Improvement of field emission properties by formation of Nb-silicide layer on silicon-tip FEAs

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Abstract

Metal-silicide on silicon-tip field emission arrays (FEAs) seems to be a promising way to the performance of the silicon-tip FEAs. The Nb(Niobium)-silicide layer was formed on silicon surface. The Nb-silicide FEAs was prepared by silicidation process.

The formation of Nb-silicide layer on silicon surface was confirmed by using X-Ray Diffractometry(XRD). The current-voltage characteristics and the current fluctuation were measured under the ultra high vacuum environment using a Kiethley SMU 237 meters. The turn-on voltage of silicon-tip FEAs was decreased from 64V to 47V by the formation of the Nb-silicide layer on silicon-tip and the emission current fluctuation (2%) was more stable than that of conventional silicon-tip FEAs.

Introduction

Microfabricated field emission arrays (FEAs) have been investigated for vacuum microelectronics and field emissive display [1]. The silicon-tip FEAs with tips to the order of nanometers can be easily fabricated by using conventional semiconductor process. However, the silicon-tip FEAs have typical problem in spite of their merits. That is the achievement of stable emission current. For ensure the stability of electron emission current in silicon-tip FEAs, refractory metals were coated and than formed silicide layer on silicon surface. Refractory metal(Φ:3.4~11.6eV)-coated silicide FEAs allow to combine the advantages of silicon-tip FEAs with metal. Therefore, various metals have been proposed for coating on silicon-tip FEAs such as Mo, Cr, Ni, Ti and diamond-like carbon [2][3][4].

Nb was used as an alloy for many years, because Nb offers nearly the corrosion resistance of tantalum and the melting temperature of molybdenum [5][6]. Nb has a low work function (4.3eV) and a high melting temperature [7].

In this study, we have investigated the formation of Nb-silicide by X-Ray Diffractometry(XRD). The Nb-silicide FEAs of volcano-type geometry were fabricated. In order to confirm the enhancement of emission characteristics by forming Nb-silicide on pure silicon-top FEAs, the characteristics and stability of electron emission of Nb-silicide FEAs were compared with that of pure n^{++} based silicon-tip FEAs.

Experiment

Fig. 1 shows the fabrication process of Nb-silicide FEAs The Nb-silicide FEAs of volcano-type geometry were prepared through three steps. The first step was the fabrication of the silicon-tip FEAs. Diode-type silicon-tip FEAs with tips of 1㎛height were fabricated on silicon substrate by isotropic etching and sharpening oxidation. Silicon-tip FEAs were spaced on 5㎛ apart with 3600 emitters(fig. 1-a). The second step was the formation of the Nb-silicide layer. Nb films were deposited 300㎚thickness on silicon-tip FEAs by electron beam evaporation. Silicon-nitride(SiN_x) films were deposited by plasma enhanced chemical vapor deposition(PECVD) at temperature of 270℃(fig. 1-b). The 200㎚thick SiN_x films prevent Nb film from oxidizing during thermal annealing. For forming Nb-silicide layer on silicon surface, the silicon-FEAs were baked at

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temperature of 1100℃ under nitrogen environment for 1 hour. After thermal annealing, remnant Nb/SiN$_x$ films were removed by hydro fluorine acid (HF) (fig. 1-c). XRD was used to investigate characteristics of the Nb-silicide layer after thermal annealing. The final step was the deposition and patterning of the gate insulator and electrode. The silicon dioxide (SiO$_2$) films of 800㎚ thickness as gate insulator were deposited on Nb-silicide FEAs by electron beam evaporation. Nb-silicide FEAs were annealed again for densification of the SiO$_2$ film at 1100℃. Mo films of 300㎚ thickness were deposited on SiO$_2$ film for the gate electrode(fig. 1-d). To get patterned the gate apertures(fig. 1-e), the gate electrode was etched by a reactive ion etcher (RIE) followed by etching the gate insulator in buffered oxide etch (BOE) (fig. 1-f).

An anode plate was placed 1㎜ above the gate and biased to +400V. Both the anode and gate currents were measured as a function of gate-to-cathode bias voltage in a vacuum of 1×10^{-8} torr using a Kiethley SMU 237 meters. During the measurements, the device was in a common emitter configuration having the emitter ground, the anode at a positive voltage and the gate driven positive to turn the device on. The gate voltage were swept from 0V to 55V.

Results

Fig. 2 and 3 show the morphology of Nb-silicide FEAs observed under a Scanning Electron Microscope (SEM). The emitters are revealed through the gate apertures in Fig. 1. The gate aperture is about 1㎛ and emitters are spaced out 5㎛ apart. And Fig. 3 is the cross section view of Nb-silicide tip. The height of Nb-silicide tips were 1㎛ as we confirmed.

The peak of Nb-silicide observed by XRD is shown in Fig. 4. After thermal annealing, the peaks of Nb_5Si_3 and $NbSi_2$ checked using by JCPDS Files are appeared. The plot A shows the peak of Nb oxide by the deposition process before thermal annealing. This means that the Nb oxide films have covered Nb layer after deposition, because the peaks like those shown in plot A were not observed in the plot B, C. Also, the plots B, C show the peaks of the Nb-silicide (Nb_5Si_3, $NbSi_2$) by thermal annealing afterward. In plot B, before removing the remnant Nb/SiN$_x$, the peaks of Nb_5Si_3 were revealed clearly. And the peak of $NbSi_2$ in plot C was observed after removing remnant Nb/SiN$_x$ films. The peaks of Nb oxide films were more decreased relatively than the peaks of Nb-silicide.

In Fig. 5, the current-voltage characteristics for Nb-silicide FEAs and pure silicon-tip FEAs consisting of 3600 tips were shown. The turn-on voltage was 64V for pure silicon-tip FEAs and 47V for Nb-silicide FEAs. Also, the measured anode current increases from 412㎁ to 3.2㎂. The operating voltage can be decreased significantly by forming Nb-silicide on silicon-tip FEAs. And the devices were broken over 60V of gate bias because of arcing between Nb-silicide tips and gate electrode.

Fig. 6 shows the Fowler-Nordheim plots for the Nb-silicide FEAs and pure silicon-tip FEAs. The slope of Nb-silicide FEAs more leans to left side than that of pure silicon-tip FEAs. The turn-on voltages for pure silicon FEAs and Nb-silicide FEAs were estimated from these plots. The effective work-function calculated from F-N plots was about 3.1eV. The work-function was decreased remarkably by forming Nb-silicide on pure silicon FEAs.

The emission current fluctuation of Nb-silicide FEAs and pure silicon-tip FEAs are shown in Fig. 7. It was confirmed that the emission current for Nb-silicide FEAs is more stable than that of pure silicon-tip FEAs. The current variation of Nb-silicide FEAs (about 2%) was smaller than that of pure silicon-tip FEAs(5%).

In fig. 8 and 9, the emission patterns of Nb-silicide FEAs were shown. The phosphor screen started to glow at the gate voltage 40V and the anode current was 0.3㎂(fig. 8). In fig. 9 it was the bright pattern at 55V gate voltage

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and 2.0㎂ anode current.

Conclusion

The Improvement of electron emission efficiency and stability in silicon-tip FEAs were achieved using Nb-silicide for vacuum microelectronic device application as FEDs. This remarkable improvement in electron emission characteristics is attributed to the properties of Nb-silicide layer formed by thermal annealing. The reduction of work-function by NB-silicide layer causes lower turn-on voltage and Nb-silicide layer produces higher emission current density.

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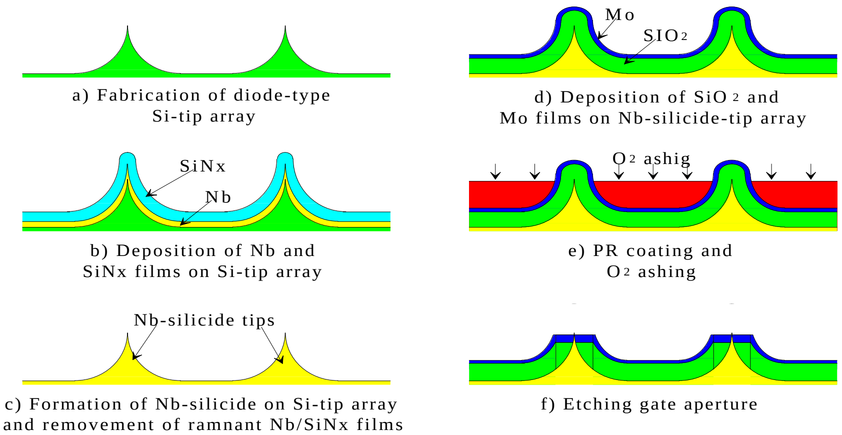

a) Fabrication of diode-type Si-tip array

d) Deposition of SiO2 and Mo films on Nb-silicide-tip array

b) Deposition of Nb and SiNx films on Si-tip array

e) PR coating and O2 ashing

c) Formation of Nb-silicide on Si-tip array and removement of ramnant Nb/SiNx films

f) Etching gate aperture

Fig. 1. The fabrication process of the volcano-type Nb-silicide FEAs

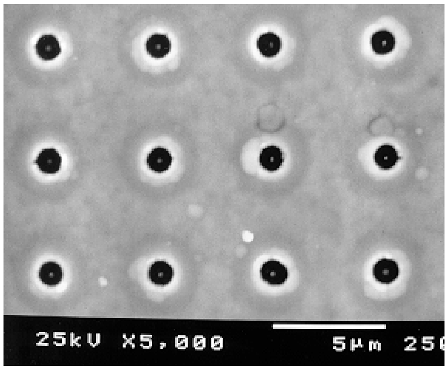

Fig. 2. The top view of Nb-silicide FEAs

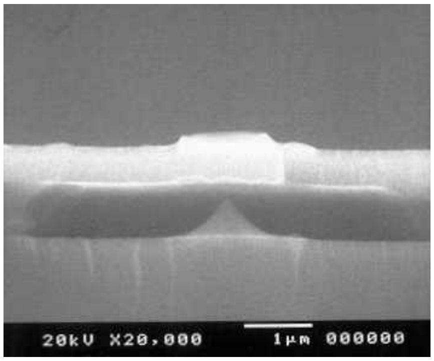

Fig. 3. The cross section view of Nb-silicide FEAs

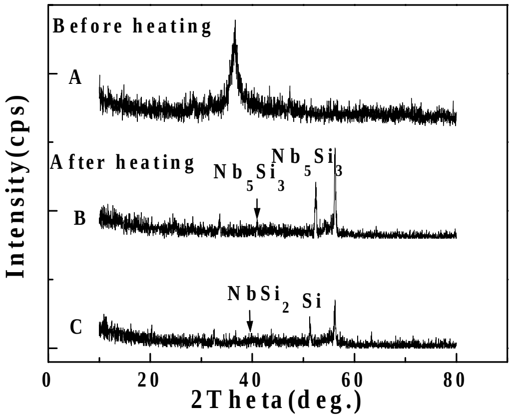

Fig. 4. The plots of XRD ;
before and after thermal annealing

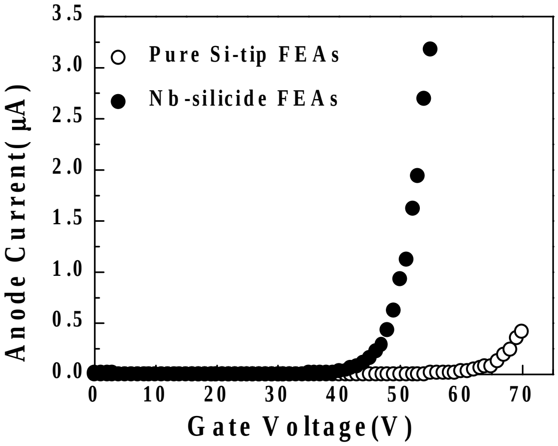

Fig. 5. The characteristics of current-voltage
for pure Si-tip FEAs and Nb-silicide FEAs

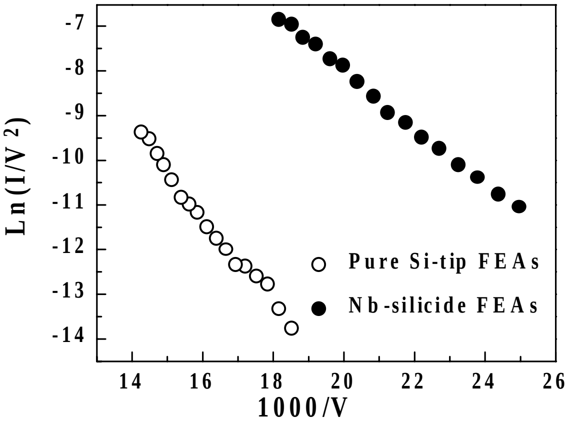

Fig. 6. The F-N plots of pure Si-tip FEAs
and Nb-silicide FEAs

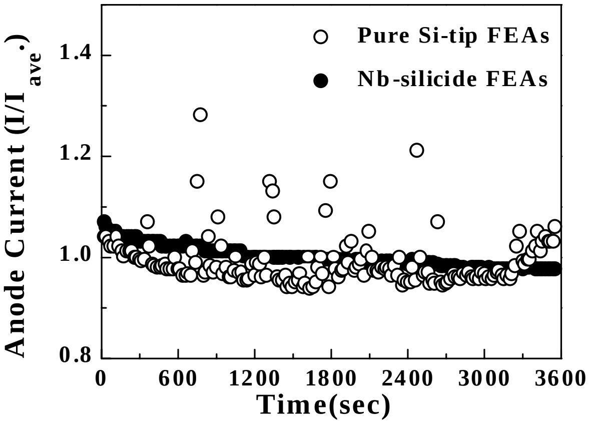

Fig. 7. The current variation of pure Si-tip FEAs
and Nb-silicide FEAs (V_g=50V, $I_{ave.}$ ≒ 1㎂)

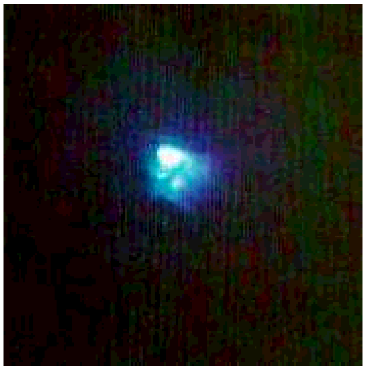

Fig. 8. The emission pattern
V_g = 40V, I_a = 0.3㎂

Fig. 9. The emission pattern
V_g = 55V, I_a = 2.0㎂

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