P-84: Effects of Environmental Gases on Emission Current in Carbon Nanotube Cathodes

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Abstract

The dependence of environmental gases such as Ar, O_2 on the emission current from carbon nanotube emitters was examined in this study. Based on our experiments, the current density is decreased in single-wall carbon nanotubes (SWNTs), but is increased in multi-wall carbon nanotubes (MWNTs) as the vacuum level decreases from 10^{-7} Torr to 10^{-4} Torr by the inflow purging gases. The current density subsequently recovered as the vacuum level increased to 10^{-7} Torr when gas inflow stopped. From those results, we conclude that the MWNTs have completely different degradation characteristics in comparison to SWNTs excluding the effect of binder materials.

1. Introduction

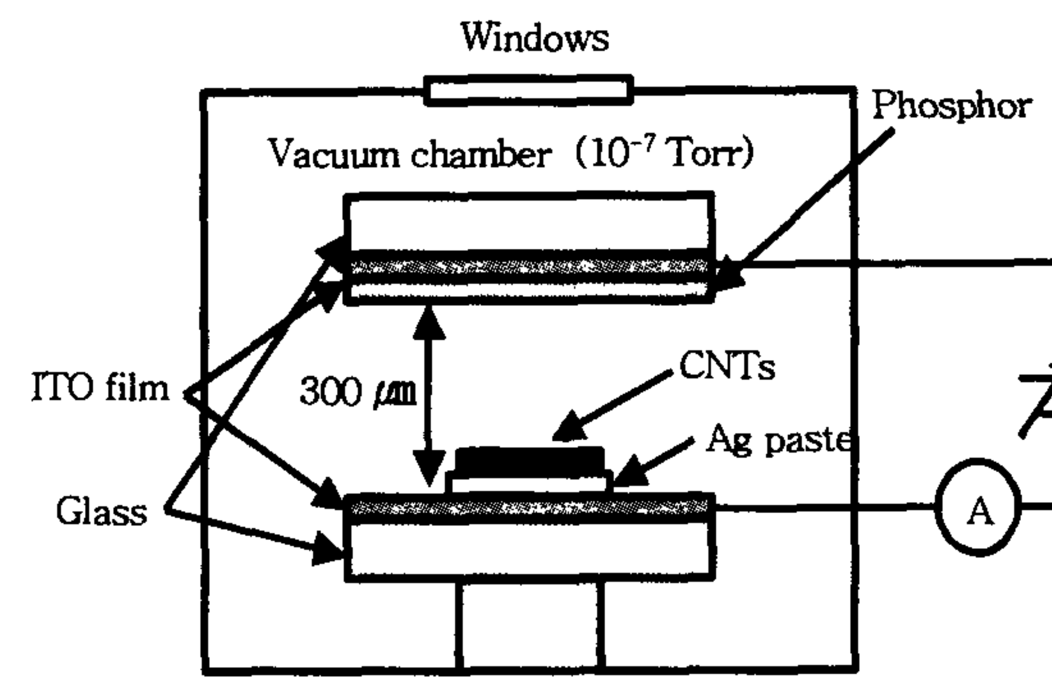
Recently, field emission displays(FEDs) have attracted considerable attention in display technology because of their similarity to cathode ray tubes (CRTs) and the possibility of making thinner and larger sizes. Carbon nanotubes (CNTs) have become a topic of particularly intense research since their discovery because of their high-aspect ratio and low-operating voltage [1]. However, all field-emitting devices require a high vacuum level from 10^{-7} Torr to 10^{-9} Torr for operation. From a practical viewpoint, it is very difficult to achieve such a high vacuum level in the shape of large and thin flat panel display in mass production. Therefore, the focus of our interest was on the development of a CNT cathode that provides uniform emission and long-time operating stability in relatively lower vacuum level. SWNTs show a lower turn-on voltage, while the MWNTs exhibit a better lifetime [2]. Several studies reported that the effect of ambient gases such as nitrogen (N_2) and argon (Ar) on emission lifetime is negligible, but oxygen (O_2) and water vapor have serious effects on emission characteristics in the vacuum range of 10^{-9} to 10^{-6} Torr [3~6]. In the case of CNTs, however, there are few reports on the effects of ambient gas on emission current in lower vacuum level than 10^{-6} Torr. In this study, we report on some experiments designed to understand how two kinds of CNTs are degraded in ambient gases such as Ar, O_2 in 10^{-4} Torr.

2. Experimental

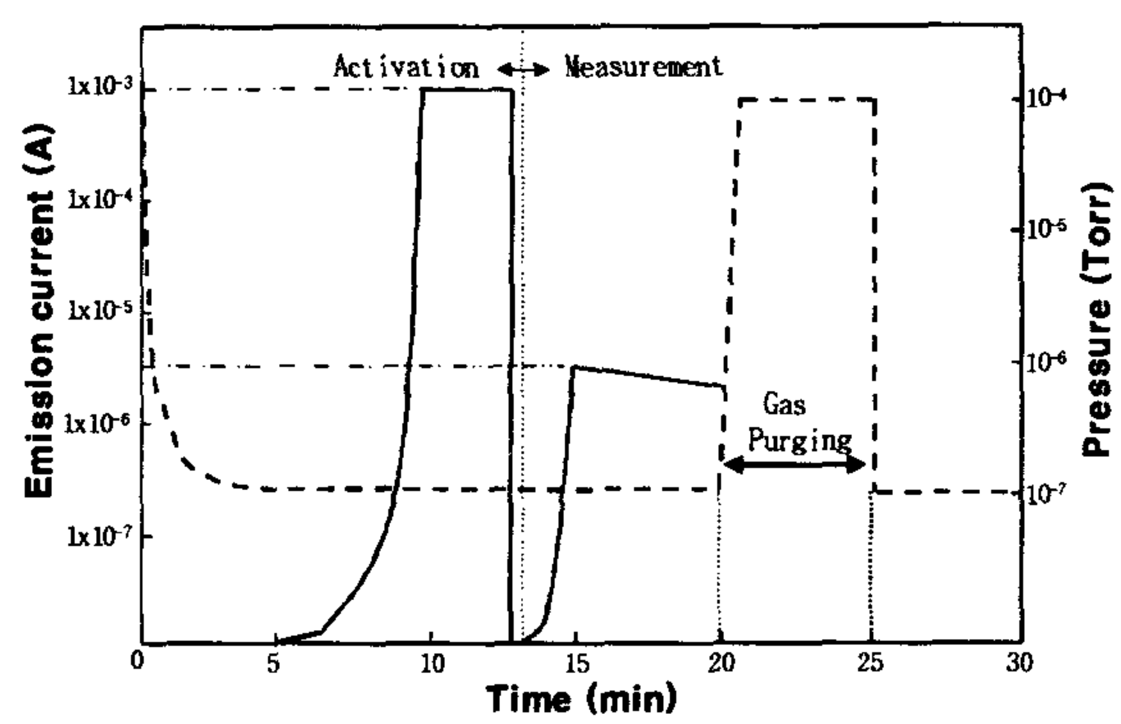
SWNTs and MWNTs produced by the arc discharge method by Iljin Nanotech Co. were used for these experiments. SWNTs paste was made using SWNTs, α -Terpineol and ethylcellulose. For screen printing process, the viscosity of SWNTs paste was controlled by the quantity of ethylcellulose. But MWNTs paste was made using MWNTs, α -Terpineol, ethylcellulose and frit glass for the good adhesion between glass and paste.

Using a screen-printing process, the CNT paste was coated on ITO glass and dried in a furnace at 360℃ for one hour. The CNT film on a cathode electrode was surface-treated by an adhesive tape.

Fig.1 shows a schematic diagram of the vacuum chamber and procedure used to measure field emission. As shown in Fig. 1(a), the distance between the cathode and anode electrodes was maintained at 300 ㎛. The base pressure of the vacuum chamber approached the 10^{-7} Torr range. After the sample was positioned in the vacuum chamber, no additional baking process for the phosphors and CNT cathode was carried out. Thus some water vapor would be expected to be present on the surface of the phosphor layer or CNT cathode. To investigate the effect of gas purging on the emission current of the CNT cathodes, a series of experiments were carried out as shown in Fig. 1(b).



(a)



(b)

Fig. 1 A schematic diagram of this study. (a) arrangement of electrodes in vacuum chamber, (b) process flow for field emission characteristics.

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The pressure change in the vacuum chamber during the experiment is plotted by a dotted line. Before measuring the effect of gas purging on emission current, the CNT cathode was activated in a high electric field to improve the uniformity of emission. In the main experiments, an initial emission current at a vacuum of 10^{-7} Torr was maintained at 50 μA by controlling the electric field. After emission of the CNT cathode for 5 min at a vacuum of 10^{-7} Torr, gases such as N_2, Ar, O_2 and H_2 were purged up to vacuum level of 10^{-4} Torr for 5 min. We then evacuated the chamber to a pressure of 10^{-7} Torr by stopping the flow of purge gas. As shown in Fig. 1(b), we continuously measured the emission current of the CNT cathode during the pressure change before and after gas purging.

3. Results and Discussion

Fig. 2 shows an emission image of a CNT cathode using MWNTs in a vacuum of 10^{-7} Torr. From this, we found that the emission properties of the initial stage, just prior to gas purging, are relatively uniform.

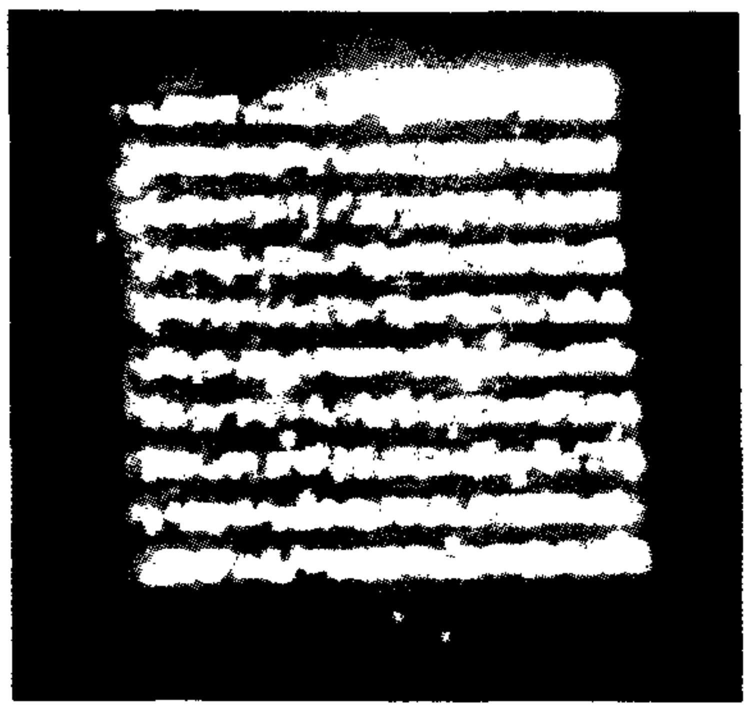

Fig. 2 A typical emission image of MWNTs.

Fig. 3 and Fig. 4 shows the effect of gas purging on the emission-current for SWNTs and MWNTs, respectively. The gas purging to a low vacuum of 10^{-4} Torr decreases the emission current for SWNTs. In the case of MWNTs, however, purging with O_2 and Ar increased the emission current, as shown in Fig. 4. When the gas purging was stopped, the emission current recovered as the vacuum level increases for both SWNTs and MWNTs. From the results of Fig. 3 and Fig. 4, we conclude that the effect of gas purging on emission was much different for the two samples. The purging gases have a negative effect on emission current for an SWNT, but a positive effect for an MWNT cathode. In region I (within 300 sec, 10^{-7} Torr) and region III (over 600 sec, 10^{-7} Torr), emission currents of the SWNTs and MWNTs decreased with aging time. In region II (10^{-4} Torr by gas purging, 300 sec ~ 600 sec), however, a large difference was noted between SWNTs and MWNTs. Region II can be further divided into 3 regimes in emission current change, i.e. an initial drop(or rise) regime, a linear decrease regime and a final rise(or drop) regime as has been reported by other research groups [4,8]. However, the increased emission current for MWNTs in region II was not reported. With general degradation model [4, 8, 9, 10], this phenomena in MWNTs cannot be explained completely. But in case of MWNTs, an increase in emission current in low vacuum level can be expected due to the activation of additional new emission sites caused by ion bombardment.

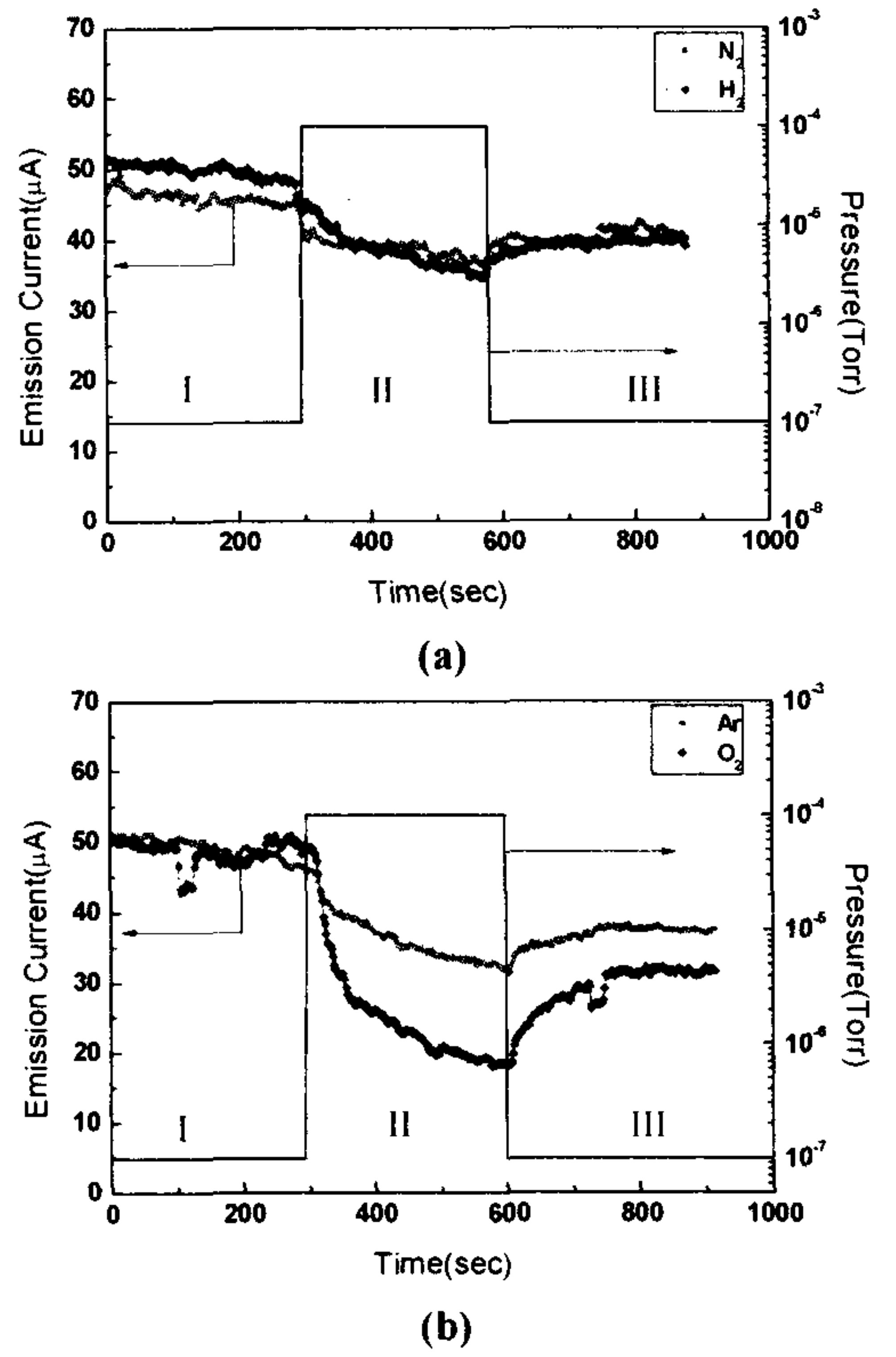

Fig. 3 The effect of ambient gases such as (a) N_2, H_2, (b) Ar, O_2 on emission current in single-wall carbon nanotubes(SWNTs). Black line means pressure level (10^{-7} Torr range: Region I, III, 10^{-4}Torr range: Region II).

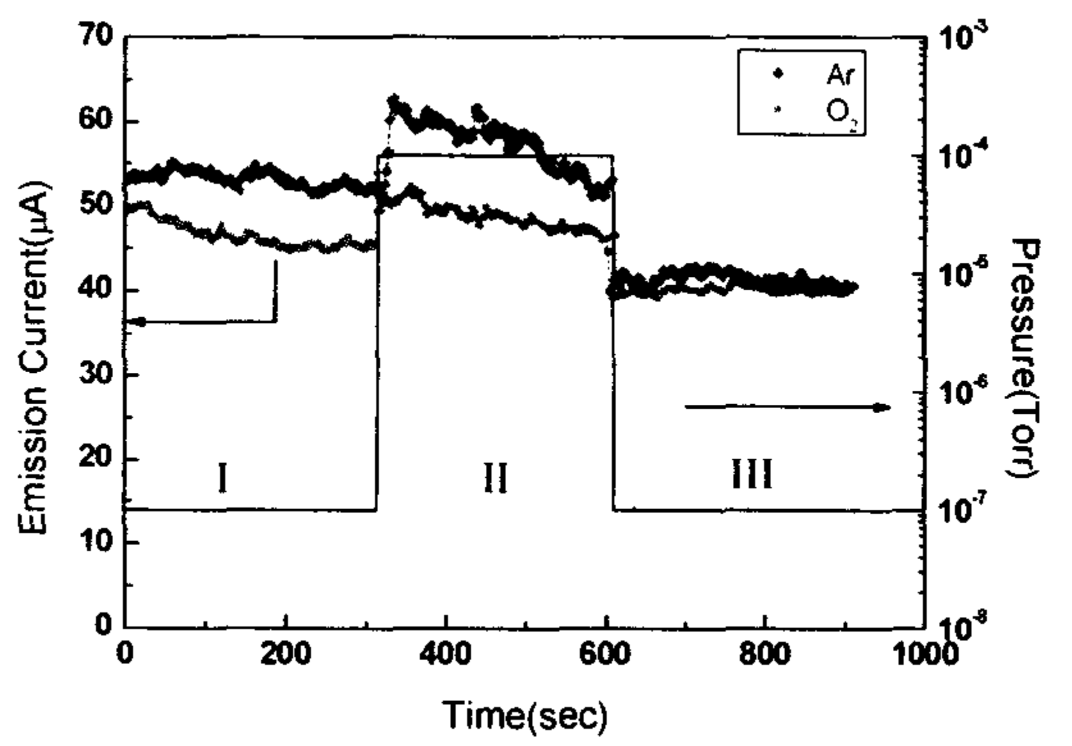

Fig. 4 The effect of ambient gases such as Ar and O_2 on the emission current in multi-wall carbon nanotubes(MWNTs). Black line means pressure level (10^{-7} Torr range: Region I, III, 10^{-4}Torr range: Region II).

In this study, experimental conditions except paste composition were the same between SWNTs and MWNTs. MWNTs paste contains frit glass but SWNTs do not. Therefore, it is possible to guess that frit glass as binder materials can affect the emission current of CNTs under low vacuum level as another reason for the above results. But there were no reports on this assumption to date.

Even though, our explain is not currently perfect for describing the effects of a purging gas on the emission current of SWNTs and MWNTs, the phenomena of Fig. 3 and Fig. 4 are very important findings from a practical point of view.

Finally, if the effect of frit glass can be excluded, we can conclude that ion bombardment on emission current is negative for SWNTs, but positive for MWNTs. The reason for this emission current is due to the intrinsically strong MWNT structure.

4. Conclusions

We measured the dependence of environmental gases such as N_2, Ar, O_2 and H_2 on the emission current from carbon nanotube emitters. From our experiments, we found that the emission current was decreased in SWNTs and increased in MWNTs as the vacuum level decreases from 10^{-7} Torr to 10^{-4} Torr by purging gases and the emission current was recovered as vacuum level increases to 10^{-7} Torr. From those results, we conclude that MWNTs have currently unexplainable different degradation characteristic in comparison with SWNTs excluding the effect of frit glass. The ion bombardment in a high pressure of 10^{-4} Torr by inflowing the purging gas could not destroy the MWNTs, but activates new emission sites in them thus leading to an increase in emission current.

5. Acknowledgements

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6. References

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