Fabrication of Carbon Nanotube Field Emitters

Hyeun Joong Yoon*, Dae Jung Jeong, Do Han Jun** and Sang Sik Yang†**

Abstract – This paper presents the fabrication and field emission of carbon nanotube field emitters for a micro mass spectrometer. The carbon nanotube is an adequate material as a field emitter since it has good characteristics. We have successfully fabricated a diode field emitter and a triode field emitter. Each field emitter has been constructed using several micromachining processes and a thermal CVD process. In the case of the diode field emitter, to increase the electric field, the carbon nanotubes are selectively grown on the patterned nickel catalyst layer. The electron current of the diode field emitter is 73.2 μA when the anode voltage is 1100 V. That of the triode field emitter is 3.4 pA when the anode voltage is 1000 V.

Keywords: Carbon nanotube, Field emitter, Ion source, Mass spectrometer, Micromachining

1. Introduction

Ions are formed from neutrals by several ionization mechanisms. Among them the electron impact ionization is the oldest and most widely used method because it is easy to ionize gas-phase molecules and to control the ion current [1]. Electron sources are necessary for the electron impact ionization. A hot-filament or a field emitter is used as the electron source. Especially, the field emission has some advantages such as no heat generation and high emission current.

Previously, a silicon tip covered with DLC (Diamond-Like Carbon) film has been used for the field emitter [2]. There is a limit to make a sharp silicon tip by etching silicon. The carbon nanotube has good characteristics such as high aspect ratio, high electrical conductivity, and high mechanical strength. Therefore, the carbon nanotube is adequate for the cathode material of a field emitter. Carbon nanotube field emitters are better, cheaper, and longer lasting than the metal tip emitters used previously [3-6]. In this paper, two kinds of carbon nanotube field emitters applicable to an ion source of a micro mass spectrometer are proposed.

2. Principle and Structure Design

2.1 Principle

Fig. 1 shows a field emitter ion source with carbon nanotubes (CNTs). If we apply some electric field between the anode and the cathode while introducing sample gases, electrons are emitted from the end of the carbon nanotubes and are collided with the gas molecules. Then, ions are formed from gas molecules and accelerated by negative electrodes. Finally, accelerated ions are flown to the detector.

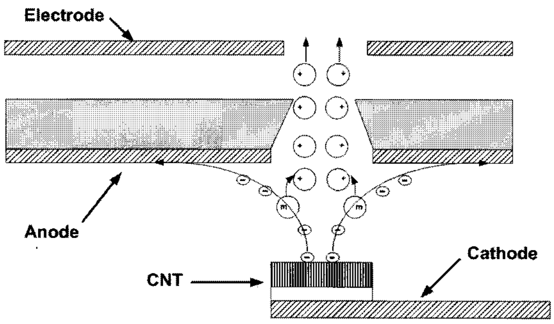

Fig. 1. Ionization by using a field emitter with CNT.

2.2 Structure Design

Fig. 2 presents the structure of the diode field emitter with selectively grown carbon nanotubes. The diode field emitter consists of a lower silicon substrate with CNTs and an upper silicon substrate with an anode electrode. CNTs are grown on the nickel catalyst layer. The diameter of the CNT is from 20 nm to 30 nm and the length of the CNT is 5 μm.

Fig. 3 gives the structure of the triode field emitter with CNTs. The triode field emitter consists of a silicon substrate with a CNT layer, a middle silicon substrate with emission holes and a grid electrode, and a glass substrate with an anode electrode. The CNTs are exposed through emission holes of the middle silicon substrate. The gap

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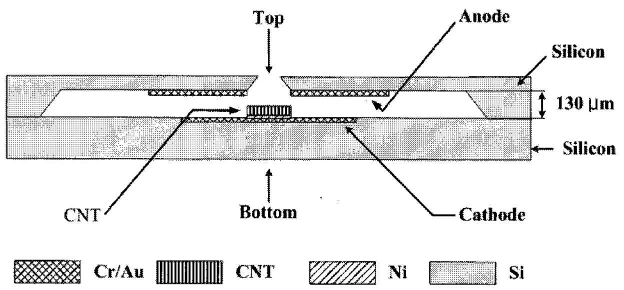

Fig. 2. Structure of the diode field emitter with CNTs.

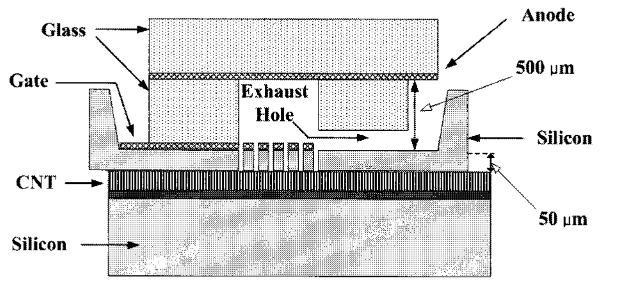

Fig. 3. Structure of the triode field emitter with CNTs.

between the grid electrode and the CNT layer is 50 μm. The distance between the anode and the grid electrode is 500 μm.

3. Fabrication Process

Fig. 4 provides the fabrication process of the diode field emitter with CNTs. Figure 4(a) shows the fabrication process of the top silicon substrate. A 0.7 μm-thick thermal oxide layer is grown on the 525 ± 10 μm-thick 4 inch n-type <100> silicon wafer. To make a gap between the anode and the carbon nanotube layer, the silicon is etched by 130 μm with TMAH solution. The thermal oxide layer is grown again to pattern the hole for the emission of ions. The hole is etched by 395 μm with TMAH solution. After etching, the Cr and Au layers (500 Å/3000 Å) are deposited by the evaporation process and patterned by the lithography process.

Figure 4(b) indicates the fabrication process of the bottom silicon substrate. The Cr and Au layers are deposited by the evaporation process and patterned to make the cathode electrode. To formulate a mold for the electroplating process, the photoresist (AZ1512) is coated and patterned. The nickel for the catalyst layer is formed by the electroplating process. After removing the photoresist layer, CNTs are grown in the thermal CVD equipment. The thermal CVD was performed at 650°C for 5 minutes under pressure of 5.5 Torr. The flow rates of Ar and C_2H_2 are 1000 sccm and 200 sccm, respectively.

Fig. 5 is the fabrication process of the triode field emitter

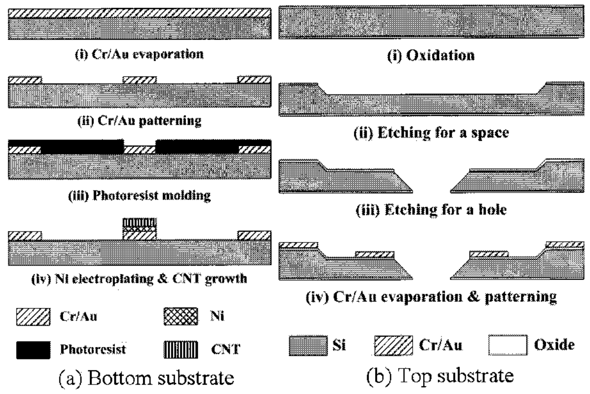

Fig. 4. Fabrication of the diode field emitter with CNTs.

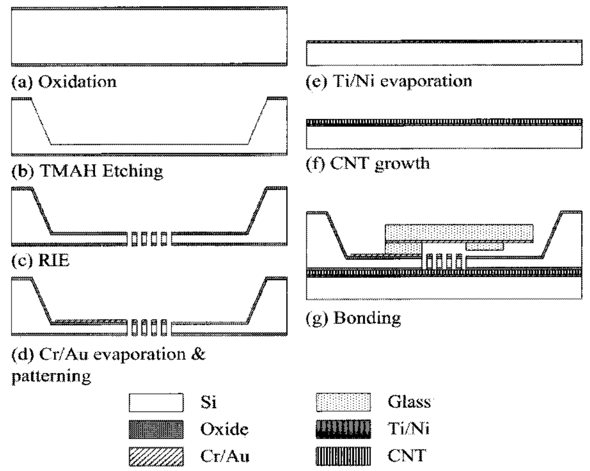

Fig. 5. Fabrication of the triode field emitter with CNTs.

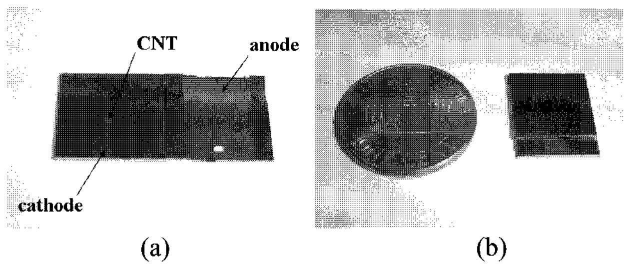

Fig. 6. Photographs of the diode field emitter with CNTs.

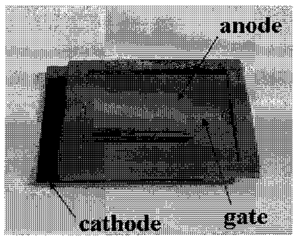

Fig. 7. Photographs of the triode field emitter with CNTs.

with CNTs. A 0.7 μm-thick thermal oxide layer is grown on the silicon wafer. After patterning the oxide layer, the silicon is etched by 475 μm with TMAH solution. The 50 μm-thick holes are formed by deep RIE process. To make a gate electrode, the Cr and Au layers (500 Å/3000 Å) are deposited by the evaporation process and patterned by the lithography process. The Ti and Ni layers (300 Å/500 Å) are deposited on another silicon wafer. The CNT layer is grown by the thermal CVD process. The thickness of the CNT layer is from 50 μm to 80 μm. The glass substrate is fabricated by the Cr/Au evaporation process and electro-discharge machining (EDM). The width and depth of the channel formed by EDM are 300 μm and 100 μm, respectively.

Photographs of the diode type CNT field emitter are shown in Fig. 6. The overall size of the fabricated device is 11 mm × 11 mm × 1.5 mm. Fig. 7 is a photograph of the triode type CNT field emitter. The overall size is 20 mm × 20 mm × 1.6 mm.

4. Experimental Results

Fig. 8 illustrates characteristics of the fabricated diode type CNT field emitter. The emission current varies from 2.2 nA to 73.2 μA when the anode voltage varies from100 V to 1100 V. According to the F-N plot in Figure 8(b), the linear region proves the measured current to be the field emission current. The characteristic of the fabricated triode type CNT field emitter is shown as Fig. 9. The electron current is measured at the gate electrode. When the anode voltage is 1000 V, the electron current is 3.4 pA. It is a very small current despite the triode type field emitter. The problem is a large distance, 500 μm between the anode and the gate electrode in the structure of the triode type field emitter. SEM images of the CNTs on nickel catalyst layer are presented in Figure 10. The grown CNTs on the cathode are shown in Figure 10(a). We have successfully attained patterned CNTs grown on two-dimensional 0.7 mm × 0.7 mm Ni square blocks on silicon substrate. The height of the CNT is 5 μm as presented in Fig. 10(d).

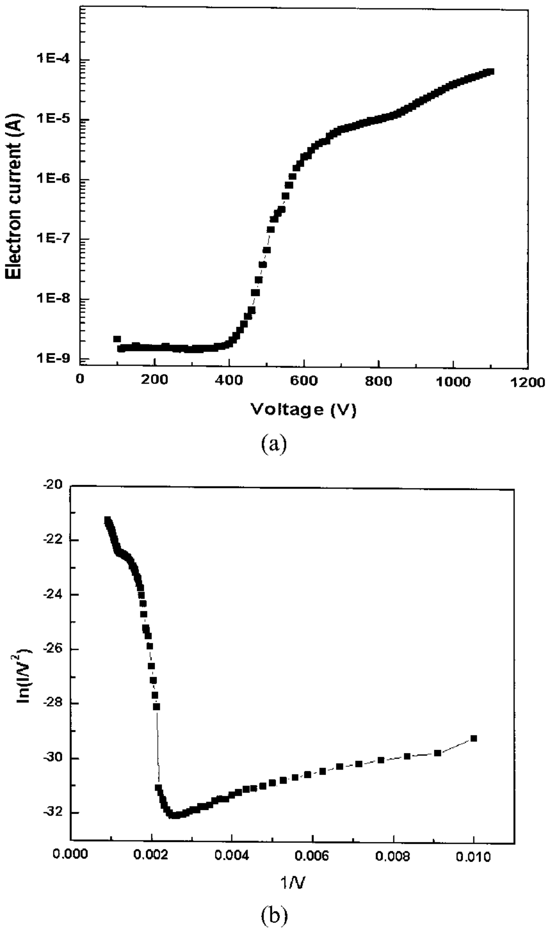

Fig. 8. Characteristics of the diode field emitter with CNTs. (a) Voltage vs. emission current (b) F-N plot

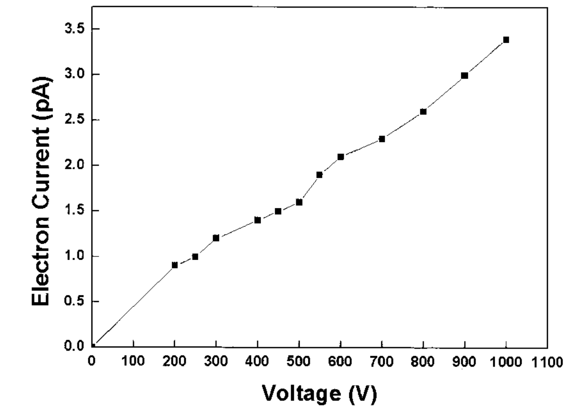

Fig. 9. Characteristic of the triode field emitter with CNTs.

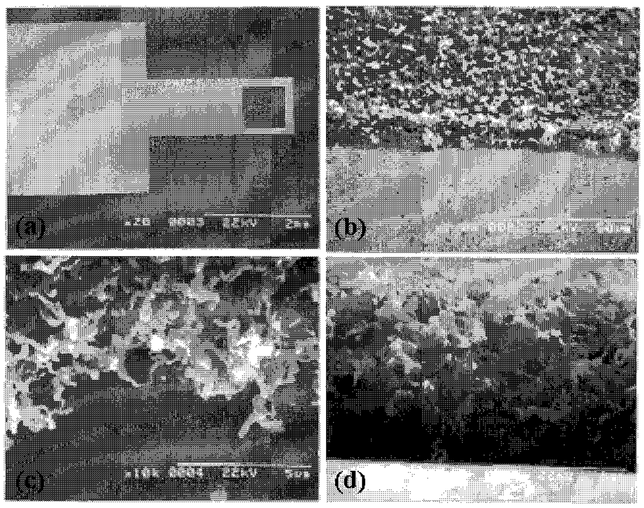

Fig. 10. SEM images of the CNTs on nickel catalyst layer.

5. Conclusion

We have fabricated CNT field emitters for a micro mass spectrometer. The field emitter consists of a bottom substrate with CNTs and a top substrate with an anode.

The diode field emitter and the triode field emitter have been fabricated and their characteristics have been evaluated. The feasibility of CNT emitters for the application to the micro mass spectrometer has been confirmed. In the near future, the development of the micro mass spectrometer with CNT emitter will be performed.

Acknowledgements

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