Electron Emission Properties of Selectively Grown Carbon Nanotubes for Electron Emitter in Microwave Power Amplifier

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Abstract

We studied field-emission characteristics of CNTs under various pre-treatment with NH_3 plasma on the substrate. The turn-on electric field is the lowest value and field enhancement factor (β) is he highest value in CNTs pre-treated by NH_3 plasma (80 W and 5 min). The field-emission property of CNTs grown on the Ta substrate is slightly better than on the W substrate.

1. Introduction

Field emitter arrays (FEAs) have potentials for use as an electron source in a wide variety of applications, including microwave power amplifiers (MPA), field emission displays, and electron microscopy. Use of an FEA as a cold cathode source for a MPA, such as the traveling-wave tube (TWT) [1], provides important technical challenges when one considers the high current and high current density coupled with the necessity for excellent beam control. With the recent advances in FEA technology, FEA with CNTs become an attractive alternative to the thermionic emitters currently used almost exclusively in such devices. However, a conventional fabrication process of FEA needs expensive and complicated semiconductor technologies. For the high emission current and simple fabrication of the cathode, we have used carbon nanotubes (CNTs) as the cathode source for TWT-MPA instead of the conventional metal-based FEAs

2. Experiments

We have directly grown CNTs on the metal substrates by direct-current plasma-enhanced chemical-vapor deposition using a gas mixture of C_2H_2 and NH_3 at relatively low temperature (550 °C). In this study, we report a systematic study on the field emission properties of CNTs depending on various catalyst metals (such as Ni, Co, and Invar426) and buffer layers (such as Cr, Mo, and TiN), which provide high conductivity, for high field-emission current. Field-emission characteristic of CNTs was evaluated in a vacuum of 10^{-6} Torr in a parallel diode configuration.

3. Results and Discussion

For control of site density of CNTs, NH_3 plasma pre-etching (20-80 W and 5-20 min) on the substrate was performed prior to the main growth of CNTs. As shown in Fig. 1(a) and inset, the turn-on electric field is the lowest value and field enhancement factor (β) is the highest value in CNTs pre-treated by NH_3 plasma (80 W and 5 min). As the NH_3/C_2H_2 ratio increased from 6/1 to 7/1 at the constant total flow rate (150 sccm) during main growth of CNTs, the turn-on electric field decreased and the emission current increased even after the identical NH_3 pre-etching (20 W and 20 min) prior to the growth. This reason may be resulted from an improvement of sp^2-graphization of CNTs due to NH_3 addition in C/H/N growth system [2]. The maximum

emission current value was up to about 9 mA/cm^2. In Fig. 1(b) and inset, the field-emission property of CNTs grown on the Ta substrate was slightly better than on the W substrate. As shown in Fig. 1(c), when the NH_3/C_2H_2 ratio was 7/1, the field-emission property of CNTs grown on the Ta substrate is better than on the W substrate like as the case shown in Fig. 1(b).

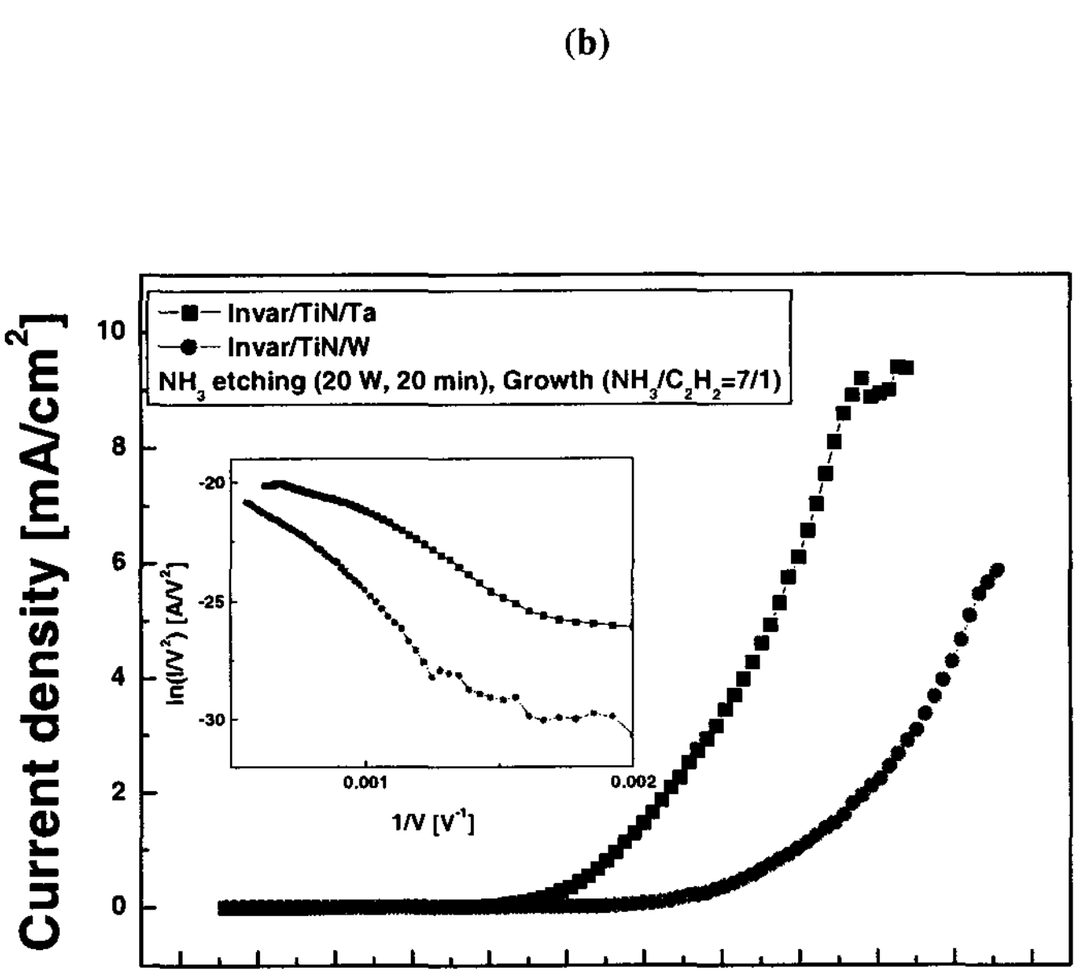
Figure 2(a) and (b) show the CNTs grown on the Ta and W substrates under the growth condition described above in Fig 1(c), respectively. More CNTs were grown on the Ta substrate than W. These may provide emission sites, leading to enhance the field emission property as shown in Fig 1(c).

In order to enhance the field-emission property and investigate the *field screening effect* of CNTs cathode, we are studying a patterned growth of CNTs using a photolithography technique. A pattern size is varied from 30 μm to 240 μm and a pitch distance is changed from 60 μm to 960 μm.

4. Conclusion

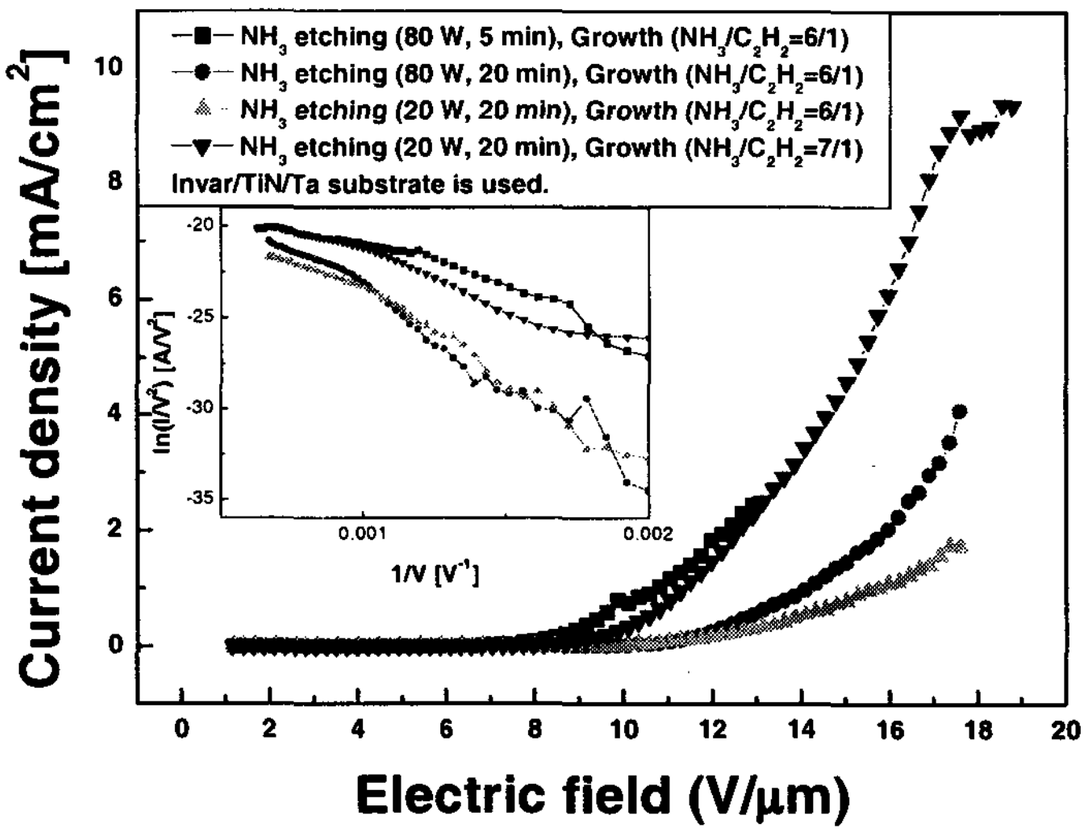
We studied field-emission characteristics of CNTs under various pre-treatment with NH_3 plasma on the substrate. The turn-on electric field is the lowest value and field enhancement factor (β) is he highest value in CNTs pre-treated by NH_3 plasma (80 W and 5 min). The field-emission property of CNTs grown on the Ta substrate is slightly better than on the W substrate.

5. Figures/Captions



(b)

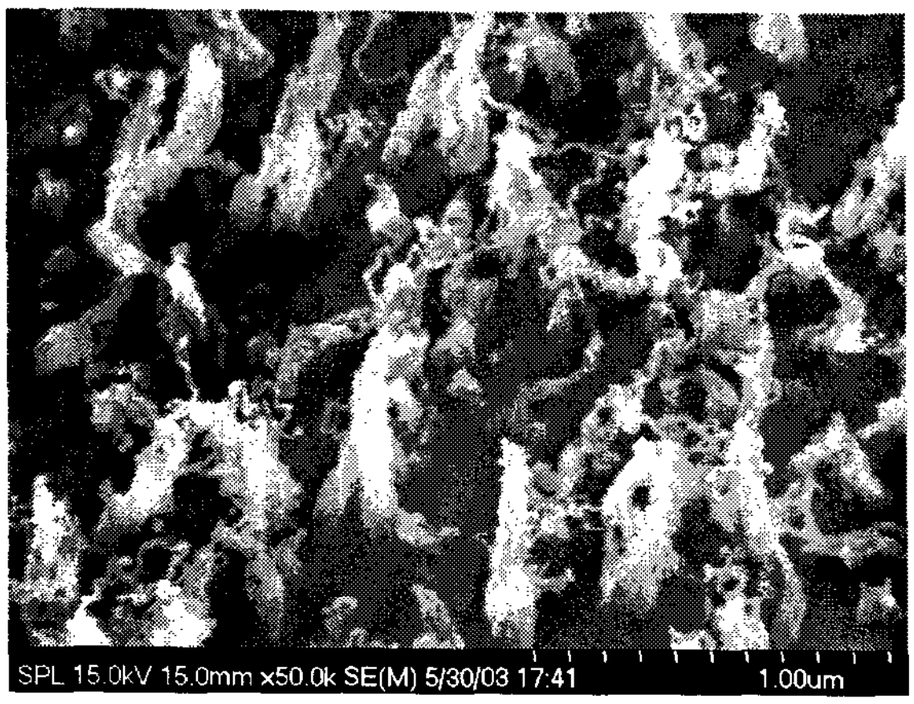
(c)



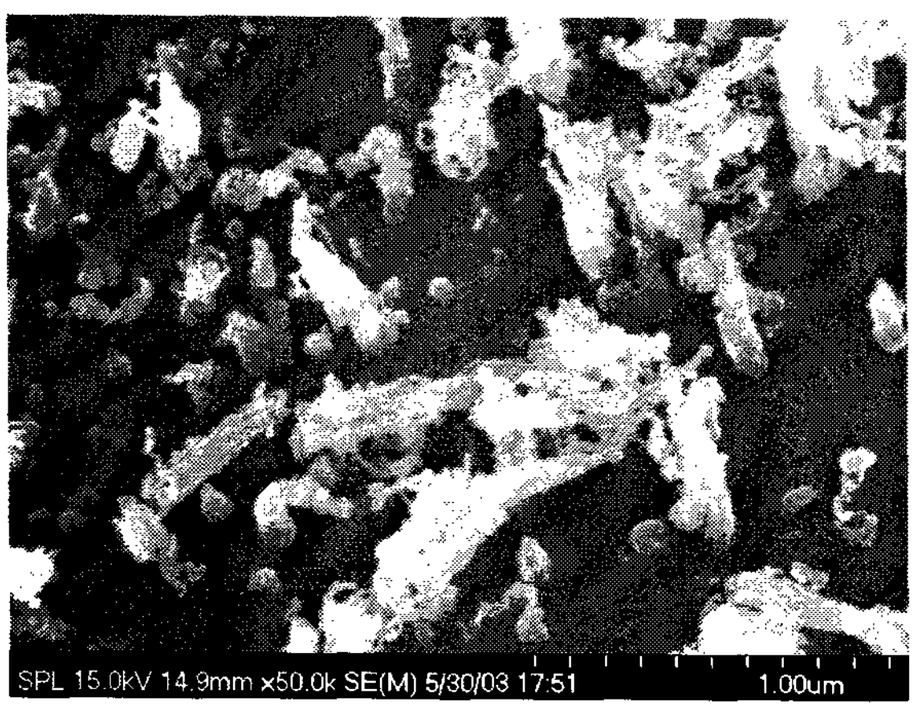
(a)

Fig. 1. (a) I-V characteristics of CNTs pre-treated by NH_3 plasma with (a) various etching conditions and with (b) and (c) different substrates (Ta and W). Insets

indicate the corresponding Fowler-Nordheim plots, respectively.



(a)



(b)

Fig. 2. SEM images showing the CNTs grown on different substrates under the growth condition of NH_3 pre-etching (20 W and 20 min) and main growth (NH_3/C_2H_2=7/1). (a) Ta and (b) W substrates.

6. References

[1] D. R. Whaley, B. M. Gannon, C. R. Smith, C. M. Armstrong, and C. A. Spindt, IEEE Trans. Plasma Sci. **28**, 727 (2000).

[2] J. H. Han, T. Y. Lee, J. B. Yoo, C. Y. Park, T. W. Jung, J. M. Kim. SeGi Yu, W. K. Yi, J. Vac. Sci. Tech. B (submitted).