Fabrication and Electrical Characteristics of a Lateral type GaN Field Emission Diode

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Abstract

A lateral type GaN field emission diodes were fabricated by utilizing metal organic chemical vapor deposition (MOCVD). In forming the pattern, two kinds of procedures were proposed: a selective etching method with electron cyclotron resonance-reactive ion etching (ECR-RIE) or a simple selective growth by utilizing Si_3N_4 *film as masking layer. The fabricated device using the ECR-RIE exhibited electrical characteristics such as a turn-on voltage of 35 V for 7 μm gap and an emission current of ~ 580 nA/10tips at anode-to-cathode voltage of 100 V. These new field emission characteristics of GaN tips are believed to be due to a low electron affinity as well as the shorter inter-electrode distance.*

1. Introduction

With the recent advances in vacuum microelectronics [1], the associated semiconductor field-emission arrays (FEAs) have recently become attractive candidates forrelevant applications, such as in flat-panel displays, vacuum microelectronics, electron source, and high-power RF circuits [1-4]. Various materials, such as molybdenum [5], silicon [6], diamond-like carbon (DLC) [7], carbon nanotubes (CNTs) [8], and GaN[9-12] have been studied for field emitter tips maintaining lower turn-on voltage and much stable long-term operation even with higher emission current densities. Interest and research in GaN-based field-emission devices are also growing rapidly because of its inherent large bandgap, low electron affinity, excellent physical and chemical stability and conductivity controllability[9-12]. In addition to the vertical Spindt-type field-emission devices, lateral-type ones are also advantageous for high-speed operation and RF applications because of simple design and fabrication processes, easy control of electrode distances and better electrical characteristics, such as lower turn-on voltages and higher current densities [2,13-15]. In this work for a possible high power microwave application, we have fabricated a GaN field emission diode using metal organic chemical vapor deposition (MOCVD). The fabrication techniques employed in this work are very simple to implement and reproducible both in shaping the sharp electrode tips and controlling the inter-electrode gaps.

2. Experimental

The lateral type Si-doped GaN field emission emitters were fabricated from the GaN film on sapphire substrate grown by using metal-organic chemical vapor deposition (MOCVD) technique. In forming the pattern, two kinds of procedures were proposed: a selective etching method with electron cyclotron resonance-reactive ion etching (ECR-RIE) or a simple selective regrowth by utilizing Si_3N_4 film as a masking layer. The schematic views of the fabricated device were shown in Fig. 1 (a). Si-doped GaN film was grown on a (0001) sapphire substrate at a temperature of 1020 ℃ by MOCVD. The respective Ga, N, and Si precursors were trimethylgallium (TMGa), ammonia (NH_3), and SiH_4. Prior to the epilayer growth, the wafers were cleaned by H_2 ambient at 1020℃, then a 34 nm-thick low temperature GaN buffer layer was grown at 550℃. During the growth, the chamber pressure was maintained at 300 torr. The thickness of n^+-GaN films was about 1.5 μm. For the electrode formation, the

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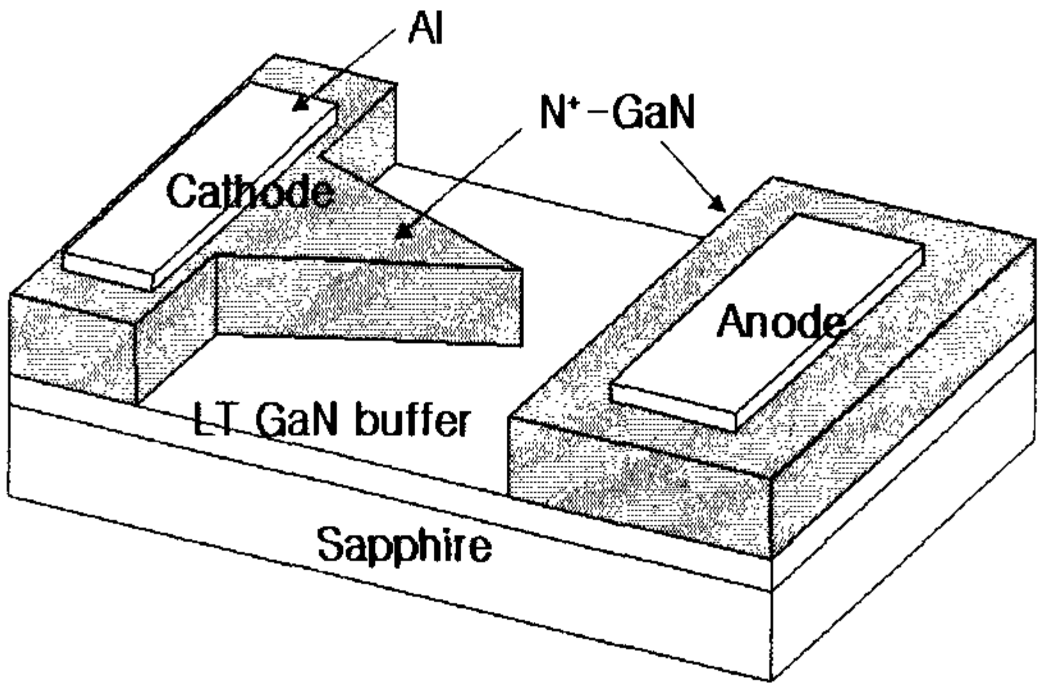
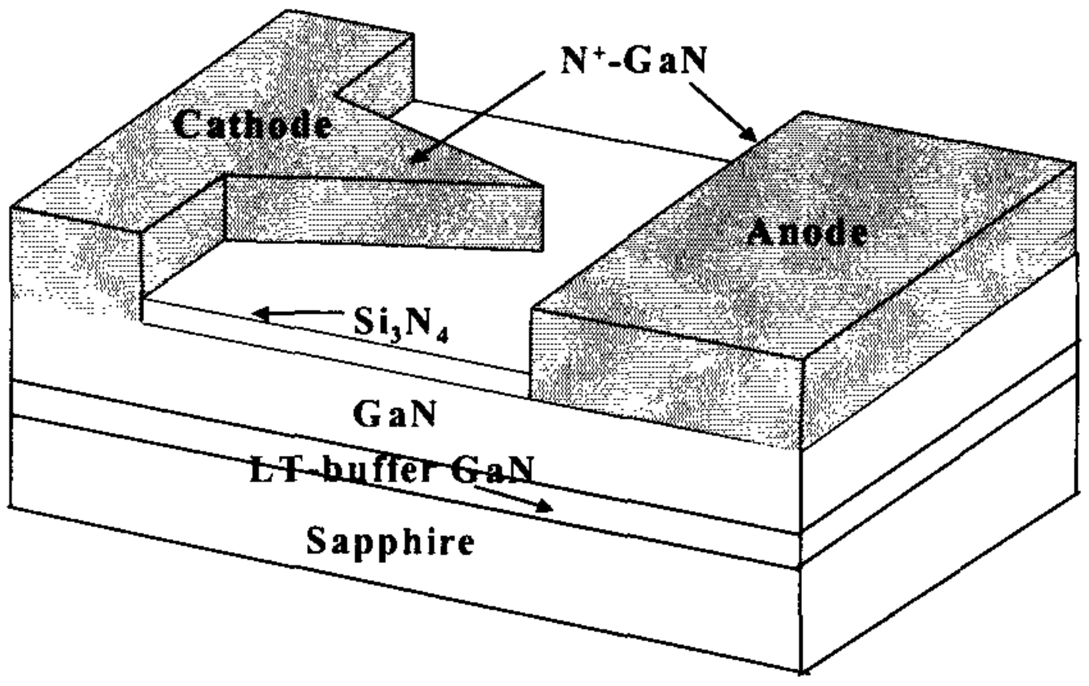
top two layers of n$^+$-GaN/LT-GaN were selectively etched down to the sapphire substrate using ECR-RIE. The Al contact was prepared by thermal evaporation of Al and subsequently annealed for 30 min. at 400 °C in nitrogen ambient. Since the GaN-based material has shown a high physical and chemical stability, the etching process was one of hard jobs during fabrication flow. The other type GaN-based field emitter was proposed as shown in Fig.1 (b). A Si_3N_4 of 2000 Å thickness as a masking layer was firstly deposited directly on the 1.5 μm-thickness GaN film by PECVD. Then, the Si_3N_4 layer was etched away selectively by BHF solution via photolithographic definition of the electrodes. Finally, the n$^+$-GaN layer was selectively re-grown on undoped GaN by MOCVD.



(a)



(b)

Fig.1. Schematic views of the fabricated lateral type GaN field emitters: (a) fabricated device by ECR-RIE etching, (b) by selective regrowth of GaN layer.

3. Results and discussion

Figure 2 shows a SEM photograph of fabricated lateral type GaN diode using the ECR-RIE. The concentration of n$^+$-GaN layer is abut ~5×10^{18}/cm^3. The distance between anode and cathode is about 7 μm. This gap is lager 3 times than the original deigned pattern due to difficulty of GaN-etching.

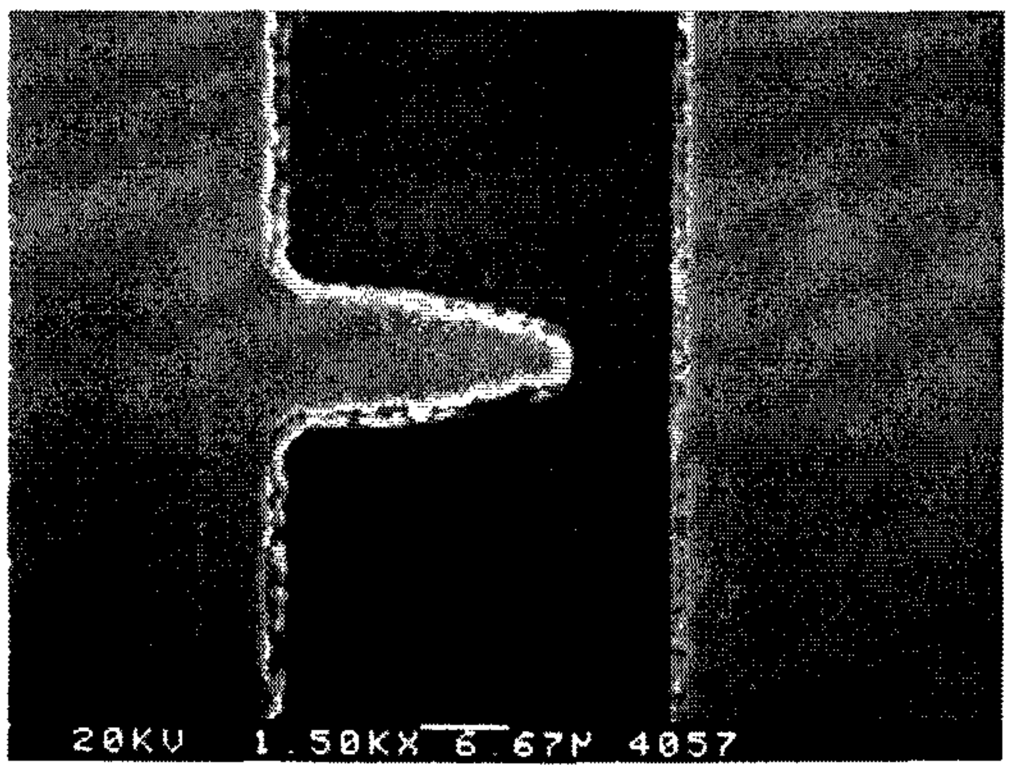


Fig. 2. SEM photograph of fabricated device using the ECR-RIE

Figure 3 shows the current-voltage (I-V) characteristics between the anode and cathode using the ECR-RIE. The turn-on voltage was as low as 35 V and the emission current was ~580 nA/10tips at anode-to-cathode voltage of 100 V.

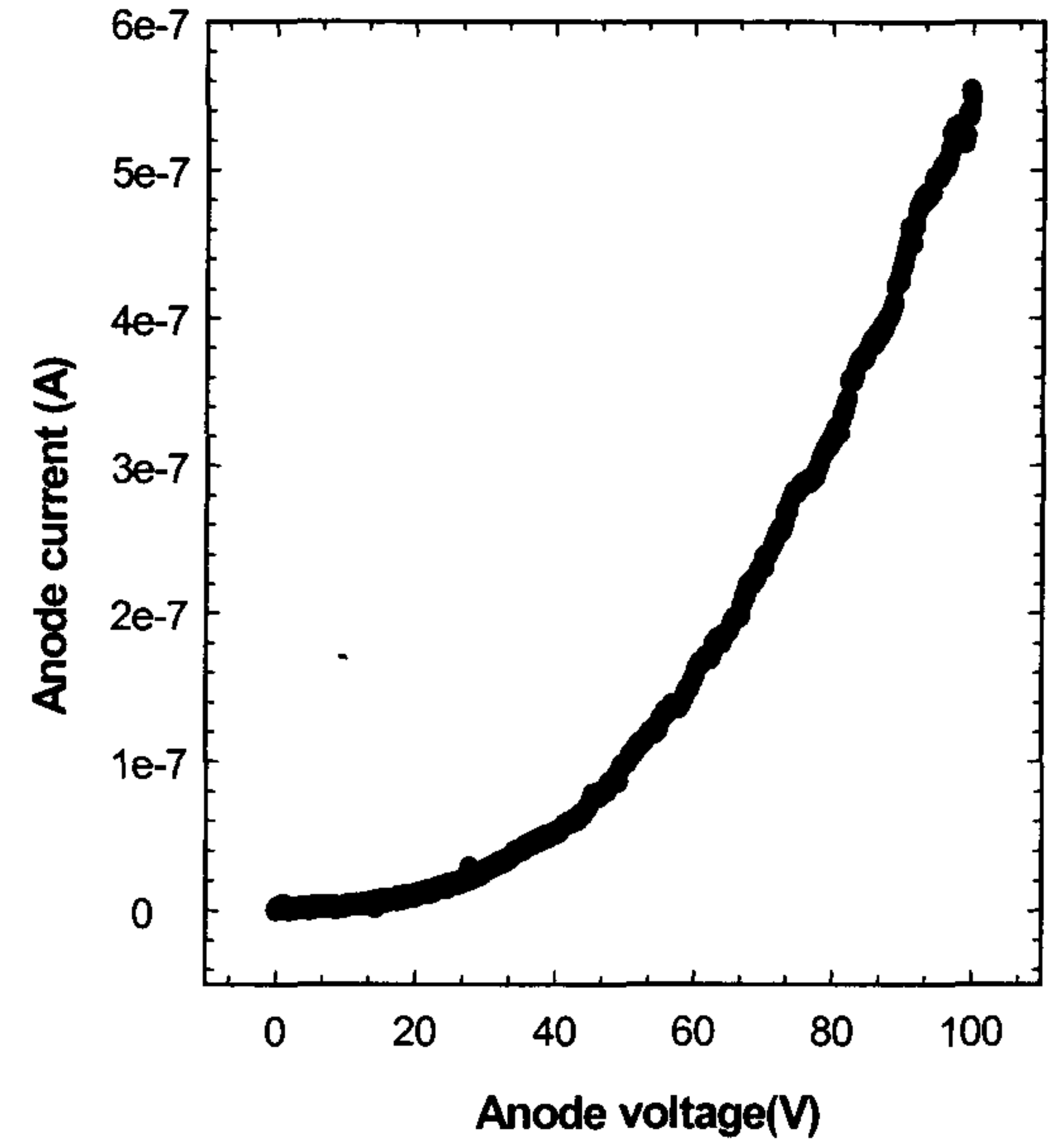


Fig. 3. I-V characteristic between anode and cathode using the ECR-RIE

Figure 4 shows the FN plot converted from I-V characteristics of the diode. The good linearity of FN plot indicates that the current is evidently from the field emission phenomena. These superior field emission characteristics are believed to be due to a low electron affinity as well as the shorter inter-electrode distance.

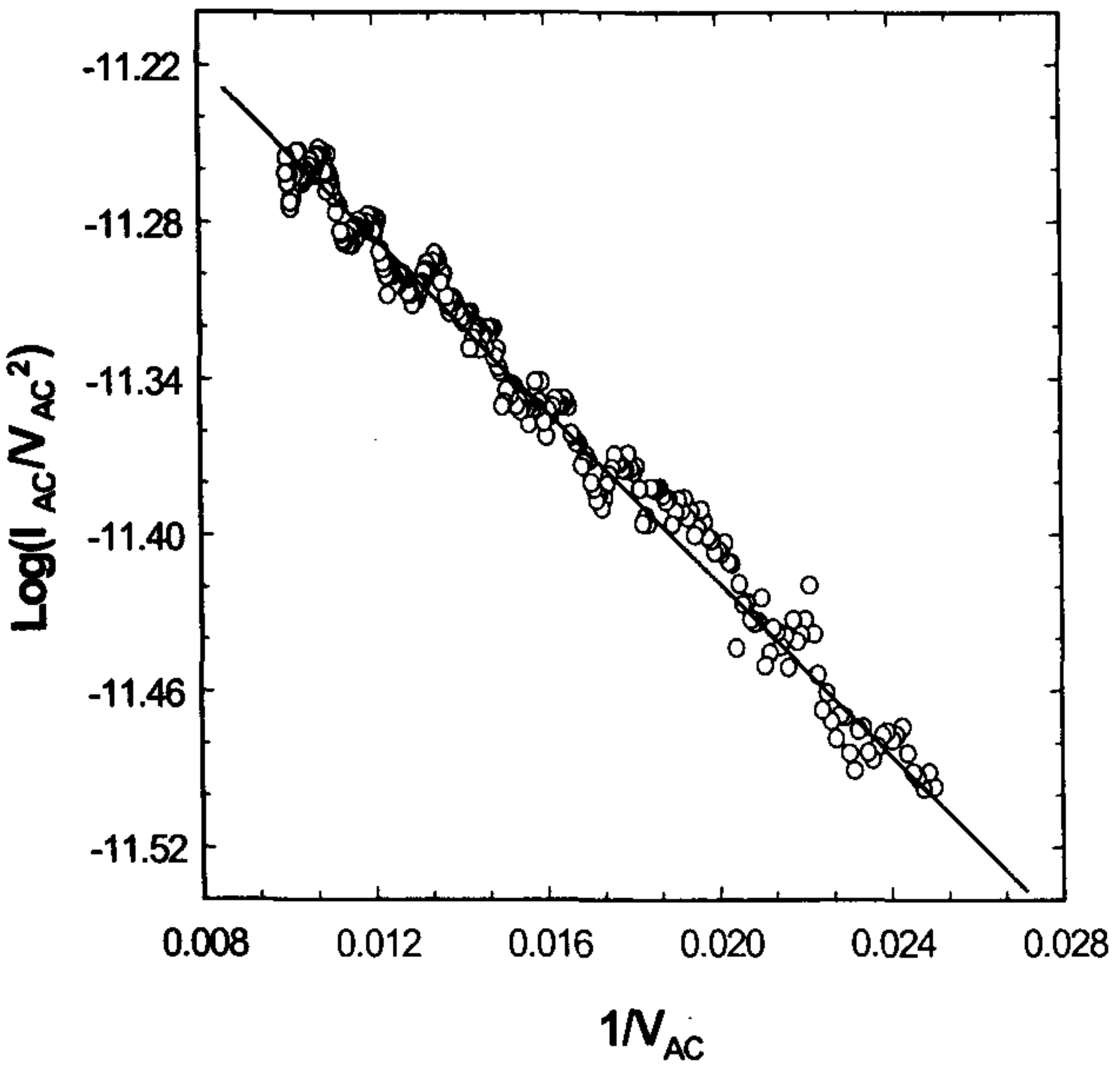
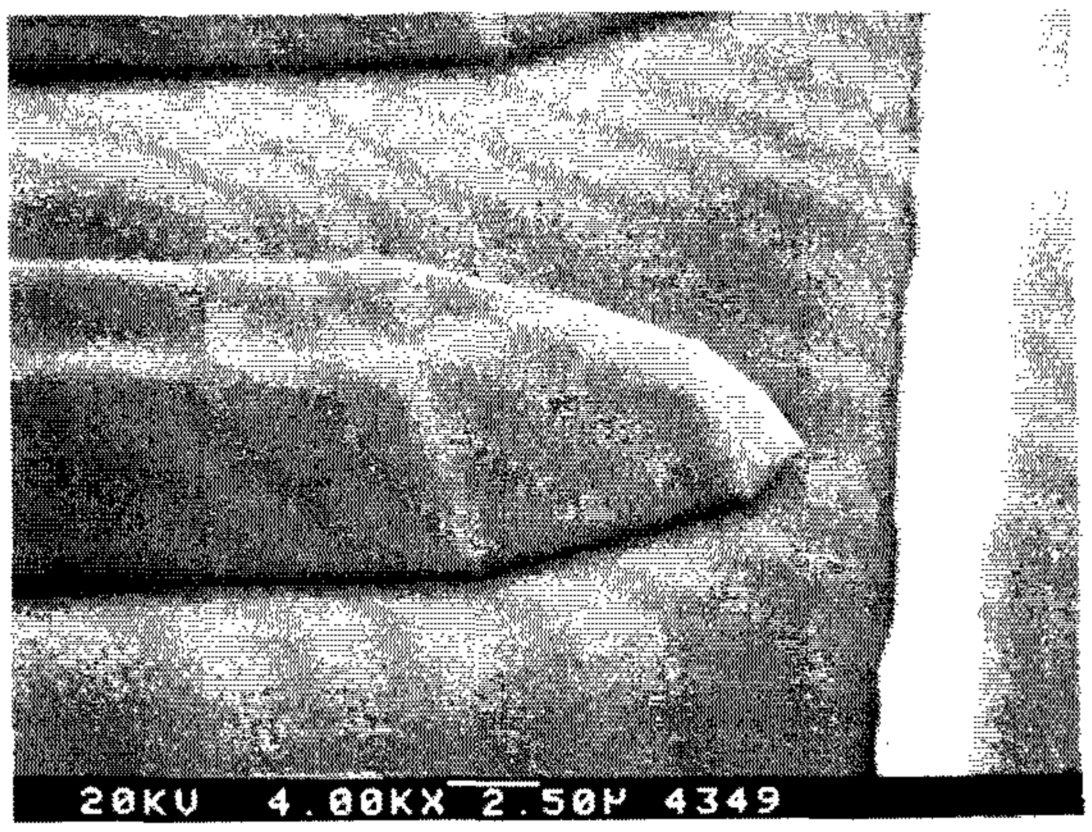


Fig. 4. Fowler-Nordeim plot of I-V curve shown in Fig. 3.

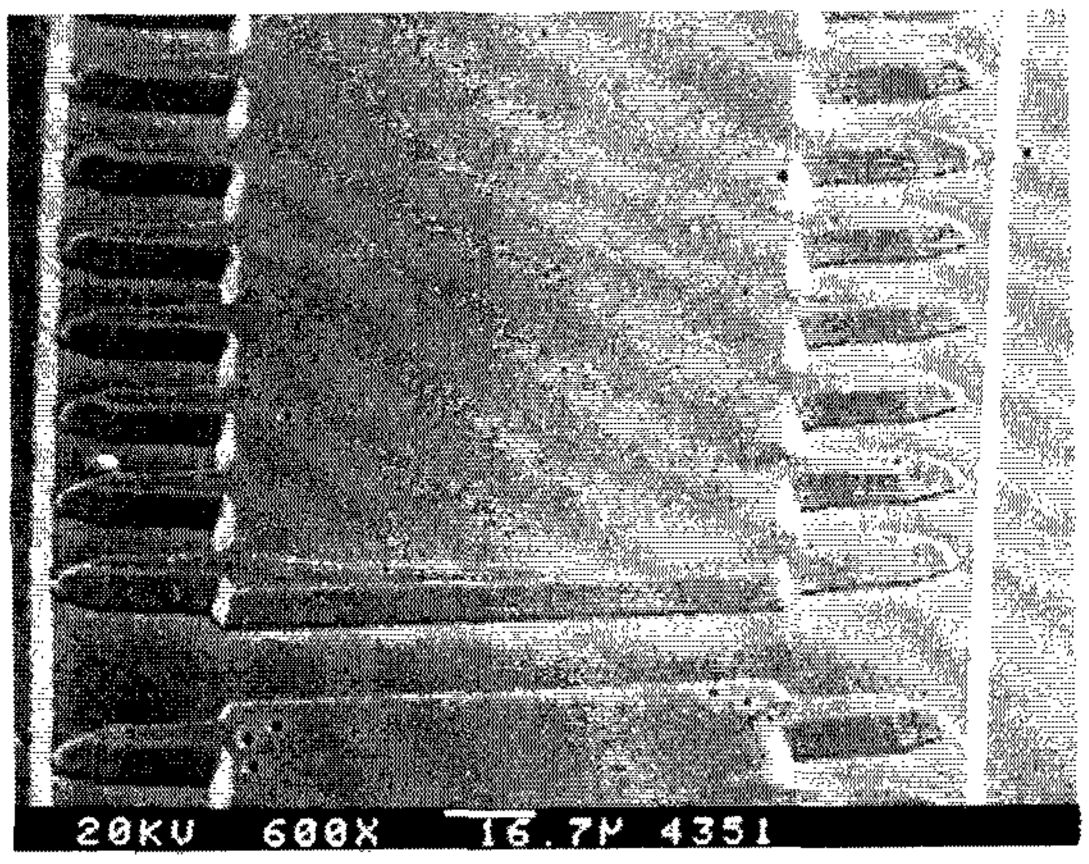
Figure 5 shows SEM photographs of selective re-grown n^+-GaN emitters on undoped GaN by utilizing Si_3N_4 film as a masking layer. Compared to lateral type GaN field emission diode using ECR-RIE, re-grown GaN emitters shows sharper shape tips and shorter inter-electrode distances. Detailed emission behaviors are under investigation by introducing a new field emission model with a consideration of statistically distributed tip radiuses.

4. Conclusions

We have fabricated a GaN field emission diode using metal organic chemical vapor deposition (MOCVD). In forming the pattern, two kinds of procedures were proposed : a selective etching method with ECR-RIE or a simple selective growth by utilizing Si_3N_4 film as masking layer. The fabricated device using the ECR-RIE exhibited electrical characteristics such as a turn-on voltage of 35 V and an emission current of ~ 580 nA/10tips at anode-to-cathode voltage of 100 V. These field emission characteristics are believed to be due to a low electron affinity as well as the shorter inter-electrode distance. Compared to lateral type GaN field emission diode using ECR-RIE, re-grown GaN emitters shows sharper shape tips and shorter inter-electrode distances.



(a)



(b)

Fig. 5. SEM photographs of re-grown GaN emitters using Si_3N_4 mask (a) sing emitter, (b) emitter arrays

5. Acknowledgements

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6. References

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