Fabrication of Triode-Type CNT-FED by A Screen-printing of CNT Paste

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Abstract
A carbon nanotube field emission display(CNT FED) panel with a 2 inch diagonal size was fabricated by using a screen printing of a prepared photo-sensitive CNT paste and vacuum in-line sealing technology. After a surface treatment of the patterned CNT, only the carbon nanotube tips are uniformly exposed on the surface. The diameter of the exposed CNTs are usually about 20nm. The sealing temperature of the panel was around 390 ℃ and the vacuum level was obtained with 1.4×10^{-5}*torr at the sealing. The field emission properties of the diode type CNT FED panel were characterized. Now, we are developing a triode type CNT FED with a self-aligned gate-emitter structure.*

I. Introduction

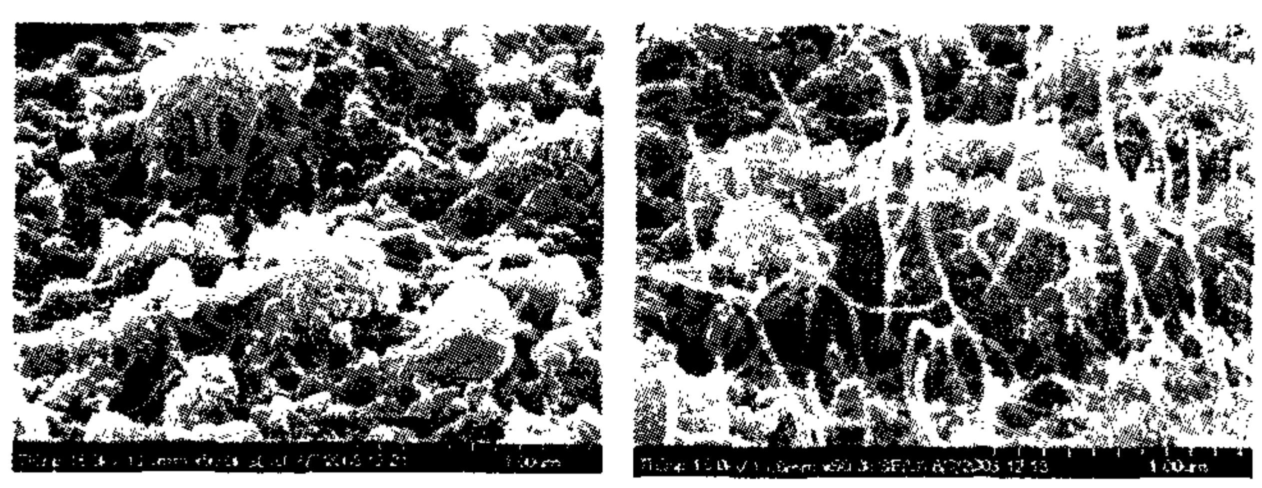
Field emission display(FED) has been generally described as a device to have CRT-like image qualities and low power consumption and has been expected to be a candidate for large-size flat panel display. Therefore it is important to find the most cost-effective way to produce FED panels with large screen size. High vacuum sealing is one of the most difficult technologies in commercializing FED. We have applied a vacuum in-line sealing technology to a CNT FEA on soda-lime glass substrate with 2 inch diagonal size fabricated by using a screen printing method of photo-sensitive CNT paste. In this paper, we have shown the characteristics of the diode type CNT FED and are going to suggest the fabrication technology of a triode type CNT FED with a self-aligned gate-emitter structure.

II. Experimental Procedures

A. Fabrication of the diode type CNT FED panel

In order to confirm the possibility of the photo-sensitive CNT paste as a good emitter and the vacuum in-line sealing method as a successful packaging technology, first of all, we have fabricated a diode-type CNT FED and characterized. First, the CNT FEA plate was fabricated by a screen printing method using CNT powder mixed paste. The CNT paste screen-printed over the patterned cathode(Cr) lines are exposed from the back-side of the glass plate through a black-matrix mask. The paste has a negative photo-sensitive feature. Therefore, the uv exposed CNT paste will be remained after a developing process, while the unexposed area is removed by a developer solution. After the development in a solvent, the remained CNT emitters are baked at 450°C for 30min. By a surface treatment process, the binder components on the surface area of the paste is removed and only CNTs are exposed. Then, the anode plate was prepared with a patterned ITO electrode. Finally, two plates are sealed by using a dispensed frit glass paste within the high vacuum chamber.

Figure 1(a) and 2(b) show the scanning electron micrographs (SEM) of screen printed CNT paste before and after surface treatment, respectively. The diameter of CNT was about 20 nm after surface treatment as shown in Fig. 1(b).



(a) (b)

Fig. 1. Scanning electron micrographs of CNT paste (a) before surface treatment and (b) after surface treatment.

Next, in order to seal the CNT emitter and the phosphor screen glass plates, two plates are loaded into a vacuum sealing chamber. The heating of the two glass plates is done by using an infrared light source from a tubular heater. After arriving at the critical temperature, the two panels are put into contact by using positional controls. That is, the lower glass plate is moved up via a x-y-z-θ manipulator until it touches the upper glass plate. The manipulator gives a large enough press to seal the two plates. The sealing area was defined as 6 cm × 5.5 cm by frit dispensing. The panel was sealed when frit glass was fired and melted at the chamber temperature of 390℃. The chamber temperature was uniformly increased with a rate of 3 ℃/min. The vacuum level was sustained at about $1\text{-}2\times10^{-5}$ torr at the sealing temperature of 390°C. Clean frit surface was obtained without cracks or pores. The gap between two glass plates was 0.2mm sustained by glass spacers.

B. Field emission characteristics of a diode type CNT FED

Figure 2 shows an operational CNT FED panel fabricated by the screen-printing and vacuum in-line sealing technology including a phosphor screen anode plate. The phosphor screen was fabricated by a spin coating method using phosphor powder mixed with vehicles, and a photolithography. Then, anode plate was fired. Finally, two plates were sealed within the high vacuum chamber. The vacuum level was maintained at 1.9×10^{-5} torr at the sealing time.

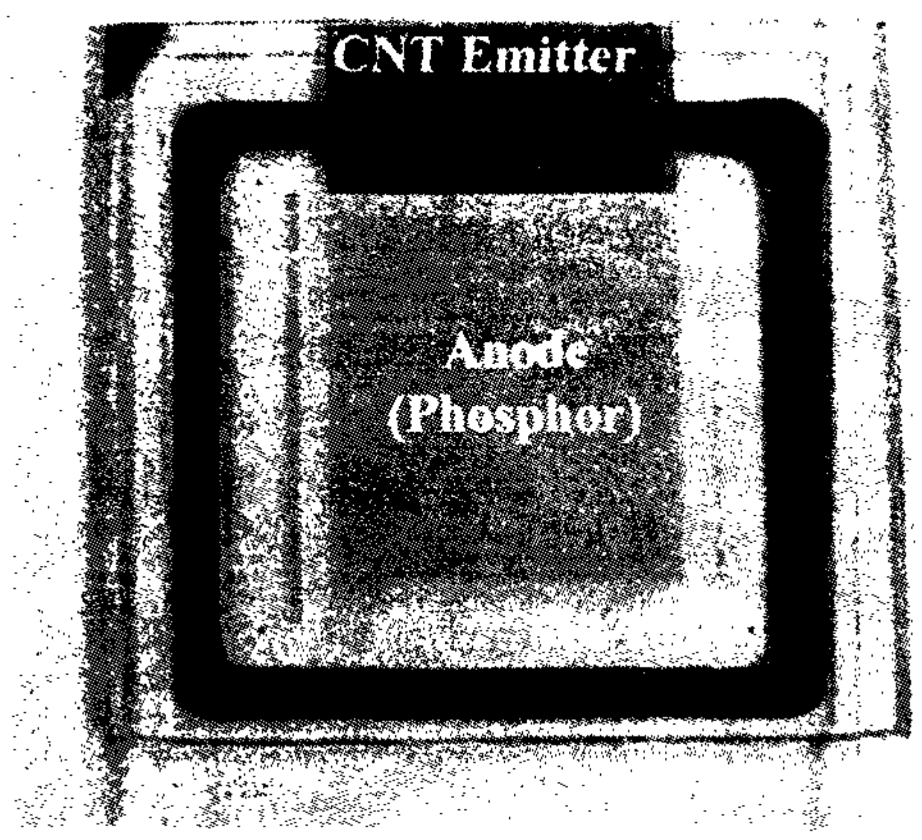


Fig. 2. An fully vacuum in-line sealed diode type CNT FED with a 2 inch diagonal size panel fabricated by the vacuum in-line sealing technology

The field emission properties of CNT FED panel with square-type CNT emitters were characterized and compared with those of the line-type CNT emitters. As results, the square-type CNT emitters showed much larger emission current and more stable I-V characteristics as shown in Fig. 3. Light emission started to be occurred at an electric field of 3.5V/μm corresponding to the anode-cathode voltage of 700V. As the applied voltage increases, the brightness increases prominently.

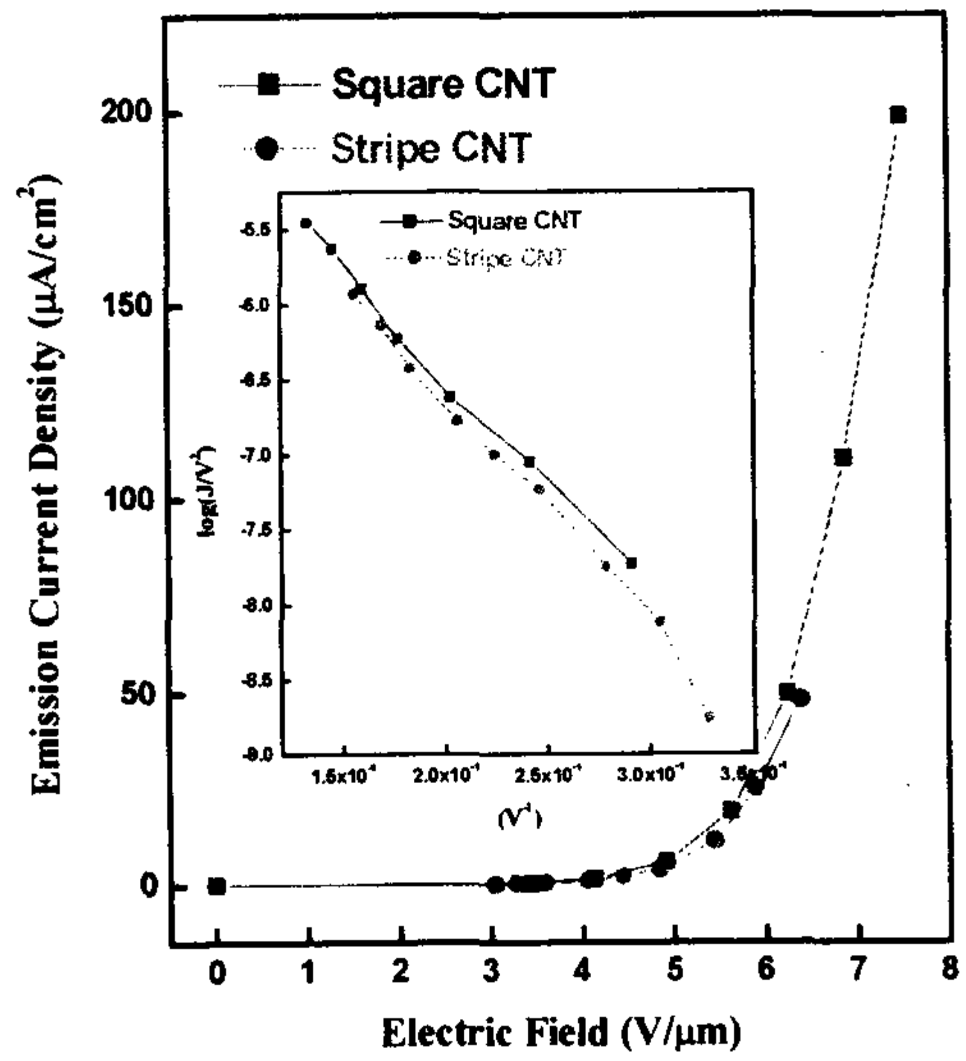


Fig. 3. Current density vs. electric field emission characteristics.

At the applied voltage of 2.0kV(corresponding to 10V/μm), almost all area of 2" CNT FEA was emitted uniformly as shown in the light emission patterns of Fig. 4.

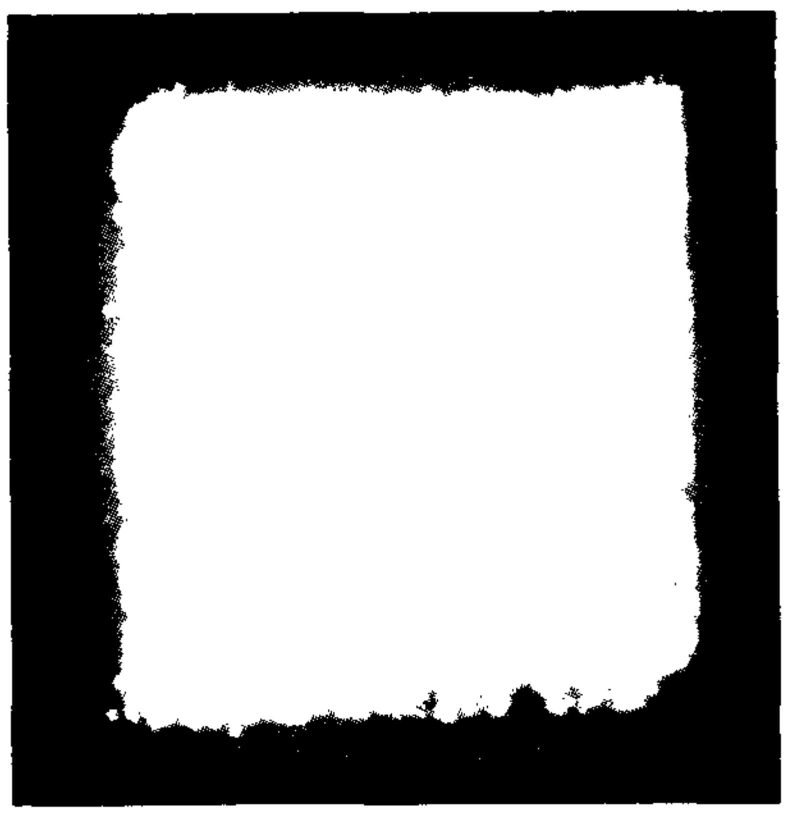


Fig. 4. Light emission pattern of the diode type CNT FED at the applied voltage, $V_{a\text{-}c}$ of 2.0kV.

III. Fabrication of a triode type CNT FED

In order to reduce the emission voltage and therefore avoid some arcing problems, a triode type CNT FED with a gate electrode is preferred. We have set up the process sequences for the triode type CNT FEA as shown in Fig. 4. In this structure, the gate hole and the CNT emitter are self-aligned each other. And the cathode lines are composed of ITO layer covered with Cr metal layer. By using only one gate hole mask, the processes including a gate hole etching, gate oxide etching, and cathode Cr etching can be sequentially proceeded.

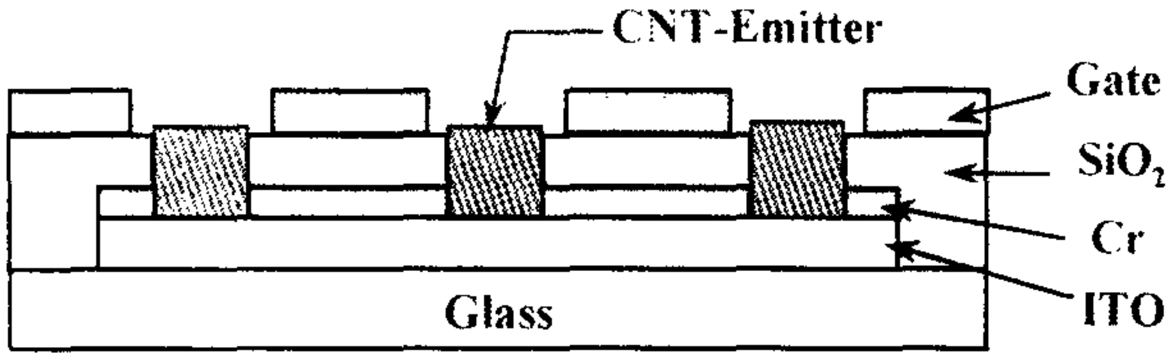


Fig. 4. The cross section of the triode type CNT FEA.

Then, a photo-sensitive CNT paste is screen printed on the top side of the glass plate for filling into the pre-formed gate holes. By exposing the uv light through the back side and developing in the solvent, the unexposed CNT paste is removed and the exposed CNT paste only inside the gate hole is remained. The diameter of the formed CNT FEA is 50μm and the diameter of the gate metal hole can be controlled easily by the gate hole etching time. In this experiment, the gate hole diameter was 64μm. The height of the CNT FEA can be controlled by the uv exposing time. The important issue is that the circle of the gate hole and that of the CNT FEA are concentric each other, which is really 'self-aligned structure'. The thickness of the CNT paste remained after the development is shown in Fig. 5 depending on the exposing time at the power of 12.5mW.

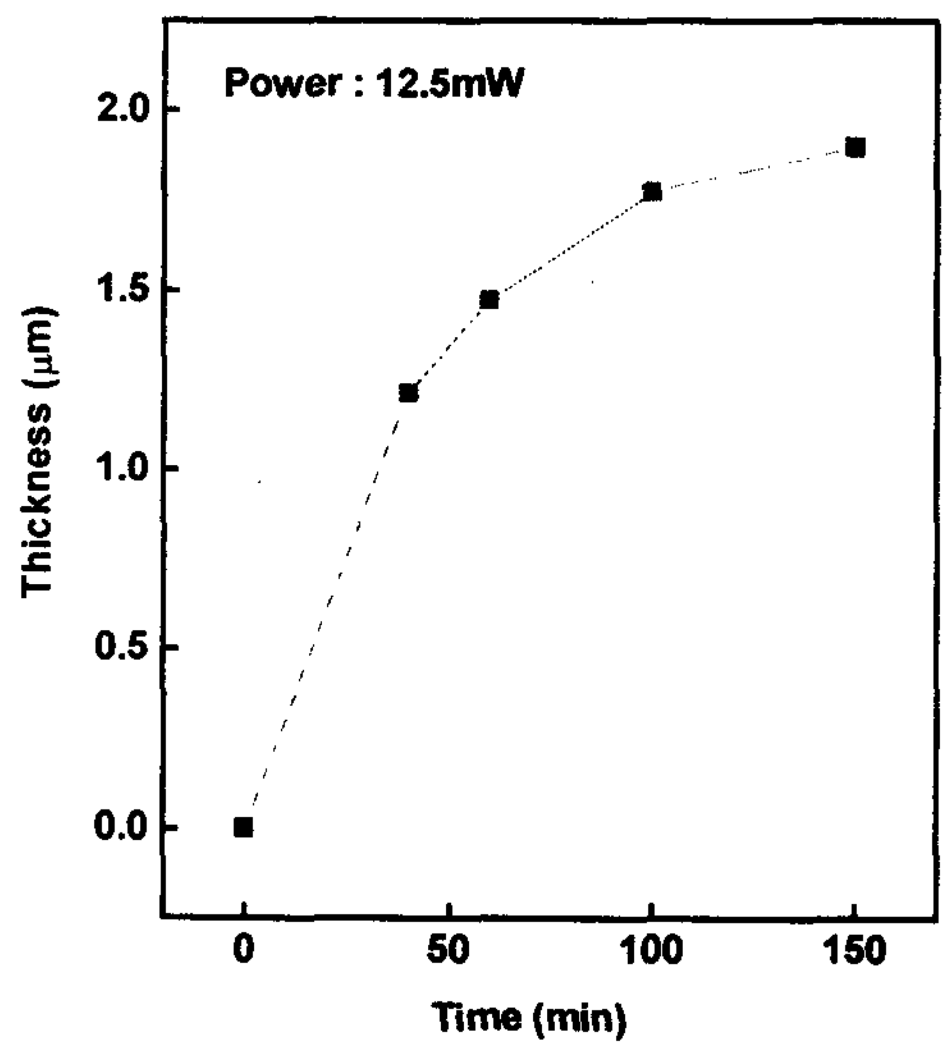
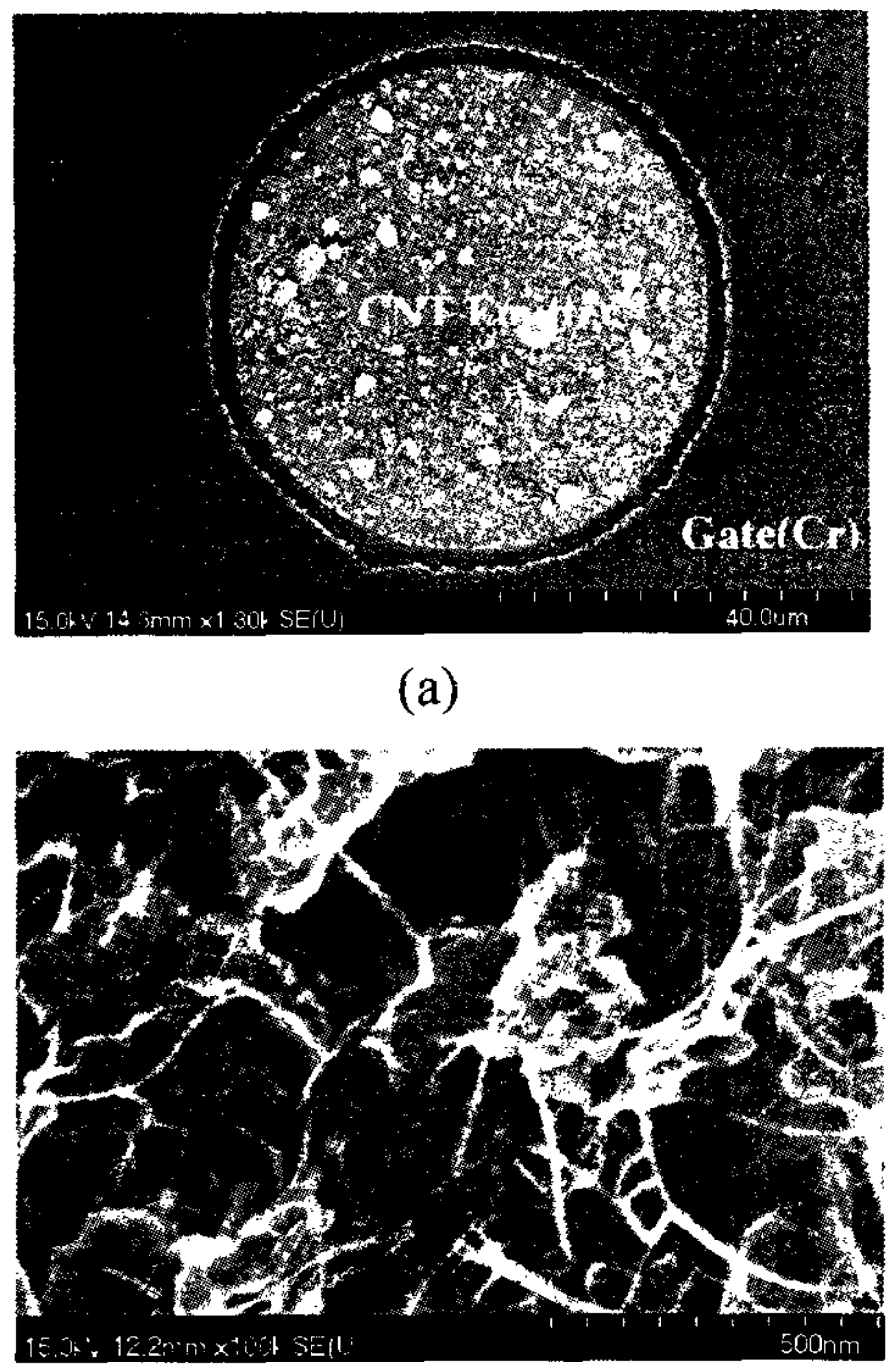


Fig. 5. Thickness variation of the CNT paste depending on the expose time right after development.

By using the exposing time of 150sec, we have processed the fabrication of the gated CNT FEA. After the surface treatment by using the same method as making the diode type, the gated CNT FEA was ed as shown in Fig. 6. Now, we are making the CNT FED for obtaining a field emission characteristics and a light emission pattern of the gated CNT FEA.

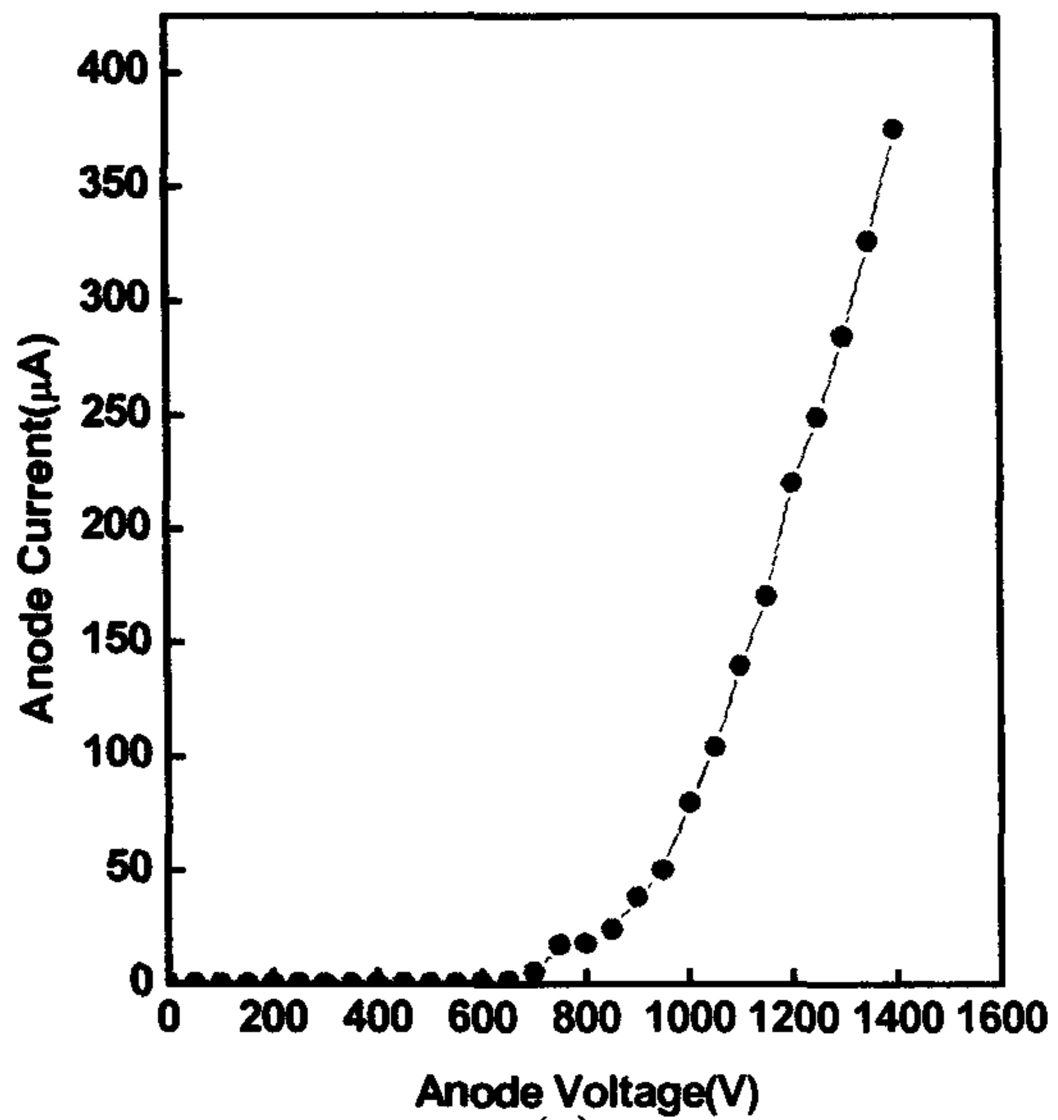


(a)

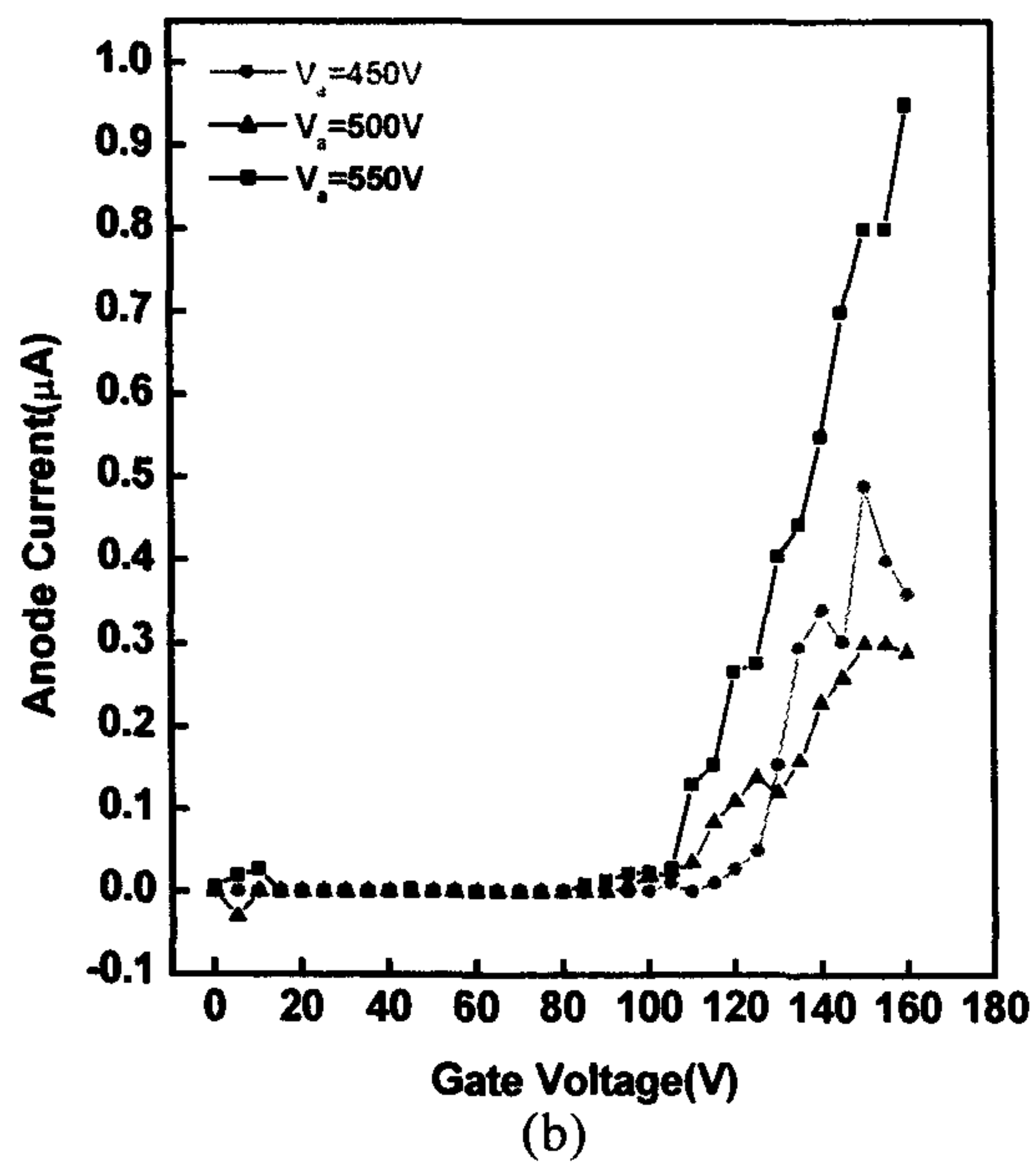
(b)

Fig. 6. SEM views of the gated CNT FEA : (a) an emitter hole, and (b) the exposed CNTs.

Field emission characteristics were performed for the triode structure CNT FEA. The cathode glass plate with CNT FEA and the ITO coated anode glass plate with phosphor screen were loaded into the vacuum chamber. The spacing between two glass plates was set by 200μm and the final vacuum level obtained by turbo molecular pump was 1×10^{-6}torr. Firstly, in order to obtain a proper anode bias, diode mode emission characteristics were measured by applying the anode voltage to the 2" diagonal full area through ITO electrode and floating the gate electrode. As shown in Fig. 7(a), the emission was started at about 600V which is according to the turn-on field of 3V/μm. Therefore, in order to suppress the diode mode emission in the triode mode operation, the anode bias voltage has to be set under about 600V for the spacing 200μm. Secondly, triode mode emission characteristics were measured for the anode voltages of 450V, 500V, and 550V. In this operation mode, the gate voltage was applied to only one line. As shown in Fig. 7(b), the turn on voltage was around 100V which is according the turn on field of about 14V/μm. However, as the anode voltage increased, the turn on voltage decreased a little and, as a while, the emission current level increased considerably. This phenomenon might come from accelerating the emitted electrons to the anode and resultantly, suppressing them to go to the gate electrode.

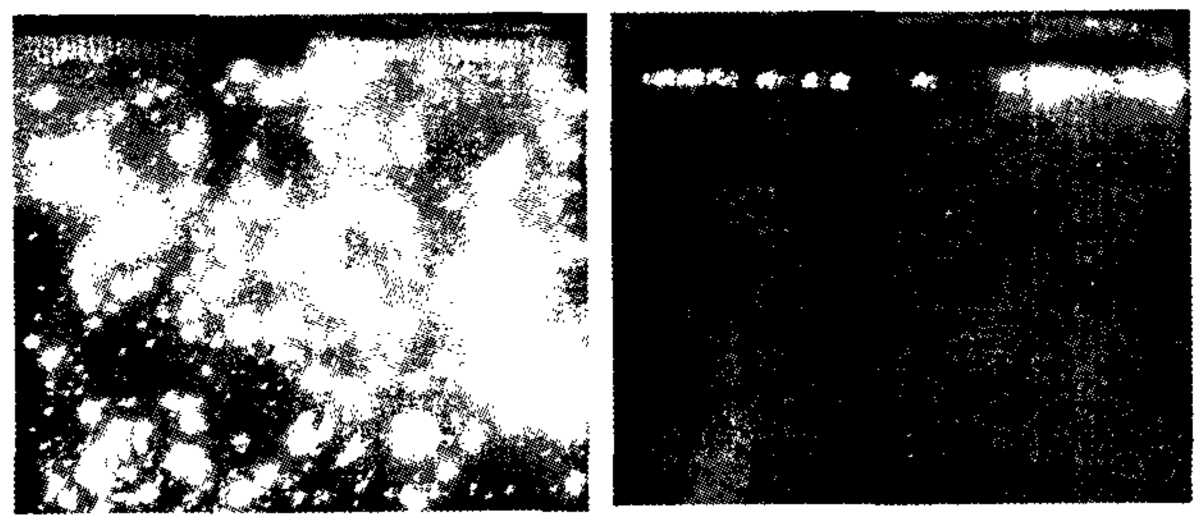


(a)



(b)

Fig. 7. I-V characteristics in (a) a diode mode emission with the gate voltage V_g floated, and (b) a triode mode emission depending on the anode voltage V_a.



(a) (b)

Fig. 8. Light emission characteristics in (a) the diode mode emission at V_a= 1kV with the gate voltage V_g floated (all anode area is biased by V_a), and (b) the triode mode emission at the gate voltage V_g = 160V and the anode voltage V_a= 550V (only top gate line is biased by V_g).

Figure 8(a) and (b) show the light emission patterns for the diode mode emission and the triode mode emission, respectively. In the triode operation mode, the gate voltage was applied to only one gate line in order to confirm the suppression of a diode mode emission.

IV. Conclusions

Triode type CNT FED panel was fabricated by using a screen printing method of a photo-sensitive CNT paste. By using a back-side uv exposure through the concentric openings of a gate metal hole and a cathode metal window, a really self-aligned gated-CNT emitter could be obtained.

By the creation of a self-aligned gate-emitter structure, it is expected that the screen printed photo-sensitive CNT paste is promising as a good candidate for the large size field emission display.

V. Reference

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