Simple fabrication process and characteristic of a screen-printed triode-CNT field emission arrays for the flat lamp application

Y. J. Jung[a], J. H. Park[a], S.Y. Jeon[a], S. J. Park[a] P.S. Alegaonkar[a,b]

J.B. Yoo[*a] and C.Y. Park[a]

[a)]Center for Nanotubes and Nanostructured Composites, Sungkyunkwan University,300 Chunchun-Dong, Jangan-Gu, Suwon, 440-746, Korea

[b)]Department of Physics, University of Pune, Pune–411 007, India

Phone: +82-31-299-4745 , E-mail: jbyoo@skku.ac.kr

Abstract

We introduced simple fabrication process for field emission devices based on carbon nanotubes (CNTs) emitters. Instead of using the ITO material as a transparent electrode, a metal (Au) with thickness of 5-20nm was used. Moreover, the ITO patterning process was eliminated by depositing metal layer, before the CNT printing process. In addition, the thin metal layer on photo resist (PR) layer was used as UV block. We fabricated the CNT field emission arrays of triode structure with simple process. And I-V characteristics of field emission arrays were measured. The maximum current density of 254μA/cm2 was achieved when the gate and the anode voltage was kept 150V and 3000V, respectively. The distance between anode and cathode was kept constant.

1. Introduction

Since the discovery of carbon nanotubes (CNTs)[1], they have attracted much attention as field emission source, due to their low threshold voltage, good emission stability and long emitter lifetime.[2] The CNT emitters are one of the best candidates for field emission devices such as, field emission displays (FEDs)[3], X-ray tubes[4] and backlight units (BLUs)[5] for liquid crystal displays (LCDs). In general, three known methods could be adopted, to use CNTs as the field emitters; screen-printing[6], spray deposition and chemical vapor deposition (CVD)[7,8]. Among them, screen printing method is the most cost effective method because of its easy appliance to a large screen size area. And hence, it has become a more matured technology in other display manufacturing areas. In general, backside expose[9] method was used for the patterned CNT emitters. Thus, expensive indium tin oxide (ITO) which has good transparent property was commonly prepared as the cathode materials. Also, to use cathode electrode at triode structure, ITO should been patterned by photolithography and etching technology[10]. The use of ITO material as cathode electrode is relatively expensive and it needs complicated sub-processes. And hence, research and development of other type of transparent electrode is required to fabricate simplified triode structure.

In this paper, we have introduced a simple fabrication process. The patterned ITO film was replaced by thin Au film with thickness ~ 5-20 nm to serve as a transparent electrode material. Therefore, the ITO patterning process was eliminated. Moreover, coated Au film on photo resist (PR) layer was acted as an Ultraviolet (UV) block. The details of the fabrication process, conducting and transmission properties of the thin Au layer are discussed.

2. Experiment

The schematic cross section of parallel triode type CNT field emitter arrays is showed in

Fig. 1.

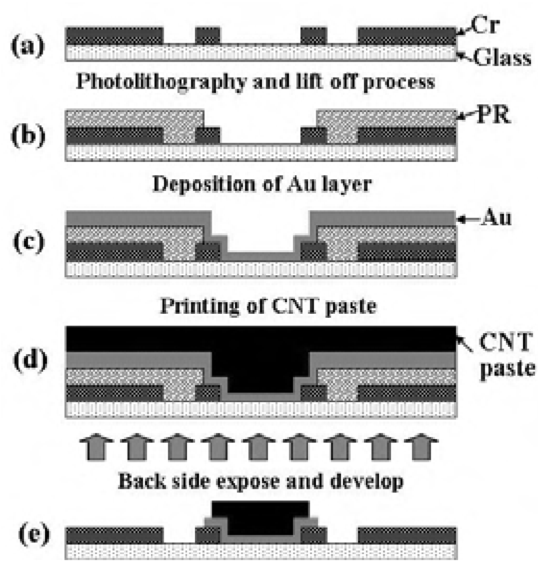

Fig. 1 Schematic depiction of fabrication processes for triode structure with CNT emitters.

The soda lime glass substrates were sonicated in acetone bath for a period of ~ 10min. After rinsing the substrates in methanol and DI water, respectively, they were baked in a furnace at a temperature ~ 110°C for 5 min. The substrates were coated by photo resist (PR, AZ1500) using spin coating method (2500rpm, 35sec), and then a opened-glass line was formed by the developer after UV exposure. To make cathode and gate electrode, thin Cr layer of thickness ~ 3000Å was deposited on the substrate by the e-beam evaporation technique. The lift-off method (Fig. 1 (a)) was adopted to fabricate cathode and gate electrode. To fabricate thin film of Au in cathode electrode and field emitter with CNT paste, PR was coated on the substrate (Fig. 1(b)). Thin layers of Au and Ti with thickness ~ 150 and ~ 20Å, respectively, were deposited by e-beam evaporation technique (shown in Fig. 1(c)). And photosensitive CNT-paste was printed by screen printing method. The photosensitive CNT-paste was composed of CNT powders, organic vehicles, photo initiator, and inorganic binder. To obtain a uniform thickness of CNT-paste, the backside exposure and development process were carried out after printing process. To obtain thickness layer of ~ 0.9 μm the CNT-paste was exposed to UV for a period of ~ 285sec. The drying of CNT paste was carried out in forced convection oven for 20 min at 90 °C. And, the PR layer was removed by soaking in acetone. Generally, the residue of organic vehicle in CNT paste leads to problems such as out-gassing and arc discharging during the field emission process. Organic materials in paste were removed in order to obtain stable emission characteristics. Therefore, the CNT-paste was fired at 450 °C for 10 min in nitrogen (N_2) ambient. The schematic diagram of fabricated triode structure with CNT emitter is shown in Fig. 1(e). After the surface treatment using adhesive tape, the field emission characteristics of parallel gated type CNT field emitters were measured. A super used stainless steel (SUS) was used as an anode plate. The distance between the cathode and the anode plate was kept constant ~ 1000μm. DC voltage was supplied between the anode and cathode electrodes using a high-voltage power supply (Fug, HCN 700-3500MOD) with different gate voltage for investigation of the triode characteristics. The fabricated triode structure and surface morphologies were observed by Field emission scanning electron microscopy (JEOL, JSM 6700F).

3. Results

Fig. 2 is recorded UV-vis spectra (Scinco, UV S-2100) for different thickness of Au film and compared with conventionally used ITO coated glass (SAMSUNG CORNING). In the present work, the Ti layer between Au and glass was used as an adhesion layer. The result revealed that, transmittance of ITO coated glass is more than 90% measured at I-line wavelength (365nm). Normally, ITO is coated by various methods such as, chemical vapor deposition (CVD), physical vapor deposition (PVD) and spin coating process. These methods need high temperature processing for make better electrical and optical properties. However, in our fabrication sequence, high temperature processing is avoided because of inclusion of the PR processing. Therefore, the thin metal layer (Au) as transparent electrode is used. The thin metal layer which is located between PR and CNT paste can also function as a block layer because the patterned PR layer can be dissolved by a solvent in CNT paste. And when back side expose, thin metal layer on PR is used as UV block.

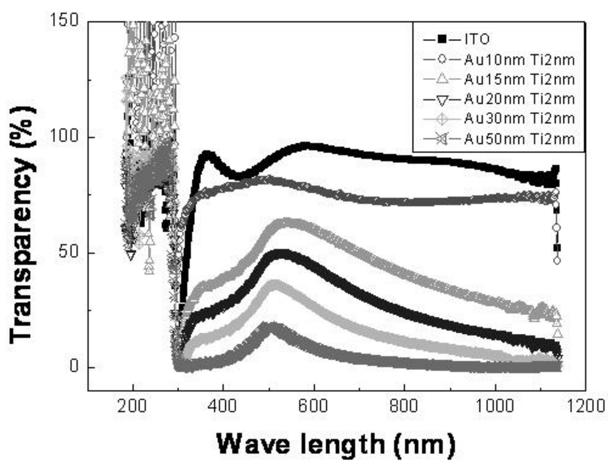

Fig. 2 Plot of variation in transmission (in %) over the measured wavelength range as a function of thickness of Au layer.

The thickness of the Au layer was varied from 5 to 50 nm. The sheet resistance and transmittance of Au layer as a function of thickness of layer are shown in Fig 3. The sheet resistance was measured by four probe method (CHANG MIN, CMT-SR 1000N) and the thickness of Au layer was measured by atomic force microscope (AFM) (THERO-MICROSCOPES CP Research). The resistance of the Au film with thickness more than 10nm was found to be always lower than that of the resistance (8.198Ω/□) of ITO film (film thickness: 185nm). It was found that the transmittance was decreased as the thickness of the Au layer was increased. When pattern of photosensitive CNT paste was formed, the transmittance of electrode and substrate is very important factor. Lower transmittance of Au layer was solved with the increased energy of radiation. The expose time of CNT paste at back side of glass was decided with this numerical formula [2J / (20mW/cm^2 x transparency) = expose time]. The thin metal layer of Au (15nm) and Ti (2nm) has characteristic of sheet resistance (4.99Ω/□) and transparency (35%) at a wavelength of 365nm. The Au thin film was introduced to make simple triode structure.

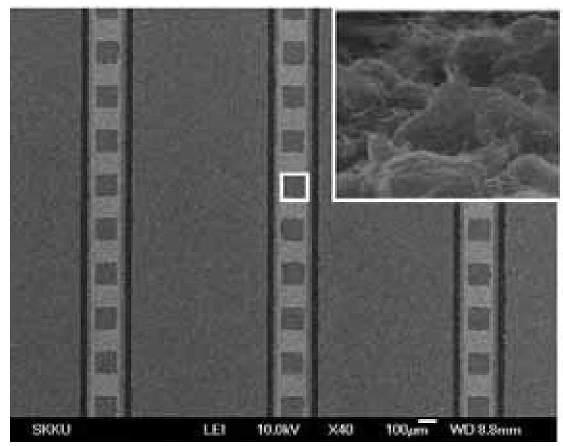

Fig. 4 Recorded SEM image for parallel triode structure and CNT emitters on a cathode electrode after surface activation by adhesive tape.

The fabricated triode structures are shown in Fig. 3(a). The width of gate and cathode were formed with 720 and 120 μm, respectively. The distance between the gate and cathode electrodes was 80 μm. After surface activation using adhesive tape thickness and morphologies of CNT-paste on a cathode electrode is shown in Fig. 3(b). The cathode electrodes with CNTs of thickness of 0.9 μm were formed by screen printing, back exposure techniques and firing process.

The emission characteristics of CNT field emitters as triode structure is shown in Fig. 4. The cathode size of triode structure was 1 x 1cm^2. The distance between cathode and anode was about 1000μm. The variation of anode current was measured when anode voltage was changed from 0 to 3200V.

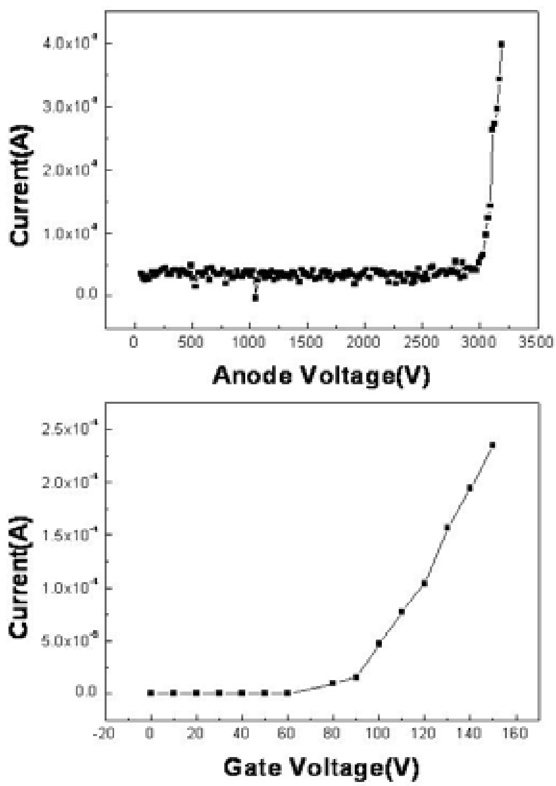

Fig. 5 Recorded I-V characteristics in triode and diode configuration with CNT emitters.(Anode voltage is 2700V)

The turn on voltage in diode was approximately 3000V. In the triode mode, the anode voltage was set at 2700V, which was slightly lower than the turn-on voltage for the anode in the diode configuration. And the gate voltage was increased from 0 to 150V at a step of 10V. Turn on gate voltage of triode emitter was 80V. The maximum current density 234μA/cm2 was obtained at the gate voltage 150V.
Based on these results, it may be concluded that the simple triode structure with CNT emitters using pattered substrate could be used for the fabrication of light source for the flat lamp application.

4. Conclusion

We fabricated the CNT field emission arrays of triode structure with the simple process. Instead of ITO material as transparent electrode, an Au-layer with thickness of 5-20nm was used. Moreover, the thin metal film which is located between PR and CNT paste can function as block layer and UV block. The turn on voltage in diode mode was approximately 3000V. In the triode mode, the anode voltage was set at 2700V; turn on gate voltage of triode emitter was 80V. The maximum current density 234μA/cm2 was obtained at the gate voltage 150V. This simple process will lead to advances in developments of CNT FEA based on flat lamp.

4. Acknowledgements

This research was supported by the Ministry of Industry and Energy of Korea (Grant No. 0401-DD2-016-005) and Korea Science and Engineering Foundation (KOSEF) through the Center for Nanotubes and Nanostructured Composites (CNNC) at Sungkyunkwan University.

5. References

[1] S. Iijima, Nature 354, 56 (1991)
[2] W.A. de Heer, A. Chatelain, D. Urgate, Science 270, 1179 (1995)
[3] J. M. Kim, W. B. Choi, N. S. Lee, J. E. Jung Diamond Relat. Mater. 9, 1184 (2000)
[4] Y. Cheng and O. Zhou: C. R. Physique 4, 1021 (2003).
[5] D. J. Lee, S. I. Moon, Y. H. Lee, J. E. Yoo, J. H. Park, J. Jang, B.K. Ju, Vacuum. 74, 105 (2004).
[6] J. H. Park, J. H. Choi, J. S. Moon, D.G. Kushinov, J. B. Yoo, C. Y. Park, J. W. Nam, C. G. Lee, J. H. Park and D.H. Choe, Carbon. 43, 698 (2005).
[7] Y. H. Lee, Y. T. Jang, D. H. Kim, J. H. Kim, J. H. Ahn and B. K. Ju, Adv Mater. 13, 489 (2001).
[8] M. A. Guillorn, M. L. Simpsou, G. J. Bordonaro, V. I. Merkulov, L. R. Baylor and D. H. Lowndes, J. Vac. Sci. Technol. B. 19, 573 (2001).

[9] D. S. Chung, S. H. Park, H. W. Lee, J. H. Choi, S. N. Cha, J. W. Kim, J. E. Jang, K. W. Min, S. H. Cho, M. J. Yoon, J. S. Lee, C. K. Lee, J. H. Yoo, J. M. Kim, J. E. Jung, Y. W. Jin, Y. J. Park and J. B. Yoo, Appl. Phys. Lett. 80, 4045 (2002).

[10]Y.J. Jung, G.H. Son, J.H. Park, Y.W. Kim, Alexander S. Berdinsky, J.B. Yoo *, C.Y. Park Diamond Relat. Mater. 14, 2109 (2005)