Low Work Function and Sharp Field Emitter Arrays by Transfer Mold Fabrication Method

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Abstract

Extremely sharp and uniform Transfer Mold FEAs with thin film low work function TiN emitter material have been fabricated by controlling the thickness of the coated emitter materials to realize high efficient, high reliable and low-cost vacuum nanoelectronic devices..Their tip radii are 8.3-13.8 nm. Turn-on electric fields of the Ni FEAs and TiN-FEAs resulted in the low electric field values of 31.6 V/μm and 44.2V/μm,respectively, at the short emitter/anode distance: less than 30 μm, which are lower than those of conventional FE As such as Spindt type FEAs and carbon nan otube FEAs The Transfer Metal Mold fabrication method is one of the best methods of changing emit ter materials with sharp and uniform emit ter shapes. .

1. Introduction

MEMS technology including vacuum nanotechnology has been rapidly expanding their field from sensors, RF-devices to displays [1-4]. Especially, Vacuum nanotechnology principally utilizing cold cathodes based on field emitter arrays (FEAs) have been expected to provide unique aspects of realizing a number of new generation and huge market devices such as flat panel displays, high quality lighting and so on. However, there are important limitations of micro fabricated FEAs in their reliability and efficiency. High efficient and high reliable FEAs can be realized by following ways: First, by emitter tip sharpening, second, by using lower work function and environment-hard emitter materials, third, by improving uniformity and reproducibility. The above requirements give the low operation voltage preventing from deterioration of FEAs caused by bombardment of ionized residual gas and breakdown effects as well as providing high efficient and high reliable field emission. There has been few fabrication process of fulfilling the above requirements. Transfer Mold fabrication method has been developed to fulfill these requirements and obtain sharp, uniform and low work function and environment-hard material FEAs.

In this paper, extremely sharp, uniform, low operation voltage, high integrated and low work function field emitter arrays have been developed by the Transfer Metal Mold emitter fabrication method using thin film emitter material (TiN) coating to realize high efficient, high reliable and low-cost vacuum nanoelectronic devices. The molds are made of not Si single crystal substrates but metal substrates by Ni electroplating. The Transfer Metal Mold FEAs with thin film emitter materials are made by coating thin film emitter materials, TiN on Ni electroplating FEAs. Their unique FEA fabrication method, nanostructures, and low operation voltage electrical characteristics are described.

2. Experimental

The Transfer Metal Mold emitter fabrication process using thin film emitter material coating is used [4]. The Transfer Metal Mold method consists of four main process, Master FEA fabrication, Metal Mold fabrication, Transfer FEA fabrication, and thin film coating. There are two ways for making the Master FEAs. The Cu Master FEAs having 1.6-10μm base length are fabricated by cutting out oxygen –free copper substrate with a diamond bite of the ultra precision Computerized Numerical Control(CNC) machine having 4 controllable axes(Linear Axis: X, Y, Z, Rotation Axis: C). The Ni Master FEAs having

1.6μm base length are fabricated by Ni electroplating using Ni sulfaminic acid solution on the Si Mold substrates which are formed by anisotropical etching and thermal oxidation of the Si. The Si Mold substrates are not etched away but separated from the Ni Master FEAs mechanically after Ni electroplating. The Si Mold substrates can be used repeatedly.

The Metal Molds are fabricated by Ni electroplating on the Cu Master FEAs and the Ni Master FEAs respectively. The Metal Molds are also separated from the Cu Master FEAs and the Ni Master FEAs mechanically. Next, The Transfer FEAs are formed on the Metal Molds by Ni electroplating and separated from the Metal Molds mechanically again. Then, the Transfer Metal Mold FEAs with thin film emitter materials are fabricated by coating emitter material thin films of physical vapor deposition method such as electron beam evaporation method and sputtering method on the FEAs. The electroplating does not need vacuum process and the thin film coating is low-cost process. The transfer Metal Mold emitter fabrication method using thin film emitter material coating is applicable for large area and low-cost FEA fabrication.

3. Results and discussion

Figure 1 shows the SEM micrograph of the Transfer Metal Mold FEAs with TiN thin film coated by the sputtering method having the flat part thickness of13.8 nm, comparing with the Transfer Mold Ni-FEA without TiN coating.. TiN is one of the environment-hard materials and its work function of bulk value is as low as 2.9 eV. while that of Ni is 4.5 eV. The emitter base length are 1.6μm. The emitter tips of Ni FEAs are extremely sharpened to 8.3nm of tip radii. The tip radii of TiN-FEAs are 13.8nm They exhibit high uniformity. There is no deformation of the tip shape such as protrusion formation. The uniformity has been kept even in the case of coating TiN thin films.

Figure 2 shows the relationship between the film thickness of TiN sputtering film on Ni thin film and the sputtering time. The formation rate of TiN thin film is approximately as low as 6 nm/min so that nanometer-order film thickness c an be controlled .

Figure 3 and 4 show the I-V characteristics and the Fowler-Nordheim plots of the Transfer Mold TiN FEAs and NiFEAs. The distance between

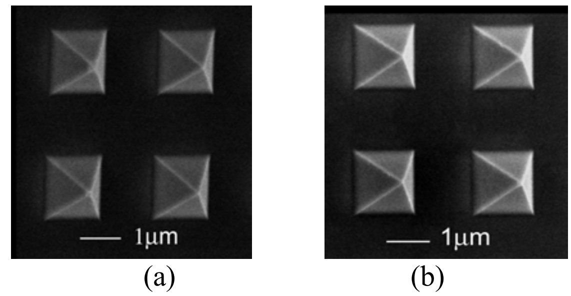


Fig. 1. SEM micrograph of Transfer Metal Mold TiN FEAs (a) and Ni FEAs (b)

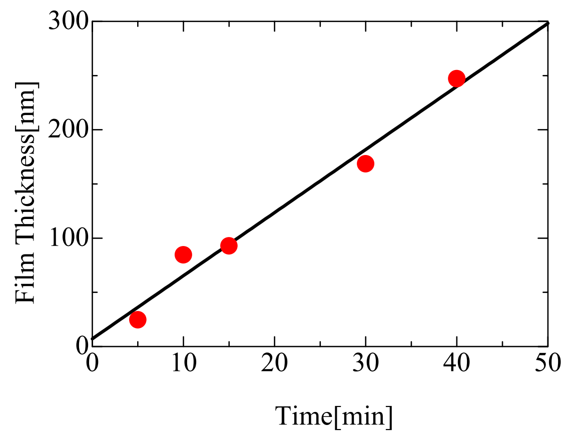


Fig.2. Relationship between film thickness of TiN sputtering film on Ni thin film and sputtering time

emitters and anode is as short as less than 30μm. The Fowler-Nordheim plots became straight lines because of field emission from the FEAs. The v alues of the turn-on fields are as low as 31.6V /μm of Ni FEAs and 44.2 V/μm in the range of the tip radius, 8.3 – 13.8 nm. Even if tip radii ar e sharpened and the electrode distance are so clos e each other, the extraction voltages of field emi ssion need more than the surface barrier heights, that is, the work function of emitter materials. According to the slopes of the Fowler-Nordheim plots and the geometrical factors from the experimental tip radii and the theoretical models, the work function of TiN FEAs are as low as 3.8eV, comparing with 4.5eV of Ni FEAs. The reason that the turn field of TiN FEAs is larger than that of Ni FEAs is the increase of geometrical factors.

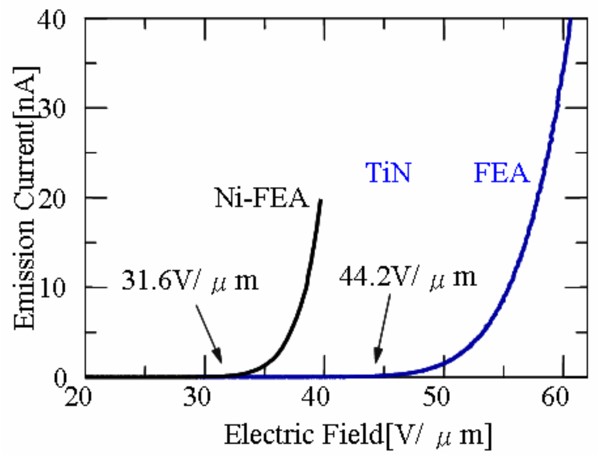


Fig. 3. I-Vcharacteristics of Transfer Mold TiN FEAs and Ni FEAs

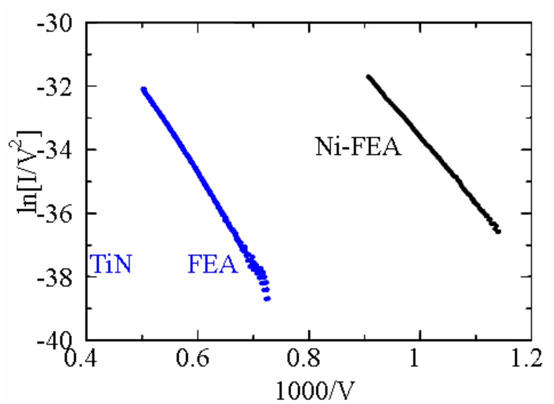
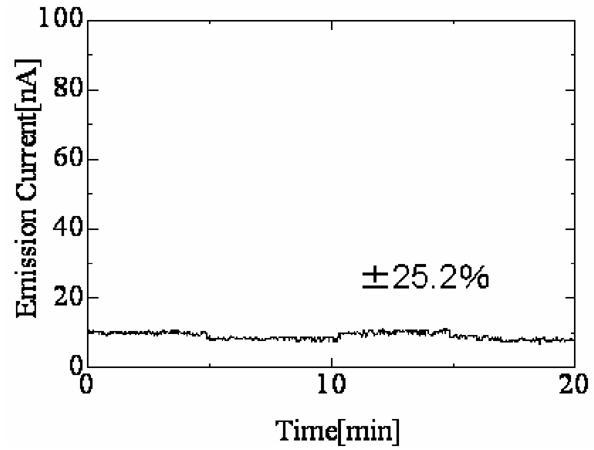
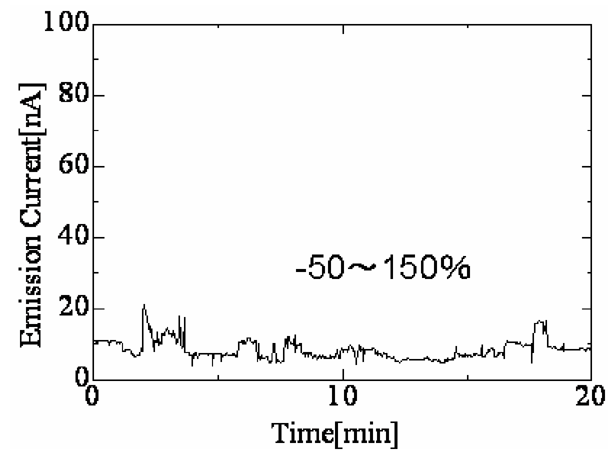


Fig. 4. Fowler-Nordheim plots of Transfer Mold TiN FEAs and Ni FEAs.



(a)



(b)

Fig. 5 Emission current fluctuation of Transfer Mold TiN FEAs (a) and Ni FEAs (b)

There are so many reports about the turn-on field of 0.5 – 2 V/μm in the distance between emitters and anode of 1 mm to 2 mm such as those of carbon nanotube FEAs. Because the work function of carbon nanotubes is more than 5 eV, if the distance between emitters and anode is reduced to less than 30μm., the turn-on field is increased 100 – 600 V/μm. Those of other F EAs such as Spindt type FEAs and carbon n anotube FEAs are usually 100 – 600 V/μm. at t he short emitter/anode distance: less than 30 μm

Therefore, the values of the turn-on voltages, 31.6 – 44.2 V/μm are lower than those of other FEAs, and applicable for the nanoelectronic devices.

Figure 5 shows the emission current fluctuation of the Transfer Mold TiN FEAs (a) and Ni F EAs (b). The FEAs have no resistive layer. T he emissions of the FEAs are remarkably stable without big spike noise. The fluctuation rate of Ni-FEA is from -50 % to 150%. That of TiN FEA is reduced to less than ± 25.2 %. It might be due to the environment-hard characteristics of TiN. The emission current fluctuation rates of the conventional FEAs with resistive layer and those of the conventional FEAs without resistive core layer are usually more than 5-100% and more than 100%, respectively. The low value of the emission current fluctuation rate, ever reported, is that of the Transfer Mold FEAs with resistive layer, less than 0.7% [3]. The Transfer Mold TiN FEAs have the excellent emission current stability characteristics.

4. Summary

Transfer Mold emitter fabrication method using thin film low work function emitter material (TiN) coating has been developed to realize high efficient, high reliable and low-cost vacuum nanoelectronic devices. The FEAs having nanometer-order tip radii of 8.3 – 13.8 nm have been fabricated by controlling the thickness of the emitter materials from 0-20 nm. Turn-on electric fields of the Ni FEAs and TiN-FEAs are the low electric field values of 31.6 V/μm and 44.2V/μm,respectively, at the short emitter/anode distance: less than 30 μm, which are lower than those of conventional FEAs such as Spindt type FEAs and carbon nanotube FEAs The Transfer Metal Mold fabrication method is one of the best methods of changing emitter materials with sharp and uniform emitter shapes.

5. References

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