Immunity Improvement of Mo Silicidized a-Si FEA to Vacuum Environments

Byung Chang Shim, Jong Duk Lee and Byung-Gook Park

Inter-University Semiconductor Research Center(ISRC) and School of Electrical Engineering,
Seoul National University, San 56-1, Shinlim-dong, Kwanak-gu, Seoul 151-742, KOREA

ABSTRACT

In order to improve electron field emission and its stability, tip surface of amorphous silicon field emitters have been coated with molybdenum layer with a thickness of 25 nm through the gate opening and annealed rapidly in inert ambient. Compared with amorphous silicon field emitters, Mo silicidized amorphous silicon field emitters exhibited lower turn on voltage about 9 V, 3.8 times higher maximum current, 3.1 times lower fluctuation range and less change of the emission current depending on the vacuum level.

I. INTRODUCTION

There is size limitation problem in making field emission display(FED) panels from single crystal silicon(c-Si) wafers. It is also difficult to isolate pixels electrically and optically. The fabrication of polycrystalline silicon(poly-Si) FED[1] and amorphous silicon(a-Si) field emitter arrays(FEAs) were reported to overcome these problems[2]. Especially, the a-Si FEAs showed improved electrical characteristics which come from smaller surface roughness and better defined gate apertures in comparison with poly-Si FEAs.

Low electrical and thermal conductivity and poor stability are the major drawbacks of silicon FEAs. To overcome these drawbacks, Mo silicide was formed on the silicon tips. In particular, it was reported that Mo silicide has lower work function, higher electrical and thermal conductivity, and higher melting point than those of silicon. By changing such material properties, the silicidized emitters have better emission stability and lower turn-on voltage. [3, 4].

In this study, Mo silicide technique has been applied to the gated a-Si field emitters so as to enhance and stabilize the electron emission characteristics. Investigations on the emission characteristics of Mo silicide field emitters based on a-Si will be described and compared.

II. EXPERIMENTS

625 tip silicon FEAs with a gate opening of 1.4 μm were fabricated by dry etching and sharpening oxidation[5]. The silicide was formed by coating of 25-nm thick Mo-layer on the tip and subsequent annealing in inert gas ambient by rapid thermal process (RTP). After formation of the silicide, the unreacted metal and unwanted by-products were removed by wet etching.

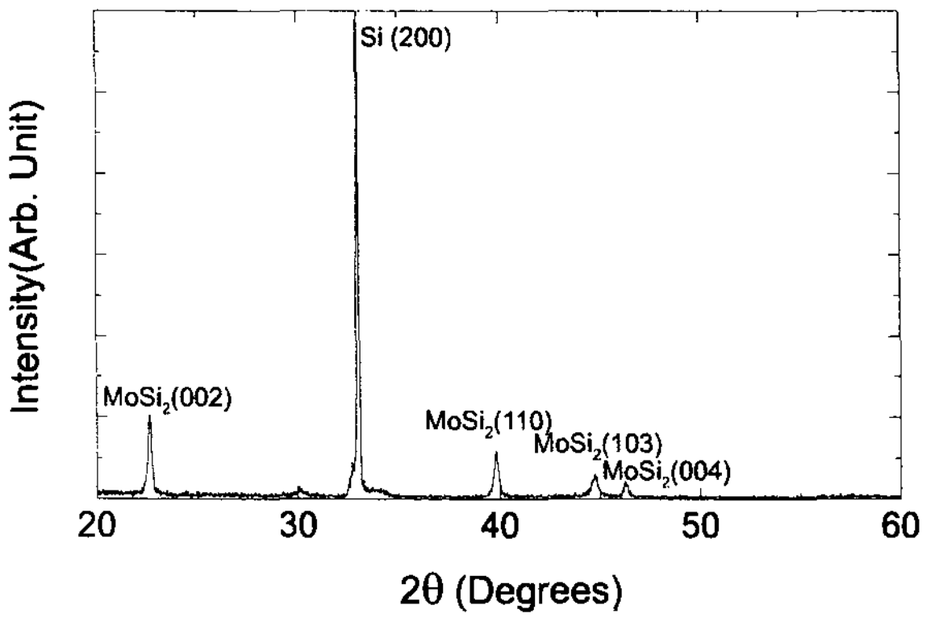

Fig. 1. X-ray diffraction spectrum for the Mo/Si annealed in N_2 ambient using RTA. Metal peak was not shown to confirm successfully grown Mo silicide.

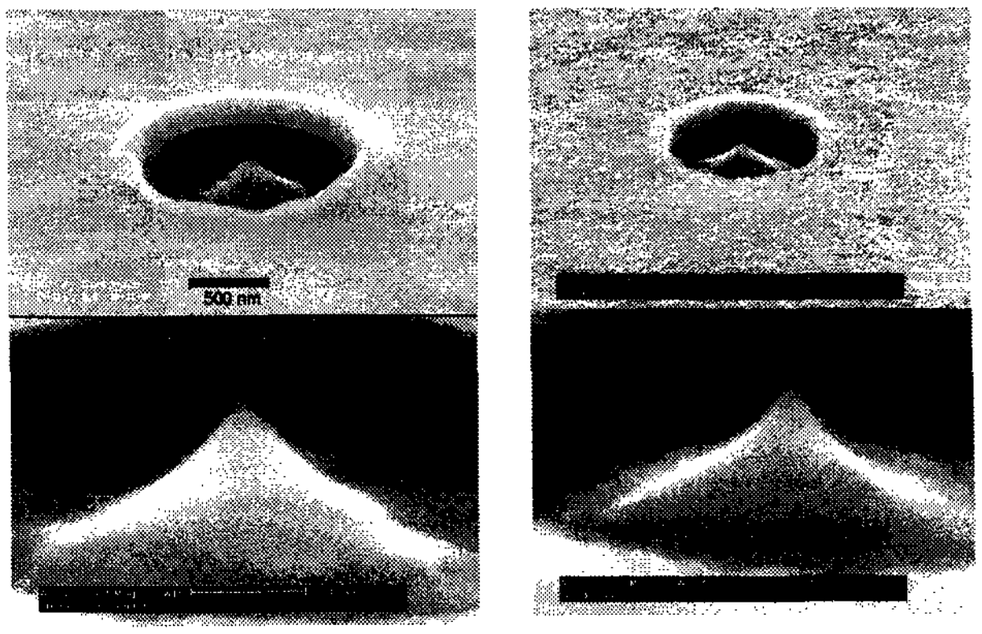

Fig. 2. SEM micrographs for the fabricated (a)a-Si emitter and (b)Mo silicide emitters based on a-Si.

III. RESULTS AND DISCUSSION

In order to examine the constituent and the dominant bindings of the metal-Si compounds, X-ray diffraction(XRD) measurement was performed. It is confirmed that all the metal was completely transformed into $MoSi_2$ phase as shown in Fig. 1.

Figure 2 shows the scanning electron microscope(SEM) photographs of gated a-Si and Mo silicide field emitters based on a-Si. The surface morphologies of a-Si and silicidized a-Si emitters are similar. The measured tip radii of silicon and Mo silicide tips were about 35 Å and 50 Å, respectively.

Field emission properties of the fabricated devices were characterized in an ultra vacuum chamber at a base pressure of 6.6×10^{-9} torr. The anode plate was 3 mm apart above the top of gate and biased to +300 V. Mo silicide and silicon FEAs with 625 tips were prepared through an identical fabrication lot apart from the metal deposition followed by annealing for the silicide emitters.

Figure 3 shows the I-V characteristics of Mo silicide and silicon FEAs with 625 tips. The silicide emitters have lower turn-on voltage about 9 V and higher emission current than silicon emitters.

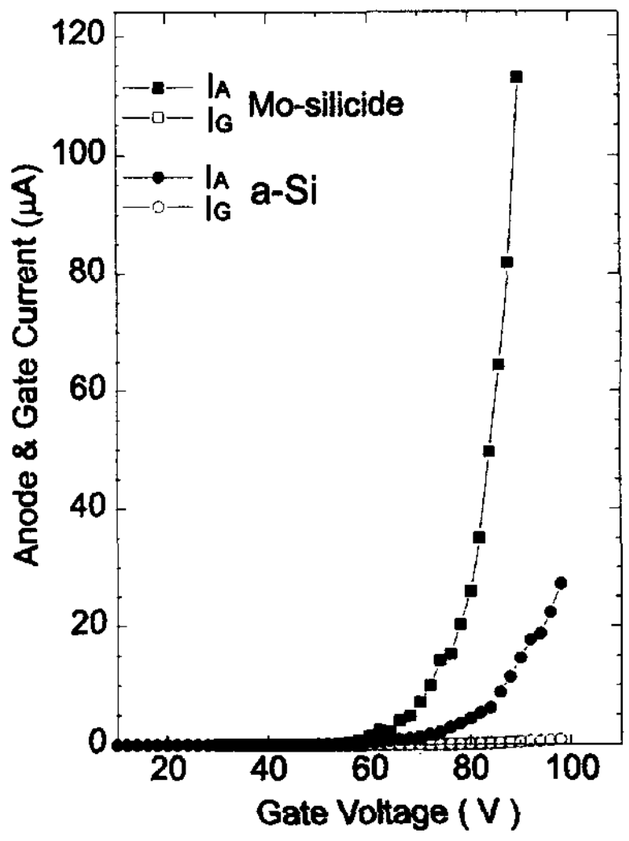

Fig. 3. I-V curves taken from a-Si and Mo silicidized a-Si FEAs with 625 tips, where, I_A and I_B denote anode and gate currents, respectively.

Our SEM study indicates that the emitter failure is due to arcing between tip and gate electrode.

From the slope of Fowler-Nordheim plot and tip radius measured from Fig. 2, the effective work function of Mo silicide based on a-Si is calculated to be about 2.91 eV, which is similar result reported previously[6]. The work function of Mo silicide FEAs based on a-Si was decreased by about 19.6 %, comparing with that of a-Si FEAs.

The emission current fluctuation of the a-Si FEAs normalized with average anode current at a fixed gate bias was ranging from -34.8 % to +19.1 %. Whereas, that of Mo silicidized a-Si FEAs was ranging from -6.9 % to +10.5 %, as shown in Fig. 4. The notable fluctuation reduction of Mo silicide FEAs supports that the silicide emitters are less influenced by gas adsorption and desorption and/or destruction of sharp emission site and these have lower work function than silicon emitters.

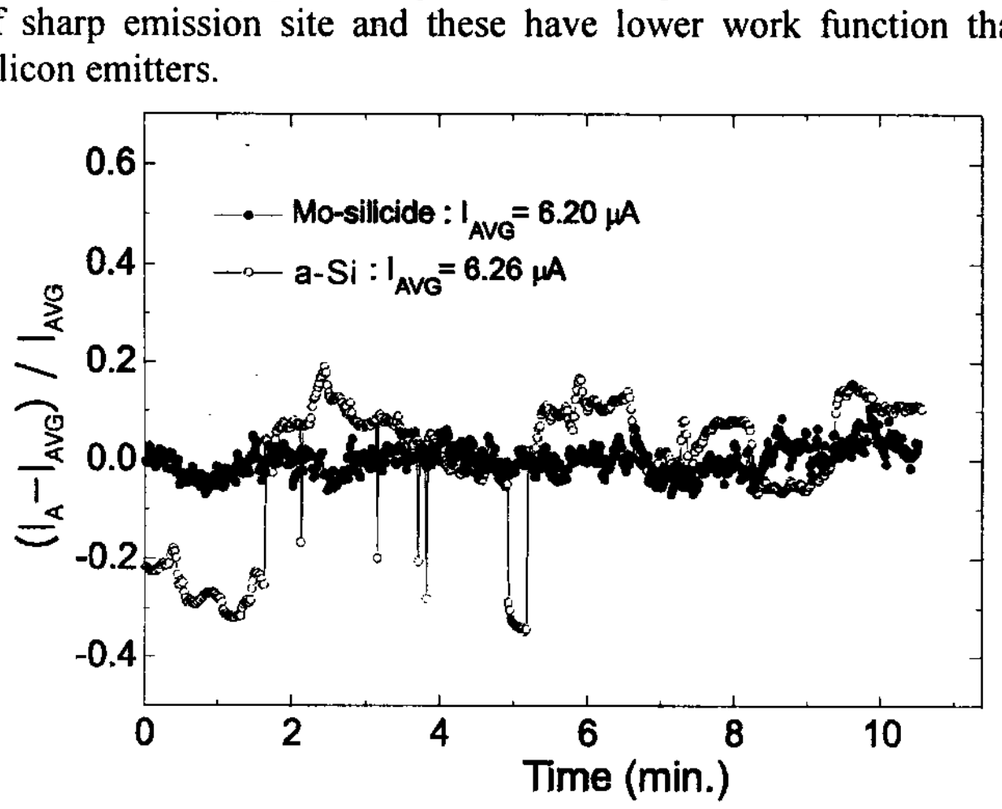

Fig. 4. The emission current fluctuations of the a-Si and Mo silicidized a-Si FEAs, where, I_{AVG} means average anode current.

For the practical applications of field emitter arrays, it is essential to investigate the vacuum dependence of emission characteristics, because field emission property depends sensitively on the work function change of the emitter surface by gas absorption[7]. Figure 5 shows experimental results on the change of the emission current depending on the vacuum level. The emission current of the a-Si FEAs depending on vacuum level decreases in the range of 10^{-9} ~ 10^{-6} torr. However, that of the Mo silicidized a-Si FEAs is almost same in the range of 10^{-9} ~ 10^{-6} torr, as shown in Fig. 5. This result shows that silicide is more robust for the absorption of air molecules than silicon itself.

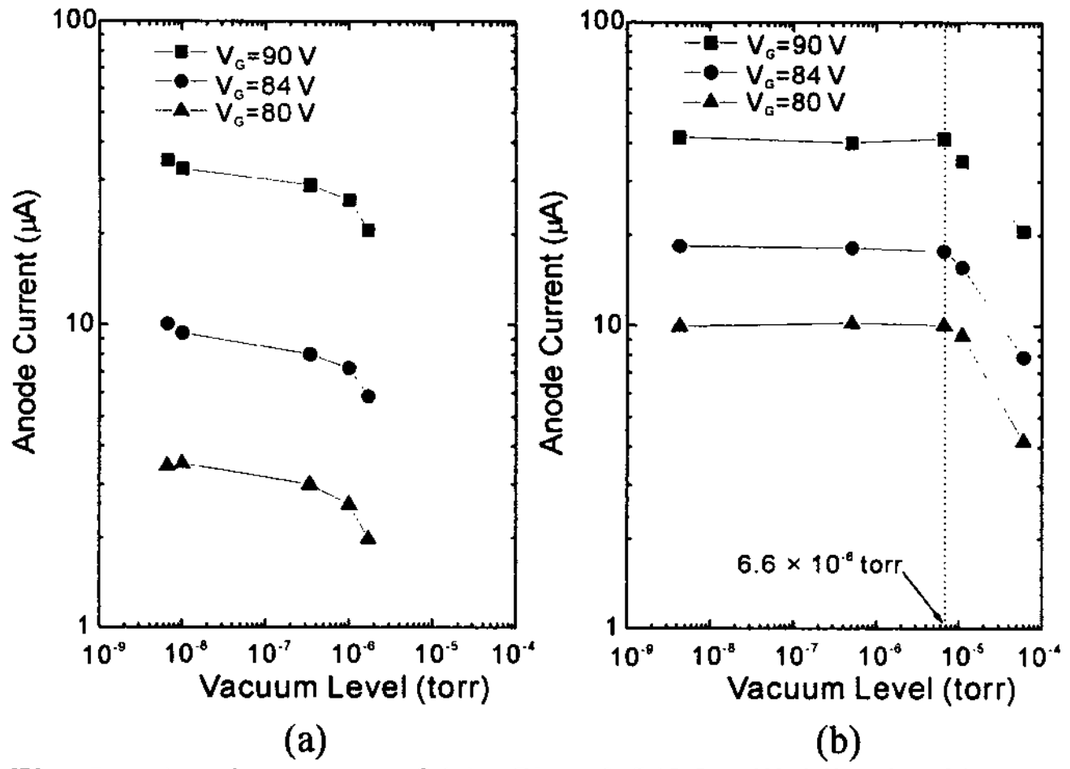

Fig. 5. Anode current of (a)a-Si and (b)Mo silicidized a-Si FEAs depending on the vacuum level. The emission current of the Mo silicide FEAs depending on the pressure does not decrease up to 6.6×10^{-6} torr.

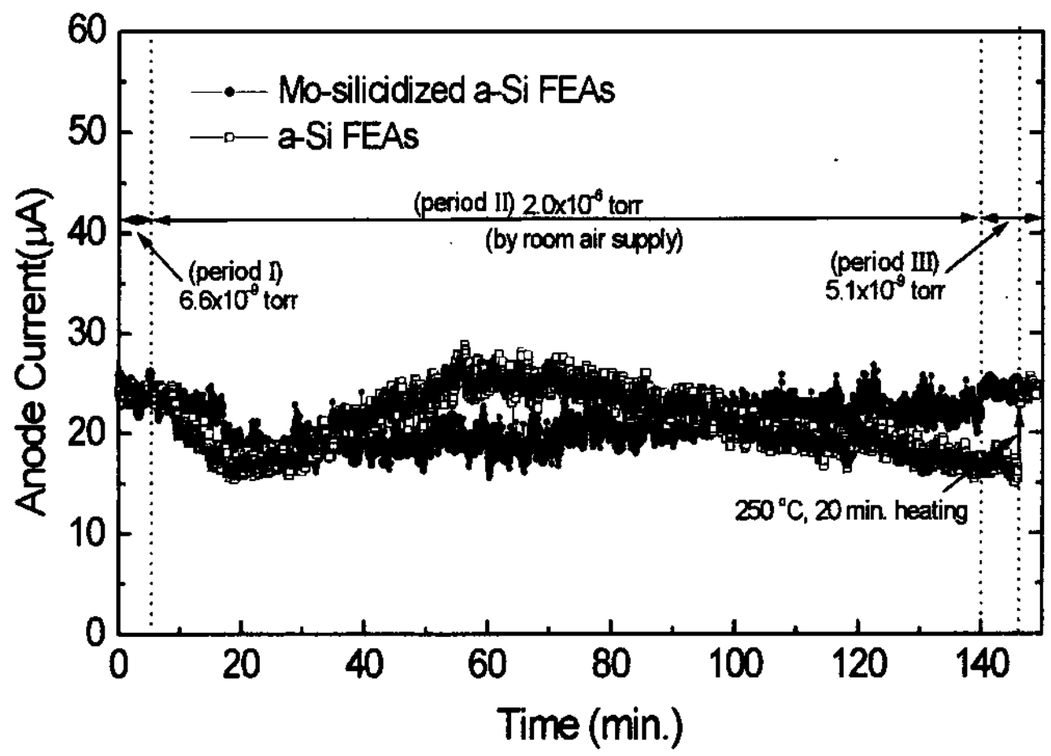

Fig. 6. Change of anode current according to vacuum environments.

As a test of inertness of the silicide emitters to air molecules, the emitters were operated at high vacuum level of 10^{-9} torr(period I) and increased air pressure up to 10^{-6} torr(period II) and then the vacuum level increased to 10^{-9} torr again(period III). During period II in Fig. 6, the emission current of Mo silicidized a-Si FEAs gradually decreased and then slightly increased and remained constant. On the other hand, that of a-Si FEAs inconsistently changed. This is thought to be the formation and deformation of native oxide, and/or absorption and desorption of unwanted gas. The anode current of Mo silicidized a-Si FEAs was completely recovered to the original value when the the pressure reduced to 10^{-9} torr, whereas that of a-Si FEAs didn't recovered only by reducing pressure. After baking at 250 °C, anode current of a-Si FEAs was recovered, as shown at period III in Fig. 9.

IV. CONCLUSIONS

The Mo silicidized a-Si FEAs can be obtained by depositing Mo on a-Si tip and its annealing. Compared with a-Si field emitters, the silicide FEAs exhibited lower turn-on voltage, higher emission current, better emission stability and immunity to vacuum environments. Lower effective work function, higher electrical and thermal conductivity, and better surface inertness of silicide emitters than those of silicon emitters could explain the reasons for the improved emission characteristics.

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