Defense Technical Information Center Compilation Part Notice

ADP011308

TITLE: A Field Emission Display Using Carbon Nanotubes as Emitters

DISTRIBUTION: Approved for public release, distribution unlimited

This paper is part of the following report:

TITLE: Display Technologies III Held in Taipei, Taiwan on 26-27 July 2000

To order the complete compilation report, use: ADA398270

The component part is provided here to allow users access to individually authored sections of proceedings, annals, symposia, etc. However, the component should be considered within the context of the overall compilation report and not as a stand-alone technical report.

The following component part numbers comprise the compilation report:
ADP011297 thru ADP011332

UNCLASSIFIED

A Field Emission Display using Carbon Nanotubes as Emitters

Feng-Yu Chuang*, Cheng-Chung Lee, Jyung-Dong Lin, Jane-Hway Liao, Hua-Chi Cheng, Cheng-Xian Han, Jon-Lian Kwo[1)], Wen-Chun Wang
Electronic Research & Service Organization, Industrial Technology Research Institute, Hsinchu, Taiwan, R.O.C.
[1)]Department of Electrical Engineering, National Cheng Kung University, Tainan, Taiwan, 701, R.O.C.

ABSTRACT

A fully sealed field emission display (FED), indicator, using carbon nanotubes (CNTs) as emitters is examined. The CNTs chunk, synthesized by arc discharge, were crushed, mixed with conductive pastes and then screen-printed on glass for the cold cathode. And the anode plate, an ITO glass printed P15 phosphor, was separated from cathode using 90μm spacers. The indicator display performed a turn-on voltage as low as 250 V, and the emission current density 2.2 mA/cm^2 under 300 V with brightness of 500 nits. The pixels, driven by open drain IC with 5 V gate voltage, showed the clock image which indicated the application of CNTs-FED. No significant degradation of this performance was observed during 1000 mins testing. The influence of printing condition and surface treatment process on the emission characteristics will also be discussed in this letter.
Keywords: field emission display, indicator, carbon nanotubes, arc-discharge

Correspondence: Email: fychuang@itri.org.tw; Fax: 886-3-5826842

I. INTRODUCTION

Carbon nanotubes, grown on the cathode of arc discharge process, were first observed by Iijima in 1991 [1]. The needle-like tubes comprised coaxial tubes of graphite sheets and ranged in size from 4 to 30 nm in diameter and up to 1μm in length. The discovery of carbon nanotubes has been attracting considerable attention because of their own unique physical properties and their potential for a variety of applications [2~4]. Due to their high aspect ratios and small tip radii of curvature, the nanotubes (CNTs) exhibit excellent field emission characteristics. High field emission current density of 10 mA/cm^2 [5] and low turn-on electric field of 0.8 V/μm have been demonstrated [6,7]. Recently, Ise Electronic Corp. has demonstrated a CRT-lighting-element, which used MWNTs as the cold emitter source, with a lifetime of more than 5000 hours [8]. Further more, Samsung shows a matrix-addressable diode display using CNTs-emitters [9]. CNTs show potential in the application for vacuum fluorescent display (VFD) and field emission display (FED). Nowadays, CNTs can be synthesized by arc discharge [10,11], laser ablation [12], and chemical vapor deposition process [13,14], etc. Arc discharge is suitable for its throughput. In this work, we use DC arc discharge process to synthesize CNTs. The electron emission characteristics of CNTs films, which were patterned by printing process, will be investigated and a prototype of CNTs-FED will be demonstrated in this paper.

2. EXPERIMENTAL

The anode used in DC arc discharge process was a pure graphite rod with 15 cm in length, and the cathode was a graphite disc (18 mm in diameter) mounted into water-cool copper. The chamber was maintained in helium atmosphere (500mbar). Arc constant DC current (70~80 A) was applied to the anode and cathode separated with a gap about 2~3 mm, whereas the voltage across the gap was 20~24 V.

The morphology and structure of the CNT-bulks were examined using scanning electron microscopy (SEM). Field emission characteristics of the CNT-emitters were measured by a diode technique using an electrometer. Anode plate, a glass coated with ITO layer and P15 phosphor, was separated from the cathode by using 90 um spacers. The turn-on field (E_0) were designated as the field at which the Fowel-Nordheim plot, ln (I/V^2)-$(1/V)$ deviates from the straight line.

To fabricate CNT emitters, silver paste was first printed on glass as bottom electrode. The tube was crushed using ball milling to reduce its length to 1~2 um. The slurry containing CNTs was then printed upon silver paste. The fully sealed CNTs-FED was fabricated using VFD-like vacuum sealing process. All the interfaces between the anode plate/spacer

In *Display Technologies III*, I-Wei Wu, Heiju Uchiike, Editors, Proceedings of SPIE Vol. 4079 (2000) • 0277-786X/00/$15.00

bar/CNTs-emitter plate were sealed with glass frits, followed by thermal annealing to enable the reaction of the glass with glass frits.

3. RESULTS AND DISCUSSION

SEM micrographs of the bulk, shown in Fig. 1a and 1b, indicate that consists of multi-wall nanotubes embedded in fibrous bundles. Each bundle is approximately 50 um in diameter. The nanotubes are about several tens of nm in diameter. The carbonaceous particles attached on the CNTs can easily be removed by post treatment at 600□ in air. The yields of nanotubes embedded in fibrous bundles are higher than 70% after thermal treatment. To reduce the length of nanotubes, ball milling was introduced to crush it for 2 hours.

To study the characteristics of CNTs emitters, the silver was first screen-printed in dot pattern on the glass as cathode. Each dot has 1×1 mm^2 in area. The slurry containing CNTs and binders was then screen-printed upon silver paste, followed by oven curing. Figure 1c shows a cross-sectional SEM micrograph of CNTs-emitter. Most of CNTs are aligned perpendicularly to substrate after surface treatment process on the surface. The density of CNTs-emitters was markedly larger than the typical density of microtips in conventional Spindt-type FEDs. Further, the P15 phosphor was screen printed on another ITO glass plate as anode. The emission property of CNTs-emitter was measured using diode structure, as shown in Fig. 2. The CNTs-emitters turns on at a field as low as 1.45 V/um and the current rise to 0.5 mA under electric field of 5.5 V/um. The current significantly increased to 3.4 mA under 5.5 V/um applied field after surface treatment. The resultant fabrication process is shown in Fig. 3. The gap spacing between both plates, separated by the spacer bar, is 90 um. All the interfaces between the anode/plate/sapcer bar/CNTs-emitter plate was sealed with glass frits, followed by thermal annealing to enable the reaction of the glass with glass frits. Exhaust process was performed with a conventional vacuum pump, which is almost the same as VFD vacuum sealing process.

To study the image and measure the characteristics of sealed FED device, the anode is applied with high voltage (300-350 V) and the cathode electrodes are switch-driven. Fig. 4 shows a sequence of the images of a counting clock. The images indicated that each dot could be controlled well using an MOSFET as a current switch. At the on-state, the voltage between gate and source was 5 V, i.e., turned on the channel. The voltage drop between the drain and source are neglected which compared to anode voltage. At the off-state, the voltage between gate and source was 0 V, thus there is no induced current in the channel due to floating.

Moreover, to demonstrate the driving of CNTs-FED, a seven-segment numerical indicator was designed using diode structure. Each segment has 1 mm wide and 5 mm long in size. The system of indicator consists of two components, control and driving circuits, as shown in Fig. 5. The control circuit, using FPGA, operated under duty cycle of 1/10~9/10. The high voltage driving circuit was n-channel open drain interface IC. Fig. 6 shows the emission image of seven-segment indicator. The brightness is as high as 500 nits when applied with 300 volts between anode and cathode. The voltages of 5 V and 12 V are applied to FPGA and driving IC, respectively. During 1000 min testing, the emission current decay is about 14% and saturated after 50 hours under 280 V applied anode voltage. It is still testing.

4. CONCLUSION

In summary, the seven-segment numerical indicator shows the excellent electron emission characteristics of CNTs-FED using diode structure. The brightness is as high as 500 nits when applied with 300 volts between anode and cathode, using open drain driver IC. Most of CNTs are aligned perpendicularly to substrate and its emission current density significant increase after surface treatment process on the surface. During 1000 min testing, the emission current decay is about 14% and saturated after 50 hours under 280 V applied anode voltage. It indicates that CNTs-FED is very promising for application of flat panel display.

REFERENCES

1. S. Iijima, "Helical microtubules of graphite carbon", Nature 354,pp56-58, 1991.
2. Saito,Susumu, Science ,V278,p77(1997).
3. P. G. Collins, A. Zettle, and R. E. Smalley, "Nanotube Nanodevice", Science, 278,p100(1997).
4. Walt A. De Heer, A. Chatelain , D. Ugarte , "A carbon nanotube field emission electron source", Science, 270, pp1179-1180, 1995.
5. J.M. Bonard, J.P. Salvetat, T. Stockli, "Field emission from single-wall carbon nanotube films", Appl. Phys. Lett. 73, pp918-920, 1998.
6. Q. H. Wang , T. D Corrigan , J. Y. Dai and R. P. H. Chang ,"Field emission from nanotube bundle emitters at low fields", Appl. Phys. Lett., 70, p3308(1997).
7. P. G. Collins, and A. Zettl ,,"Unique characteristics of cold cathode carbon-nanotube-matrix field emitters", Phys. Rev.

B55, pp9391-9399, 1997.
8. S. Uemura , T. Nagasako , J. Yotani ,T. Shimojo , SID 98 DIGEST,p1052(1998).
9. W. B. Choi, D. S. Chung, S. H. Park, J. M. Kim, "Fully sealed high-brightness carbon-nanotube field emission display", Appl. Phys. Lett.75, pp3129-3131, 1999.
10. J. M. Lauerhaas , J. Y. Dai , A. A. Setlur , and R. P. H. Chang, J.Mater. Res., 12 No.6, p1536(1997).
11. P. M. Ajayan ,Ph. Redlich , and M. Ruhle, J.Mater. Res., 12 , No. 1, p244(1997).
12. A. G. Rinzler, J. Liu, and R. E. Smalley, "Large scale purification of single wall carbon nanotubes", Appl. Phys. A, 67, pp29-37 1998.
13. J. M. Mao, L. F. Sun, L. X. Qian, Z. W. Pan, B. H. Chang, W. Y. Zhou, G. Wang and S. S. Xie, "Growth of highly orinted carbon nanotubes by plasma-enhanced hot filament chemical vapor deposition", Appl. Phys. Lett. 72, p3297-3299, 1998.
14. G. Che, B. B. Lakshmi, and E. R. Fisher, Chem. Mater, 10, p260 (1998).

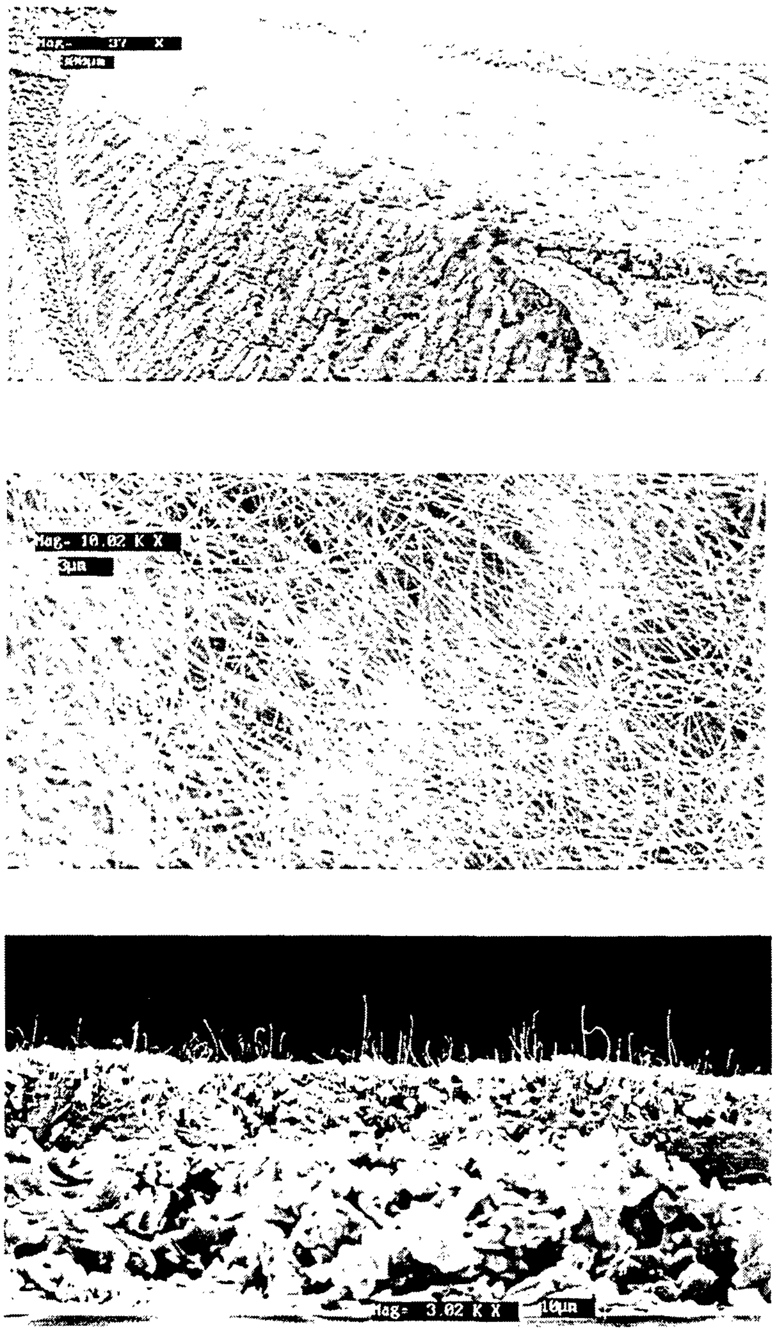

Fig.1 SEM micrographs show (a) as-grown bulk bundles, (b) multi-wall nanotubes embedded in bulk bundles, (c) cross-sectional image of screen-printed CNTs-emitters are perpendicular to substrate after surface treatment.

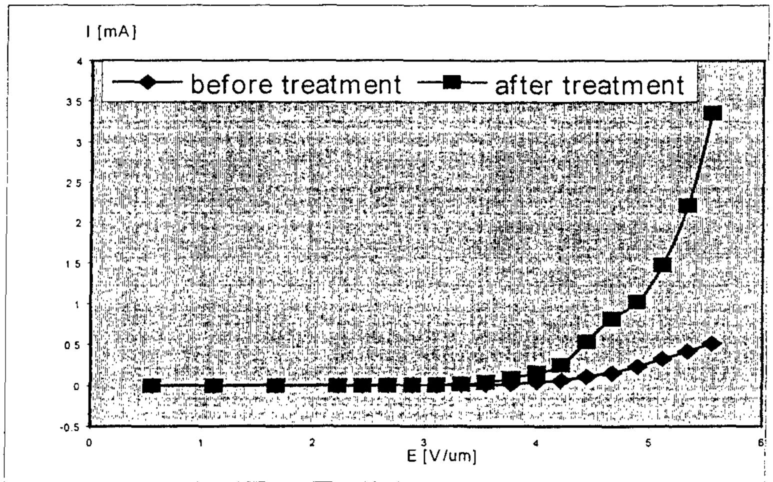

Fig. 2 Emission current of CNTs-emitter as a function of applied electric field, with and w/o surface treatment.

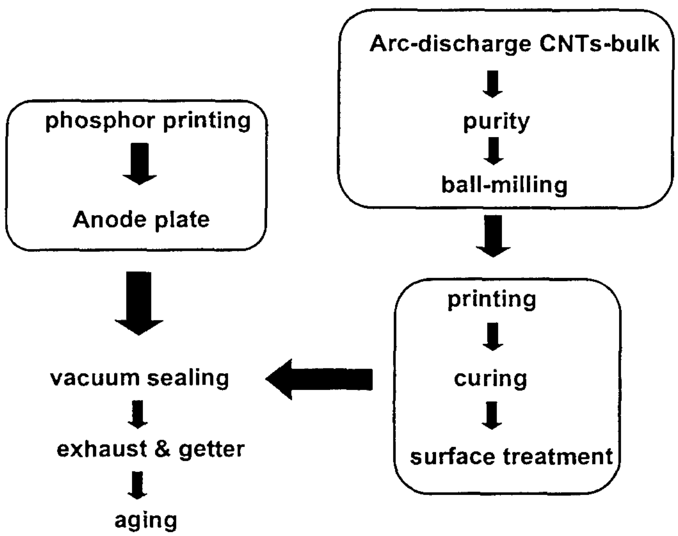

Fig.3 Fabrication process of CNTs-FED, using VFD-like vacuum sealing process.

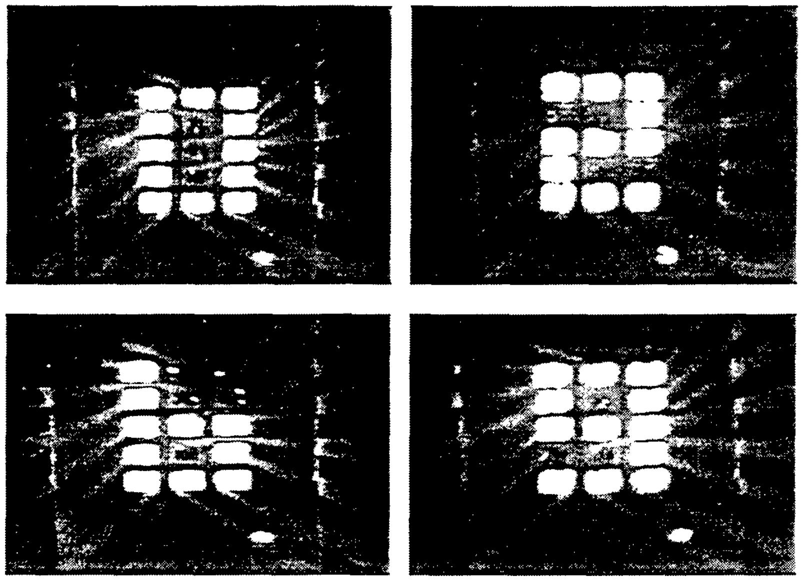

Fig. 4 Electron emission image of 15-pixels CNTs-emitter using diode structure, operated at 5 V/um applied electric field.

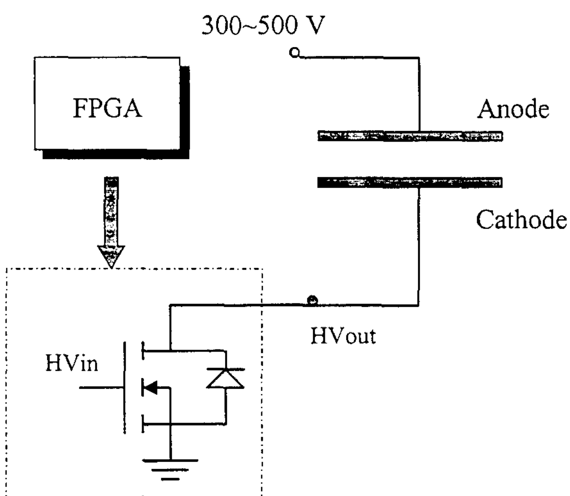

Fig. 5 Schematic diagram of driving circuit used in seven-segment CNTs-FED.

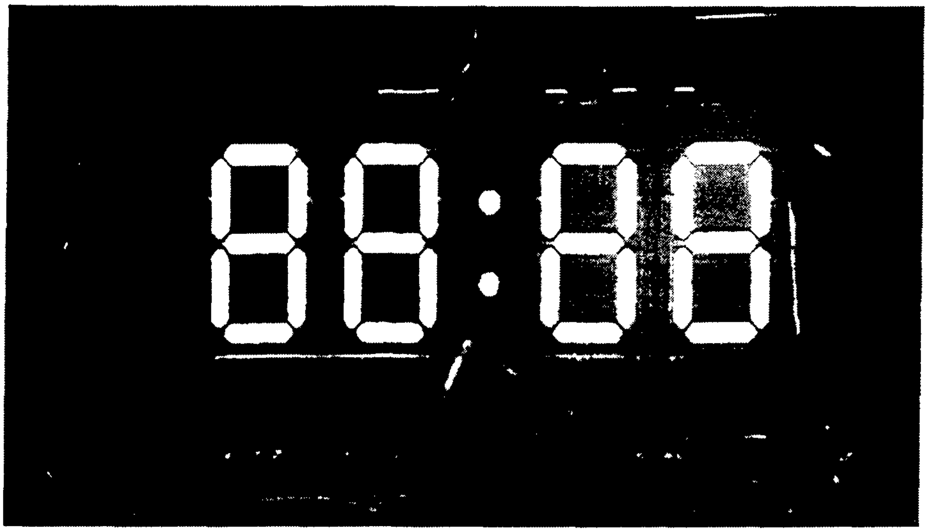

Fig. 6 Electron emission image of seven-segment numerical indicator using CNTs-emitter, the applied electric field is 5 V/um.