Thermal bonding method for fabricating Micromegas detector and its applications

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Abstract: Over the past decade, thermal bonding method (TBM) has been developed for the efficient fabrication of Micromegas detectors. This method provides a concise and etching-free mass-productive process to fabricate the sensitive structure of the Micromegas for gas avalanche. In this paper, our research work on the TBM is presented exhaustively. X-rays were used to characterize Micromegas prototype built with this method. A typical energy resolution of ~16% (FWHM) and an absolute gain of >10^4 were obtained for 5.9 keV X-rays. Because of its lab-friendly operation, the TBM facilitates the exploration of applications and new Micro-Pattern Gaseous Detector structures. One such structure is the Double Micro-Mesh gaseous structure (DMM), which shows very low ion-backflow (~0.05%) and very high gain (>10^6 for single electrons).

Key words: Micromegas fabrication, Thermal bonding, high gain, low IBF.

1. Introduction

Micromegas is a typical Micro-Pattern Gaseous Detector (MPGD) invented in 1996 [1]. It is designed as a two-stage structure: a 3-5 mm drift region for primary ionization of charge particles and a ~0.1 mm micro-gap for gas avalanche. Because of its excellent energy resolution, rate capability, and large area possibility, many methods have been developed to manufacture detectors, in which, the narrow avalanche gap is the most challenging part to fabricate. Among the fabricating methods, chemical etching [2,3] has been well developed and validated through many experiments, such as T2K [4] and future upgrade of ATLAS [5]. Nonetheless, for circumstances that demand extremely high gain ratio and low ion back flow, new amplification structure developments are of the highest priority; thus, new fabrication methods are being explored.

Newly developed in the past decade, the thermal bonding method (TBM) has shown potential to provide an easier and more efficient way to manufacture Micromegas and interesting derivatives. As opposed to etching pillars, the TBM uses spacers made of thermal bonding film, which have an adhesive-polyester-adhesive triple-layer structure [6], to support and fix the stainless steel mesh on the readout anode, thus forming the micro gap between them.

The rest of this paper is organized as follows. The TBM is introduced in the next section. Section 3 presents the performance of detectors. Section 4 details the use of TBM to fabricate several prototypes and their successful use in different purposes, such as trackers for muon tomography, neutron beam monitor, double mesh detector for single
electron detection; these applications have strongly verified the feasibility of this method.

2. Thermal bonding method

Figure 1 shows a schematic of the TBM. Round pillars made of thermal bonding film, with a diameter of ~1 mm and a thickness from several tens to hundreds of µm, are arranged at a distance of ~10 mm on the readout Printed Circuit Board (PCB) as spacers to support the mesh electrode. They are first preset on the PCB after the board surfaces are rinsed. Both manual and mechanical methods to preset spacers have been tested and found suitable for different situations. Then, stainless steel mesh is directly placed on the spacers from both sides and hot pressed as a bulk. Thermal bonding film is then melted and used to stick the mesh to the PCB after it cools down to room temperature.

![Fig. 1 Schematic of TBM for Micromegas](image)

2.1 Industrialized fabrication process

Studies on the industrialized fabrication process have led to the conclusion that this process can fabricate efficient and high-grade amplification structures. The process is presented step by step in Fig. 2.
Preparations for the TBM mainly include stainless steel mesh and spacer cutting. The mesh is fully stretched to ensure it is under high tension (25–30 N/cm), depending on the spacer settings, with a stretching machine. Figure 2 (a) shows a microscopic view of the stretched woven mesh. Spacers (black) with array patterns are made by laser cutting and retained on a release substrate paper (white) as shown in Fig. 2 (b).

Spacer arrangements are designed and bonded on a readout PCB by pre-heating with a hot roller at ~110 °C, while the pattern, shown in Fig. 2 (b), is turned over and tiled on the anode. As shown in Fig. 3, the spacers, measuring ~1 mm in diameter, are set 10 mm apart to ensure that the dead area is constrained to a small fraction (~1%). This is similar to that in the bulk method, where pillars with a diameter of 0.2–0.4 mm are set at a distance of 2 mm from each other [2]. The dead area is the ratio of spacer and active area, and is mainly limited by spacer diameter as laser cutting cannot cut the spacers as complete circles. The larger spacer and distance make it easy to keep the avalanche region clean, which is important to evade sparking in high electric field. However, a much higher stretching force is thus required on the mesh to resist the electrostatic force between the mesh and anode.

Fig. 2 TBM fabrication steps. (a) Microscopic view of the stainless steel woven mesh. (b) Thermal bonding spacers on a release paper substrate made by laser cutting. (c) Spacers preset on a readout PCB. (d) Avalanche structure manufactured by TBM. (e) Assembling of the drift electrode. (f) Micromegas detector

Fig. 3 Schematic design for spacer arrangement.
Typically, a thick metal or honeycomb plate is attached to the back of the readout PCB to achieve the acceptable flatness for some MPGDs like GEM and Micromegas equipped with tensile foils and meshes. This inevitably increases both the detector thickness and material budget, which should ideally be low. As shown in Fig. 4, adding meshes to both sides of PCB, named back-to-back structure, is a novel concept, and prevents the PCB from bending. The back-to-back structure can be implemented to resolve the bending caused by the high tension on the mesh, with stretched meshes bonded on both sides to fabricate two symmetric avalanche gaps. This configuration allows the tension to be cancelled properly. In addition, the two avalanche gaps can be operated as two independent detectors or a single detector with double avalanche gaps by concatenating the readout anodes of both sides. Furthermore, inadequate explorations on single mesh Micromegas were performed to inspect for PCB warpage. No evident hints of warpage were observed for a 2.4 mm board thickness, which has a 300 mm × 300 mm total area and 150 mm × 150 mm mesh fraction.

Fig. 2(d) shows the avalanche structure. The Micromegas detector is assembled by cutting off the excess mesh, adding a drift electrode (Fig.2(e)), gas chamber, HV box, etc. Fig. 2(f) shows the Micromegas detector, which has an active area of 150 mm × 150 mm.

In contrast with an industrialized process, a manual method only differs in terms of the spacer presetting as spacers are individually preheated with a hot-air pencil. Therefore, the manual method is time consuming and limited to small size detectors.

3. Performance study of the Micromegas prototype

The basic performance of the Micromegas prototypes is studied with a $^{55}$Fe X-ray source in a gas mixture of Ar (93%) and CO$_2$ (7%). Energy resolution of ~16% FWHM (shown in Fig. 5) and high gain ($> 10^4$) is achieved (shown in Fig. 6).
The non-uniformity of gain is defined as the ratio between variance and mean of the peak values of the energy spectra, and was tested for every 10 mm × 10 mm. The gain non-uniformity, which is typically ~18% for manual prototypes, needs to be optimized by further technical improvements. One strategy to refine the non-uniformity is to replace the frame (8 mm wide black square in Fig.2 (b) and difficult to be hot pressed) with a thinner one, which implies combining two different thick thermal bonding films in one detector. Furthermore, spacers are hardly preheated at a uniform flatness, which significantly contribute to the non-uniformity.

4. Applications
The best way to validate the stability and performance of the detectors is to use them in systematic experiments. Many prototypes are designed and fabricated for different application purposes. A six-layer tracker system is built as a cosmic ray telescope using Micromegas prototypes each with an active area of 90 × 90 mm² and has been operated periodically for approximately two years, which confirms the good stability of the detectors [7].
In the China Spallation Neutron Source (CSNS), an advanced accelerator-based neutron facility proposed to serve both scientific research and industry applications, a 2D readout MicroMegas-based neutron detector has been fabricated and characterized using the TBM. The neutron beam of CSNS Back-n was measured and, for the first time, a 2D neutron beam spot distribution at Back-n beam line was obtained. Figure 7 illustrates the fabric of the 2D beam monitor.

![Fabric of beam monitor for CSNS Back-n line](image)

In addition, because of the flexibility of the TBM, a new structure of high-gain, low ion-backflow (IBF) Double Micro-Mesh gaseous structure (DMM) detector has been developed for the purpose of single photo-electron detection. As shown in Fig. 8, two stacked meshes are bonded to achieve a two-stage cascade avalanche structure. The high gain (>10^6) and low IBF ratio (~0.05%) of the DMM indicate that it can potentially be used in Gas-PMTs and other applications; for example, readout of time projection chamber detectors for future collider experiments.

![Schematic diagram of DMM](image)

5. Conclusion

The TBM, an innovative method for Micromegas fabrication, has been proposed and studied in the past decade. In this TBM, large distance between the spacers makes it easier to keep the avalanche region clean and reduce the sparking probability. The back-to-back structure allows for no additional supports to be used; this reduces the thickness of the detector and the amount of material used for its fabrication. The good energy resolution, typically ~16% (FWHM), and high gain of >10^4 with 5.9 keV X-rays for single-stage Micromegas, and high gain of >10^6 and low IBF ratio of ~0.0005 for DMM prove the practicality of the TBM in fabricating Micromegas and feasibility in exploring new MPGD structures. The good stability and interesting potential variations of detectors made using the TBM has also been verified in applications like tracker system, neutron monitors, etc.
However, it is challenging to achieve the large active area, typically in the order of several square meters, in the fabrication method, as well as the gain uniformity. The rolling method used in the TBM provides a way to achieve this large area. Thus, this is the focus of our studies in the future.

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