Fabrication and Characteristics of CNT-FEAs with Under-gate Structure

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Abstract

We proposed new triode-type Field Emitter Arays using Carbon NanoTubes(CNT-FEAs) as electron emission sources at low electric fields. The CNTs were selectively grown on the patterned catalyst layer by Plasma-Enhanced Chemical Vapor Deposition (PECVD). In this structure, gate electrodes are located underneath the cathode electrodes and extracted gate is surrounded by CNT emitters. Furthermore, in order to control density of CNTs, we investigated effect of using rapid thermal annealing (RTA).

1. Introduction

The most familiar structure of the cold cathode in the initial FED is an array of microtips or 'spindt tip' named after Capp Spindt[1,2]. But it is susceptible to thermal damage due to resistive heating, physical sputter damage by residual gases in the surrounding vacuum environment. CNTs have presently used as sources for field emission because of a high aspect ratio, small radius of curvature, and relatively long lengths [3-5]. Hence, CNTs can generate a large electric field enhancement factor at low electric fields. However, the decrease of emission efficiency by electric-field-screening effect of the dense CNTs should be considered. So it is necessary to control density of CNTs to obtain high emission efficiency. Currently, there are many methods to control the density of CNTs. These are electron-beam lithography, micro contact printing, and shadow mask.[13] But the demerits of the methods are both expensive and inefficient in terms of controlling the density in large area..

In this study, we applied the Rapid Thermal Annealing (RTA) pre-treatment before CNT growth by PECVD. In addition, we proposed a new structure of under-gate-type triode CNT-FEAs of which extracted gate is surrounded by CNT emitters, because triode-type FED is essential to make high-quality, full gray-scale imaging and fast response. The cathode-gate short could be eliminated by locating the gate electrode underneath the cathode layer. The experimental results including fabrication process, field emission characteristics and RTA treatment effect are presented and discussed.

2. Experimental

The fabrication process of the conventional and the proposed CNT-FEAs comprise 4 photolithography steps as shown in Fig. 1, that is, (a) formation of gate electrode with a thickness of 300-nm on an insulating substrate, (b) deposition of gate insulator to to isolate gate electrode and cathod electrode and subsequent via-hole formation, (c) formation of cathode electrode and extracted gate with a thickness of 300-nm by using metal sputter(MHS-1500), and (d) completion of CNT-FEAs by Ni catalyst layer formation and selective CNT growth. 1~5-nm-thickness Ni is deposited by e-gun evaporator and patterned by lift-off process for catalyst layer formation. RTA can be optionally applied prior to the CNT growth by PECVD.

Fig.2 and Fig.3 show the schematic structure and SEM (Scanning Electron Microscope) images of the conventional and the proposed triode-type CNT-FEAs [6, 7, 9-11],]. It was found that the CNTs were selectively grown on pattern Ni catalyst layer [8]. The CNTs were grown using the mixture gas of acctylene(C_2H_2) and ammonia(NH_3) with a flow rate of 40 sccm and 160 sccm, respectively, at a pressure of 3.3 Torr and a power of 70 W. The substrate temperature was around 550℃.

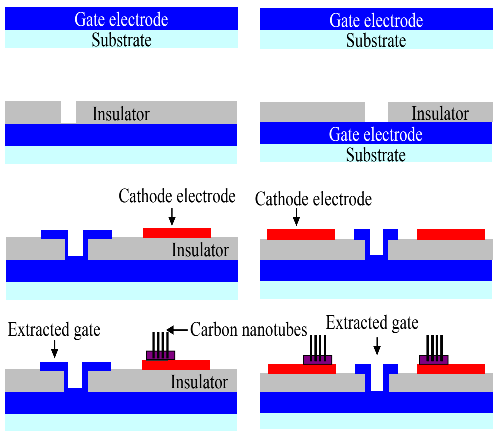

Fig. 1. Fabrication process of triode-type CNT-FEAs of conventional and proposed structure (a) gate formation (b) contact via hole formation. (c) cathode and extracted gate formation. (d) Ni catalyst layer formation and selective growth of CNTs.

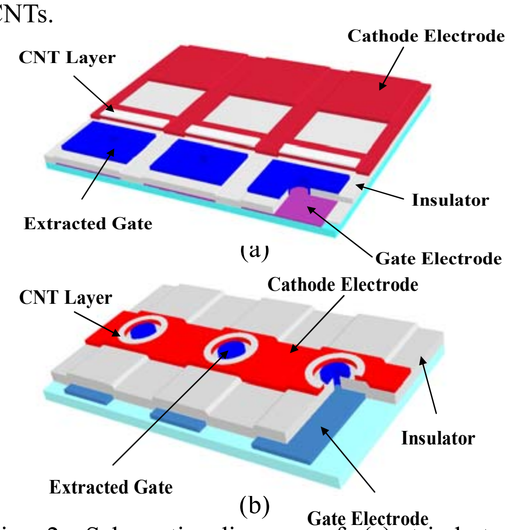

Fig. 2. Schematic diagram of (a) triode-type conventional (b) proposed CNT-FEAs.

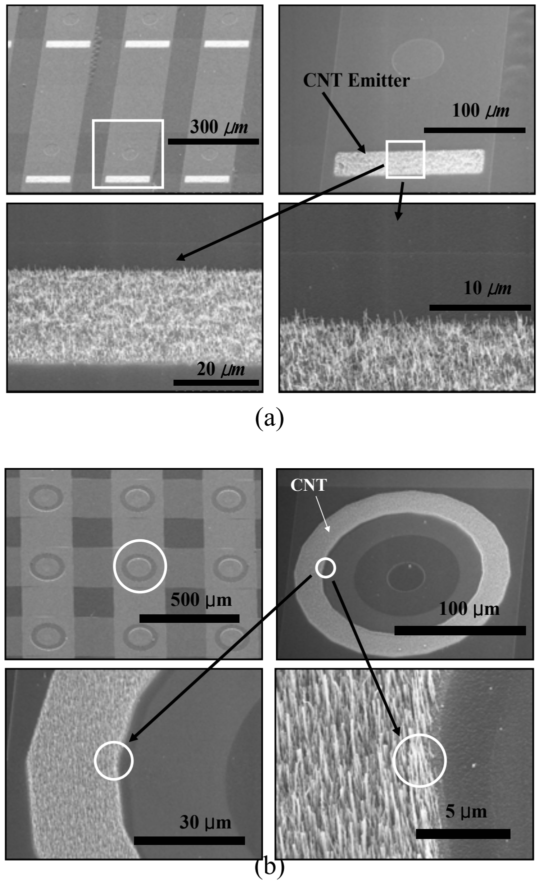

Fig. 3. SEM photograph of CNTs on patterned Ni catalyst layer. (a) triode-type conventional and (b) proposed structure.

4. Result and discussion

The device was measured in ultra-high vaccum chamber with the base pressure of 1×10^{-7} Torr. The distance between the metallic anode and the gate was kept at 1mm and the anode plate was applied to 2000V. The gate voltage was positively increased from 0 to 65V. The I-V data were taken by Keithley-487 electrometer through an IEEE-488 interface.

Figure 4 shows the I-V characteristics of conventional and proposed CNT-FEAs. The insert shows the corresponding Fowler-Nordheim plots. The linearity of F-N curve reveals that the anode current occur by field emission [12]. In Fig.4, it was found that the electron emission started at 45V and the anode current reached the level of 2.6㎂ at 65V in the conventional structure. On the other hand, the emission started at 30 V and the anode current reached the level of 5.0㎂

at 55 V in the proposed structure.

Figure 5 shows the Raman spectroscopy for the selectively grown CNTs by PECVD. The figure clearly reveals two main peaks of D-line and G-line peaks at about 1360cm^{-1} and 1600cm^{-1}, respectively. The strong G-line peak indicates a well-structured graphitic morphology of the CNTs. On the other hand, D-line peak indicates that grown CNTs have the existence of defective graphite such as amorphous carbon component or the structural disorders [8]. From Raman spectrum analysis, it is considered that overall crystallization of the CNTs is good even though there is partly defective graphite structure.

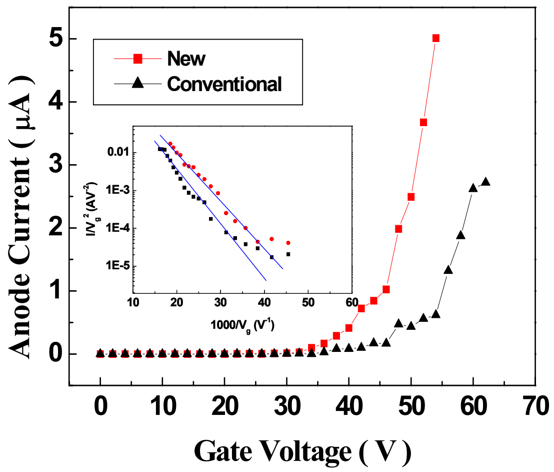

Fig. 4. Field emission properties obtained from the conventional and the proposed triode-type CNT-FEAs. The inset shows the F-N plot.

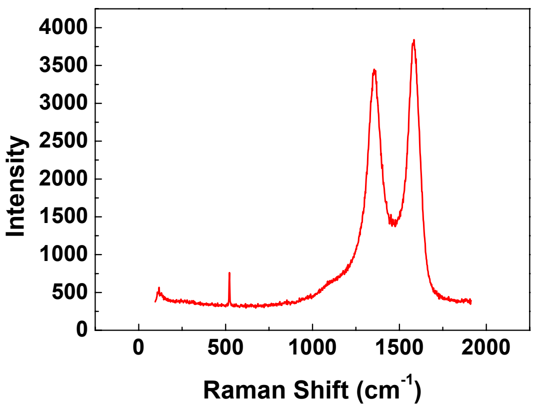

Fig. 5. Raman spectroscopy of the grown CNTs by PECVD.

In order to suppress the electric-field-screening effect due to dense CNTs, we tried to control the density of CNTs by Ni thickness and RTA pretreatment. With a view to finding optimum condition for Ni thickness and RTA temperature, we varied experimental variables. Figure 6 shows the SEM pictures of the selectively grown CNT emitters with different Ni thickness and RTA temperature. CNTs of Fig. 6(a) were grown on 5nm-thick Ni without RTA treatment and CNTs of 6(b) and 6(c) were grown on 5 nm-thick Ni with RTA treatment at 400℃ for 50 sec and 1 nm-thick with RTA treatment at 600℃ for 50 sec. Grown CNTs after RTA treatment have low density as shown in Fig 6(b) and 6(c).

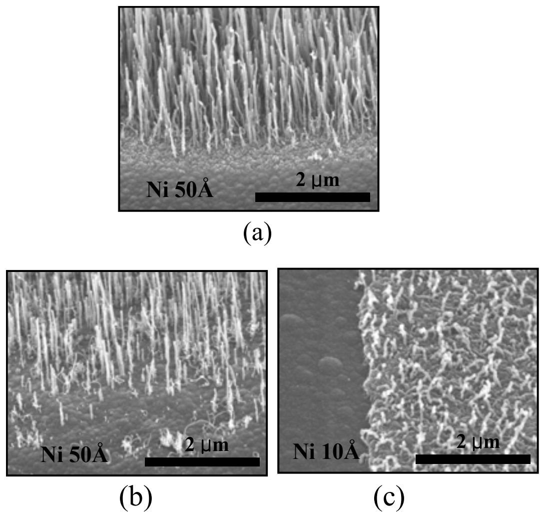

Fig. 6. SEM image of CNT-FEA (a) without RTA, (b) with RTA at 400℃ for 50 sec., and (c) with RTA at 600℃ for 50 sec.

Figure 7 shows the I-V characteristics of CNT-FEAs corresponding to the Fig. 6. Lower turn-on voltage and higher emission current were observed in the sample with 1 nm-thick Ni and with RTA at 600℃ for 50 sec., which is probably caused by low density of grown CNT. Since dense CNTs bring about higher electric-field-screening effect, high density of CNTs acts as obstacles for highly efficient field emission.

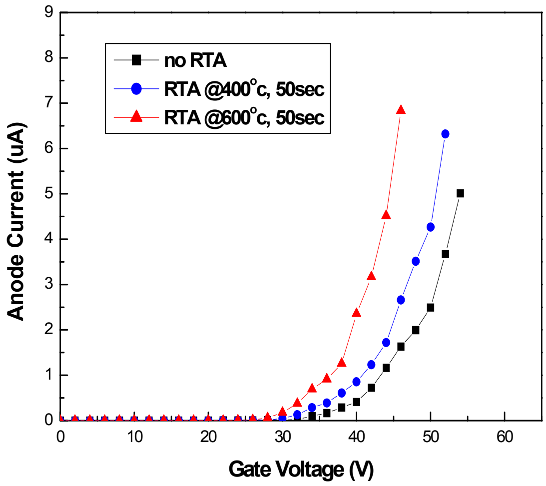

Fig. 7. I-V characteristics of triode-type CNT-FEAs with different Ni thickness and RTA temperature

5. Conclusions

In summary, we successfully fabricated new triode-type FEAs using selectively grown CNTs as an electron emitter for FEDs. Form the result, we confirmed that proposed structure has lower turn-on voltage compared with the conventional structure. Besides, sparsely grown CNTs obtained through the optimized Ni thickness and RTA temperature could lead to high emission efficiency, in comparison with as-grown CNTs without RTA treatment.

6. References

[1] C. A. Spindt, Brodie I, Humphrey L and Westerberg E R 1976 J. Appl. Phys. 47 5248.
[2] J. Vac. Sci. Technol. B, vol. 11, p. 468–473, (1993).
[3] Y. Saito et al., Appl.Phys. A : Mater. Sci. Process, A67, 95 (1998).
[4] W.B. Choi et al., Appl. Phys. Letter. 75, 3129 (1999).
[5] A. G. Rinzler, J. H. Hafner, P. Nikolaev, L. Lou, S. G. Kim, D. Tomanek, P. Nordlander, D. T. Colbert, and R. E. Smalley, Science 269, 1550 (1995).
[6] Delzeit L, McAninch I, Cruden B A, Hash D, Chen B, Han J and Meyyappan M 2002 J. Appl. Phys. 91 6027.
[7] C. G. Lee et al., 2^{nd} International Meeting on Information Display, (2002), p. 303.
[8] M. Sveningsson, R.-E. Morjan, O.A. Nerushev, Y. Sato, J. Backstrom, E.E.B. Campbell, F. Rohmund, Appl. Phys. A73 409 (2001).
[9] Q.H. Wang, M. Yan, R.P.H Chang, Appl. Phys. Lett. 78 (2001) 1294.
[10] M.A. Guillorn, M.L. Simpson, G.J. Bordonaro, V.I. Merkulov, L.R. Baylor, D.H. Lowndes, J. Vac. Sci. Tech., B 19 (2001) 573.
[11] Y.H. Lee, Y.T. Jang, D.H. Kim, J.H. Ahn, B.K. Ju, Adv. Mater. 13, 489 (2001).
[12] J.W. Gadzuk, E.W. Plummer: Rev. Mod. Phys. 45, 487 (1973).
[13] S. H. Jeong, H. Y. Hwang, K. H. Lee, and Y. Jeong, Appl. Phys. Lett. 78, 2050 (2001).