an electron. In our experiments, two applied negative high voltages are first optimized to obtain the maximum electron transparency, and then the data are taken for 300s to obtain the gain and the energy resolution. Results are plotted in Fig. 3. The gain varies exponentially with the applied avalanche voltage which is consistent with the prediction of an exponential relationship between the gain and the avalanche electric field. The maximum gas gains of more than 2×10^4 are achieved (see Fig. 3(a)) for low isobutane concretions and no excessive discharges for the tested high voltage are observed.

The energy resolution is obtained by one Gaussian function fitting of the measured X-ray spectrum (see Fig. 3(b)). The resolutions are better than 20% over one order of magnitude in gain. For spectrums with good resolutions (better than 15%), two Gaussian functions and a linear function are used to fit 5.9 keV K_α ray, 6.5 keV K_β ray (2.9% radiation probability from ^{55}Fe decay) and the noise separately. Even with an uncollimated source, the best energy resolution of 13.7% can be achieved for 5.9 keV K_α ray in 94% argon concentration with proper high voltage configuration (Fig. 4).

4.3 Uniformity

Uniformity is a key character for the design of large active area detectors. Homogeneous response of the detector is desired for the whole sensitive area. In order to test the uniformity of the prototype, the radioactive source is used to scan with a step of 5 mm horizontally (denoted as x direction) and vertically (denoted as y direction) from the center of the detector to the other two sides. The gain and the corresponding energy resolution are measured in the gas mixture of argon-isobutane 95:5. The results are shown in Fig. 5.

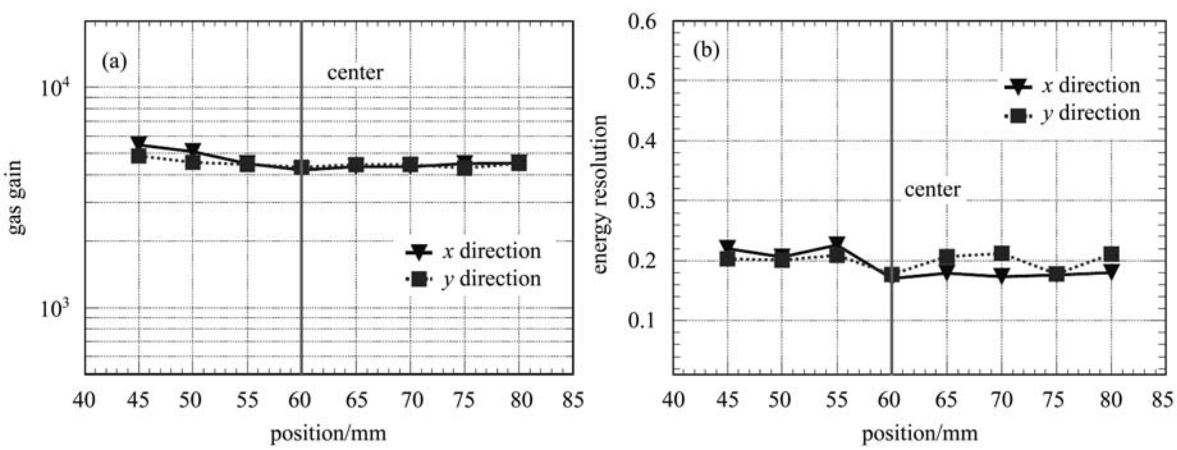

Fig. 5. (a) The gain uniformity in two directions; (b) The energy resolution uniformity in two directions (These are tested with 95% argon-5% iC_4H_{10} gas mixture, HV1=−410 V, HV2=−520 V).

The measurements show good uniformity over 30 mm for both directions, the gain variation is roughly within 10% except for the points which near the edge. Compared with the x direction, both the gain and the energy resolution uniformity of the y direction are better. This is closely related to the process of thermo-attaching, because the pressure on the mesh during adhesion is applied by hand. The uniformity of the pressure is hard to control and this will bring defects of the avalanche gap and the nonuniformity of electric field. The experimental results abovementioned also demonstrate that to keep equidistance between the mesh and the anode is of great importance to the energy resolution. It is expected that the uniformity for larger chambers can be improved by using wider thermo-bond films and using a mechanized laminator to well control the pressure and the temperature in the thermal attaching process.

5 Conclusion

A new method which uses thermo-bond film as the avalanche gap separator of Micromegas detectors is explored in the laboratory. Prototypes with active areas of 45 mm^2 using thermo-bond films and woven wire meshes are successfully made. Gas gain up to 2×10^4 can be obtained for several argon-isobutane gas mixtures and the best energy resolution of 13.7% for 5.9 keV X-ray is achieved. Simulations and experimental research on electron transparency show that almost full electron transparency could be obtained for our 350LPI mesh with pitch sizes of 70 μm and wire diameter of 20 μm. Preliminary tests of the gain and the resolution uniformity using uncollimated ^{55}Fe show that the gain variation is 10% over 30 mm for two perpendicular directions in the sensitive area.

In order to improve the results, we are planning to use a mechanized laminator in the thermal attaching process. Attempts to construct prototypes with larger sizes are now in progress.

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