Emission Profile Studies of Thermionic Cathodes and Field Emitters

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Abstract

Emissions of thermionic cathodes and field emitters were studied using a cathode emission profiler which works based on the anode scanning method. Findings about impregnated cathodes in thermal activation and gas poisoning processes are shown. Effects of surface treatments for field emitters are studied from the viewpoint of emission profiles and characteristics of the emitters.

1. Introduction

Cathode application for information display devices has been an important technology, and the importance never decrease even in recent years. Not only thermionic cathodes for CRT devices, but also research on field emitters for flat panel display devices has been actively carried out in this decade. Although properties of cathodes and emitters are often evaluated based on the total emission current, we consider that local emission properties or emission profiles are essential for the detailed research and the development. For this purpose, our laboratory has developed a cathode emission profiler (CEP) system for the measurement of emission and emission density distribution of electron emitting devices. [1] This system is a powerful tool for the research on thermionic and field emitting cathodes. In this paper, we introduce the ability of the CEP system and discuss about the emission data of some types of cathodes obtained by this machine.

2. Cathode Emission Profiler

Figure 1 shows the schematic diagram of the machine. The whole emission current of the cathode, I_P, is measured using a fixed anode (ϕ14mm). The anode-cathode spacing, H, can be set arbitrary. The anode has a micro-hole (ϕ20μm) at the center, and the emission current through the anode-hole (I_{FC}) can be collected by the Faraday cage simultaneously to measure the I_P. Under a suitable condition, namely high voltage and narrow anode-cathode spacing, the I_{FC} corresponds to the local emission current from the point of the cathode facing to the anode-hole. In this way, the whole and local emission characteristics of the cathode can be obtained simultaneously by the CEP system.

Emission profiles are obtained by the anode-hole scanning method, in which the local emission current (I_{FC}) is collected and stored in the electronics with the anode-hole position. Possible scanning area is maximum 8mm to minimum 0.1mm square and it can be set around a desired point on the cathode. Obtained emission density distribution can be displayed as one, two and three-dimensional profiles.

For the thermionic cathodes, I_P and I_{FC} were measured

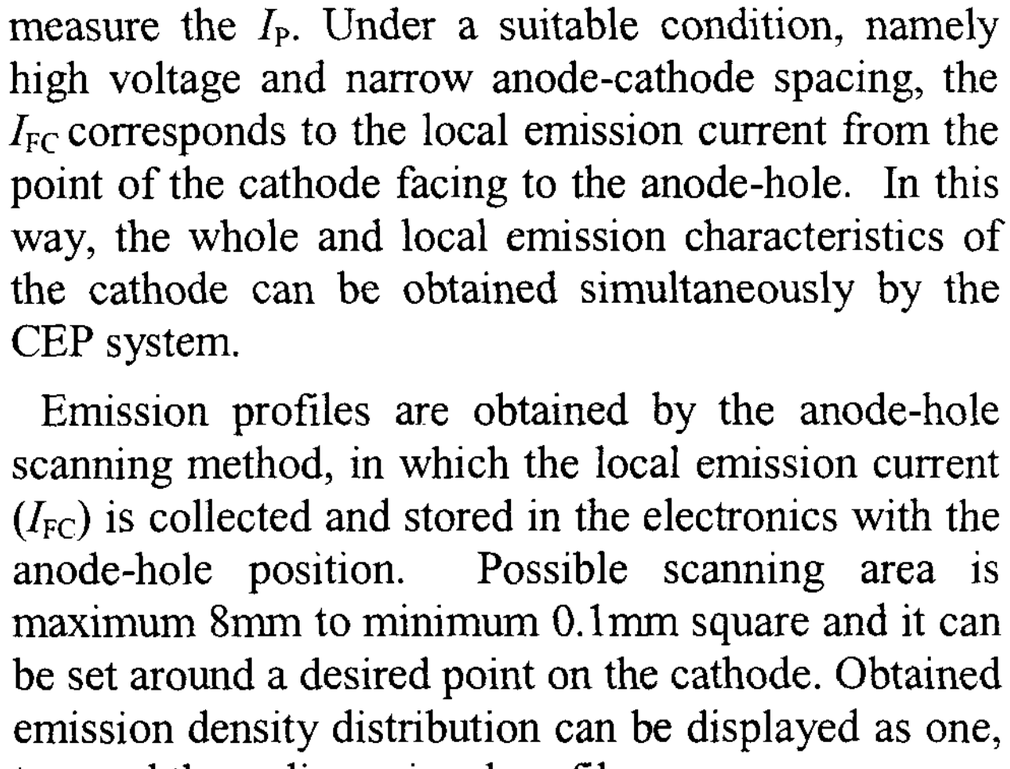


Figure 1 Schematic diagram of cathode emission profiler

with single-pulsed voltage of 20μs width, while pulsed voltage of 100Hz repetition rate and 150μs width was used for the measurements on the field emitters.

The ultimate pressure of the machine was less than 10^{-7} Pa. Effects of ambient gases for emission properties were also measured with the partial pressures of 10^{-6} to 10^{-5} Pa using gas introducing system attached to the measuring chamber.

3. Studies on Thermionic Cathodes

Typical three dimensional emission profiles of oxide cathode, impregnated cathode and Ni-pressed cathode [1] fabricated in our laboratory for CRT use are shown in Fig.2. The profiles were obtained in temperature-limited region. Emission uniformity of the impregnated one is quite excellent compared with other two types of the cathode.

Figure 3 is a three dimensional emission profile of a 411-type impregnated cathode with Os/Ru coating [2]. In this profile, some irregular peaks are observed on the right side shoulder. The emission characteristics of the point with the highest peak were measured and compared with that of center of the cathode. Coordinates of the peak point were determined as X=1520μm and Y=900μm in the scanning area of 2000μm square. Figs. 4(a) and (b) show the Schottky and Richardson plots of the cathode with the highest peak area and the centered

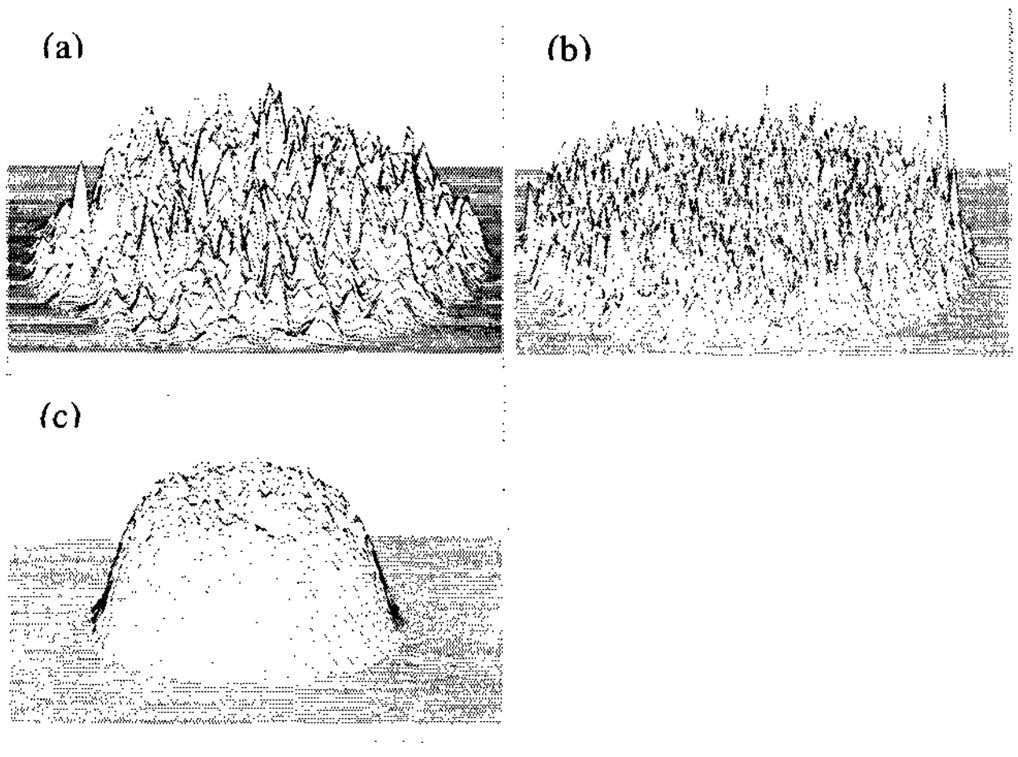


Figure 2 Three dimensional emission profiles measured by CEP for (a) an oxide cathode, (b) a Ni-pressed cathode and (c) an impregnated cathode. The height of the profiles shows the emission current (linear scale) at each position.

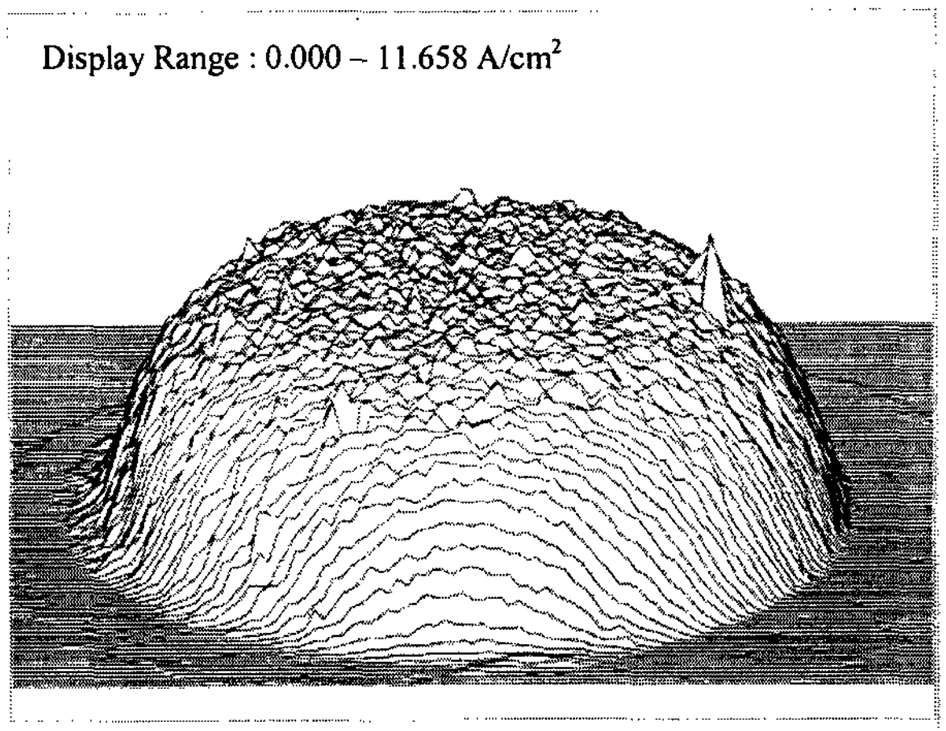


Figure 3 Emission profile of a 411-type impregnated cathode with Os/Ru coating.

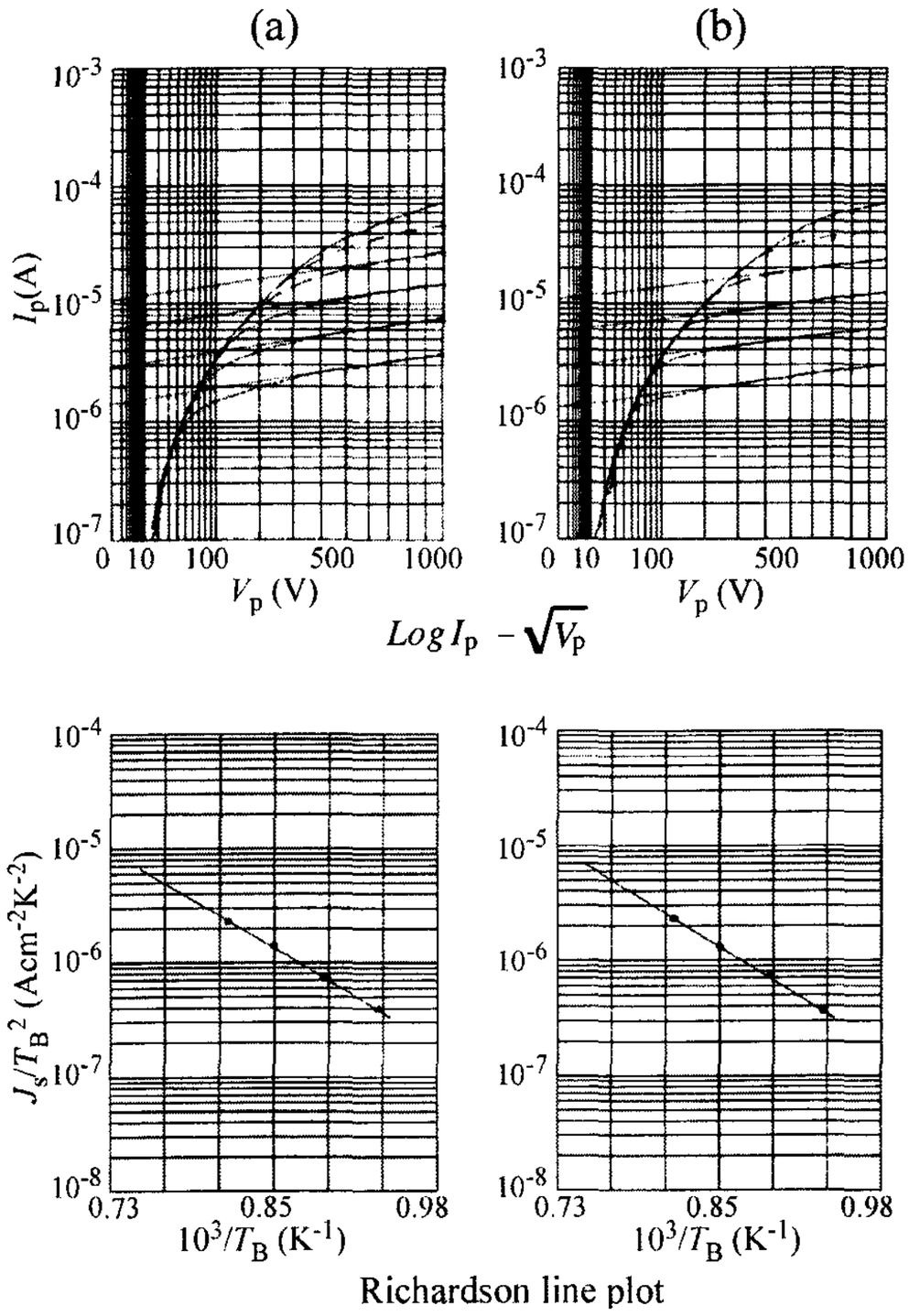


Figure 4 Emission characteristics of the impregnated cathode. Log I_p – V_p (Schottky plots) and Richardson plots of the emission at (a) the point with highest emission-current peak and (b) the centered point of the cathode with normal emission property.

normal area, respectively. The work function (ϕ) of each area was estimated from the temperature dependence of the local emission current (I_{FC}). The calculated ϕ values at 975 Cb (brightness) are as follows.

highest peak area : $\phi = 1.87$eV

normal area : $\phi = 1.88$eV

In the Schottky plot of this cathode, we can see that the highest peak area has slightly steeper slope than the normal area. These results suggest that the highest peak area has a projecting structure.

Figure 5 is the variation of the emission profile of an impregnated cathode accompanied with thermal activation at 1150 Cb. The profiles were obtained just after the evacuation (1), after 15min-1150 C heating (2), after 30min heating (3), after 45min heating (4) and after 60min heating (5). These line profiles were obtained on the same position on the cathode (centerline of Y=1000μm). The data show that the thermal activation rapidly proceeds within first 30min. One feature of the thermal activation, which can be seen in Fig. 5, is that the activation process does not change the original shape of the emission profile, and it leads only to emission increase. This behavior strongly suggests that the emission uniformity of an impregnated cathode is determined in the fabrication processes and cannot be improved by thermal activation process.

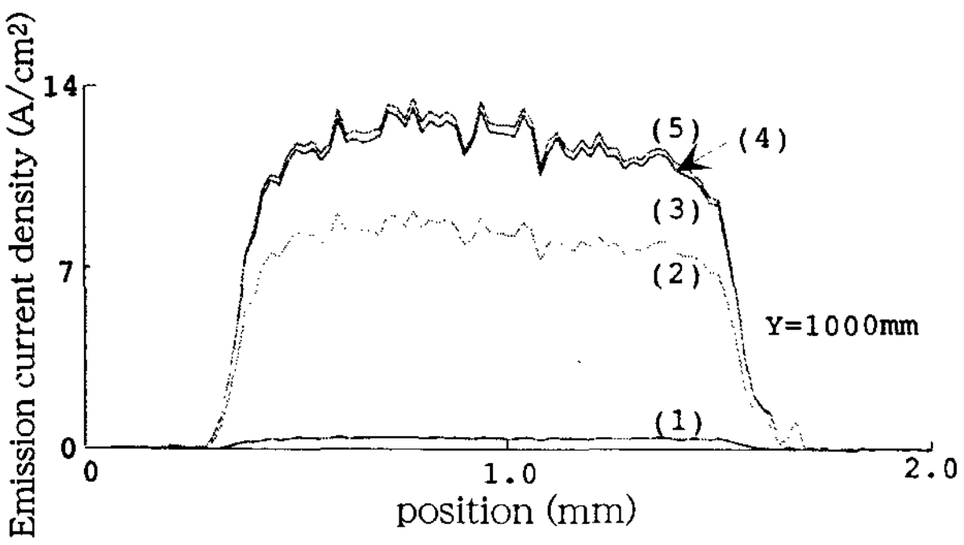
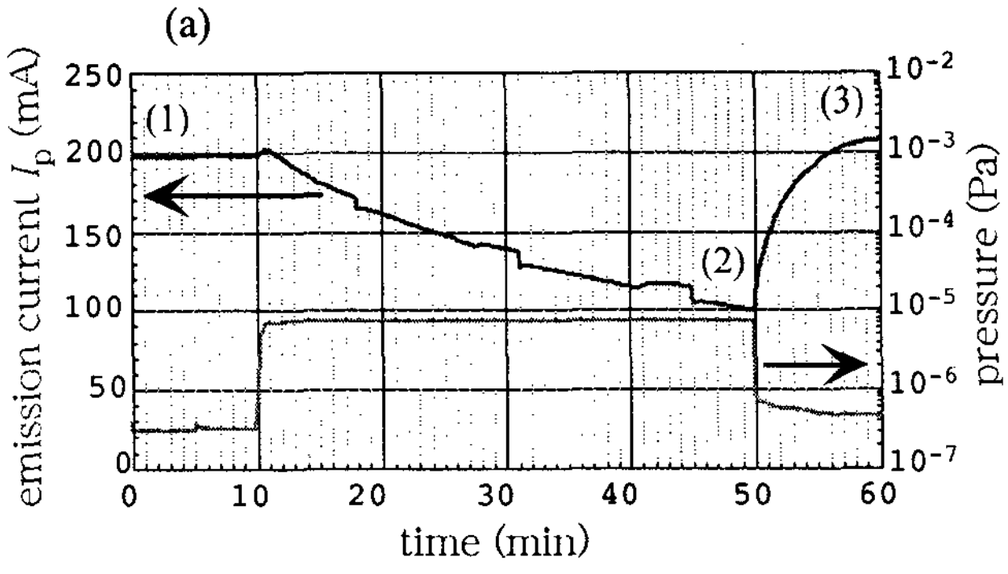


Figure 5 Variation of emission line profile of an impregnated cathode accompanied with thermal activation at 1150 Cb. The line profiles were measured by CEP (a) just after the evacuation, (b) after 15min heating, (c) after 30min heating, (d) after 45min heating and (e) after 60min heating.



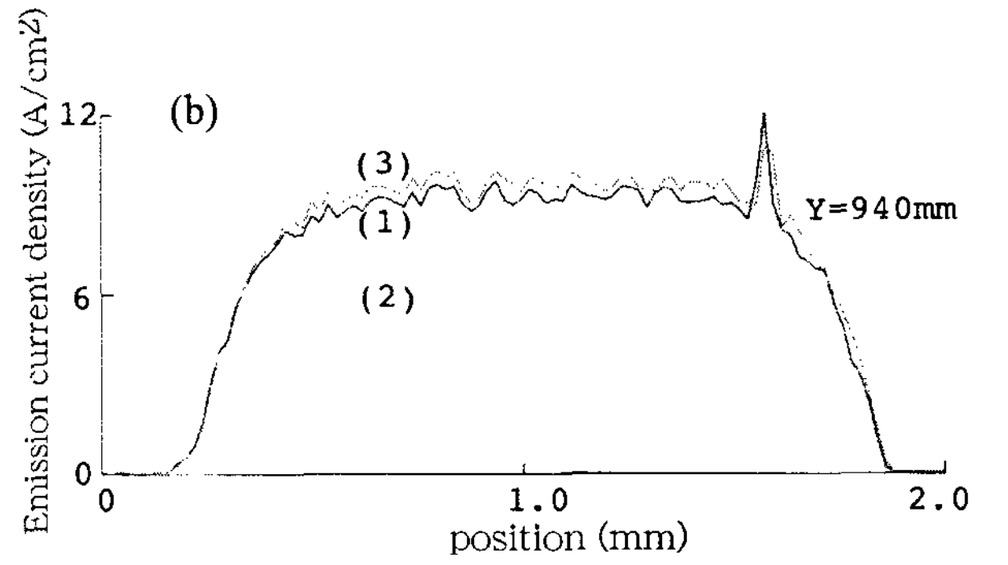


Figure 6 (a) Time profiles of ambient gas pressure and emission current of an impregnated cathode and (b) variation of the emission line profile of the impregnated cathode during oxygen poisoning and recovery processes. (1) shows the data before the poisoning, (2) during the poisoning and (3) after the poisoning process. The cathode was heated at 975 Cb and all data were collected by CEP.

Oxygen gas poisoning and recovery processes were studied for the same impregnated cathode as shown in Fig.3. Figure 6 (a) exhibits the time profile of I_p and the ambient oxygen pressure (P) at the cathode temperature of 975 Cb. Ten minutes after the measurement start, 5 x 10^{-8} torr of oxygen gas was introduced into the chamber and kept for 40min. This period of 40min corresponds to the poisoning process. After that, oxygen gas was evacuated off. The whole current, I_p, decreased and finally came close to 50% of the initial value by the oxygen poisoning. After the oxygen evacuation, however, the emission gradually recovered and reached the initial value after ten minutes. The variation of the emission line profile is shown in Fig. 6 (b). The emission profile shape after

the recovery is almost same with that before the poisoning. The emission decrease accompanied with the oxygen poisoning mainly takes place at the periphery of the cathode, and the current at the centered region shows relatively small decrease.

4. Studies on Field Emitters

Figs. 7 (a) and (b) show a typical three-dimensional profile of emission distribution and I_p-V_p curve on a carbon-based field emitter. We usually use pyrolytic graphite (PG) [3] and carbon nanotube (CNT) as source materials of the emitters. The spacial uniformity of the emission from these emitters is not so good and local emission points disperse in the sample emitter. In order to improve the emission characteristics, some chemical surface treatments were carried out on the PG-based emitters. Fig. 8 exhibits emission characteristics of an electrochemical treated PG emitter. Although spacial uniformity of the emission was not improved by the treatment, onset voltage was decreased from 900V to 400V when the spacing between the anode and the emitter surface was 0.1mm. Here, the onset was defined by the voltage inducing 3μA of I_p. The lowest onset voltage of the electrochemical treated emitter that we obtained was 295V at the present stage. On the other hand, CNT-based emitter had lower onset voltage even if chemical surface treatments were not applied. The advantage of the CNT for field emitter use, which is already well known, appeared in our results, while the spacial emission uniformity of the CNT emitter was similar to the PG-based one. These behaviors suggest that the better emission characteristics of the CNT field emitter does not come from the increase of the emitting points, but originates from the decrease of the onset voltage at each emitting points. These data also shows that the CEP effectively works in the research of field emitters.

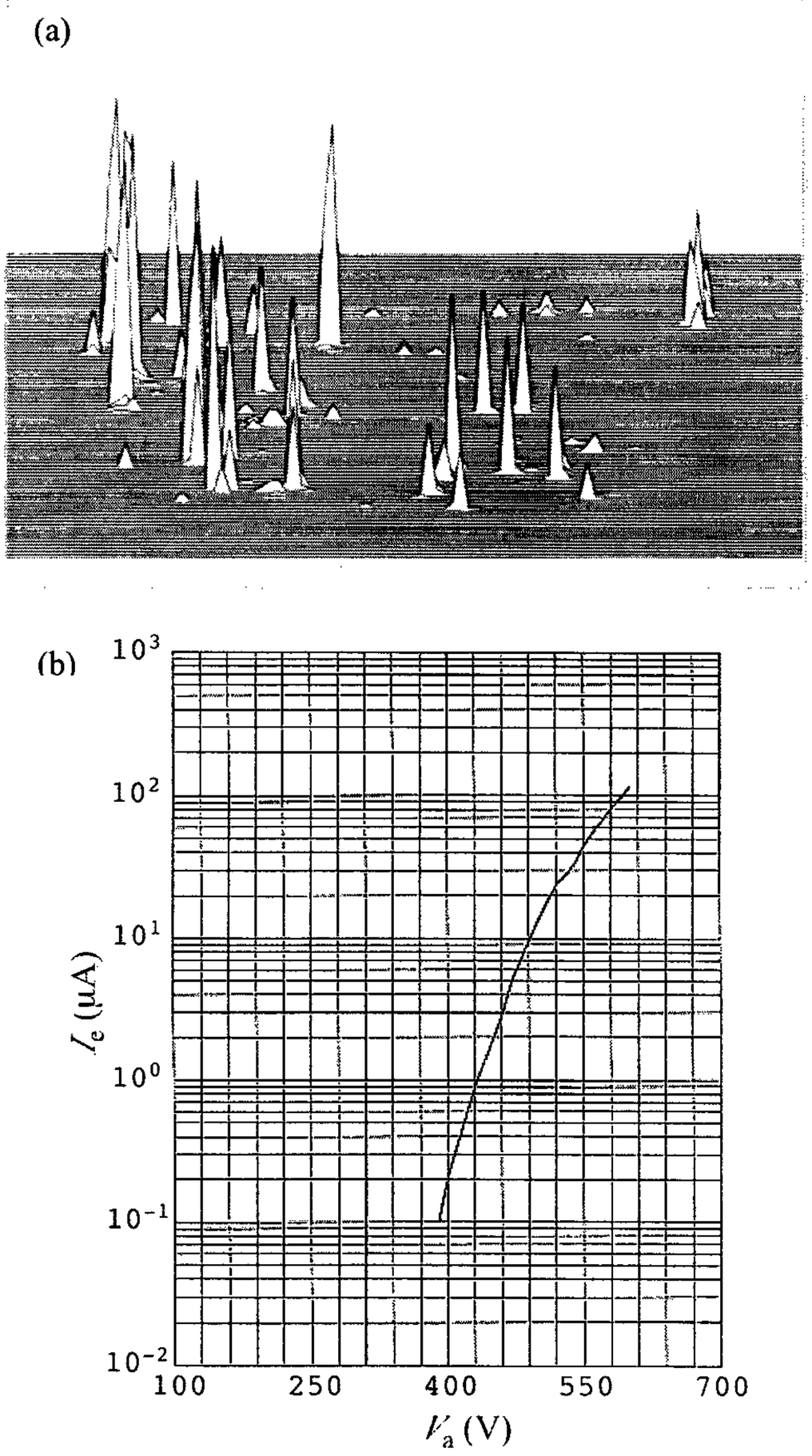


Figure 7 (a) Emission profile and (b) I_p-V_p curve of a chemical treated pyrolytic graphite-based field emitter.

Fig.8 is a time profile of emission current from the CNT-based emitter and ambient gas pressure. In general, local emission current of field emitters is not so stable. The figure shows that our carbon emitter also has instable local emission characteristics (I_{FC}). The whole emission (I_p) is much more stable than the local one due to an averaging effect, but a few to 10% fluctuation remains.

Oxygen gas poisoning of CNT-based emitter shows unique behavior as sown in Fig. 8. Ten minutes after the measurement starting, 4 x 10^{-5} Pa of oxygen gas is introduced into the chamber and kept for 20 minutes. Roughly estimating, the local emission current (I_{FC}) decreased down to 20% of the initial value just after the oxygen introduction. On this sample, however, a jump up of the I_{FC} was observed 11min after of the gas introduction, namely during the poisoning process. The whole emission current (I_p) also had a tendency to recover during the poisoning gradually, and it reached the initial value a few minutes after the evacuation of the oxygen. These behaviors indicate that the intrinsic poisoning mechanism is different between the CNT field emitter and usual thermionic

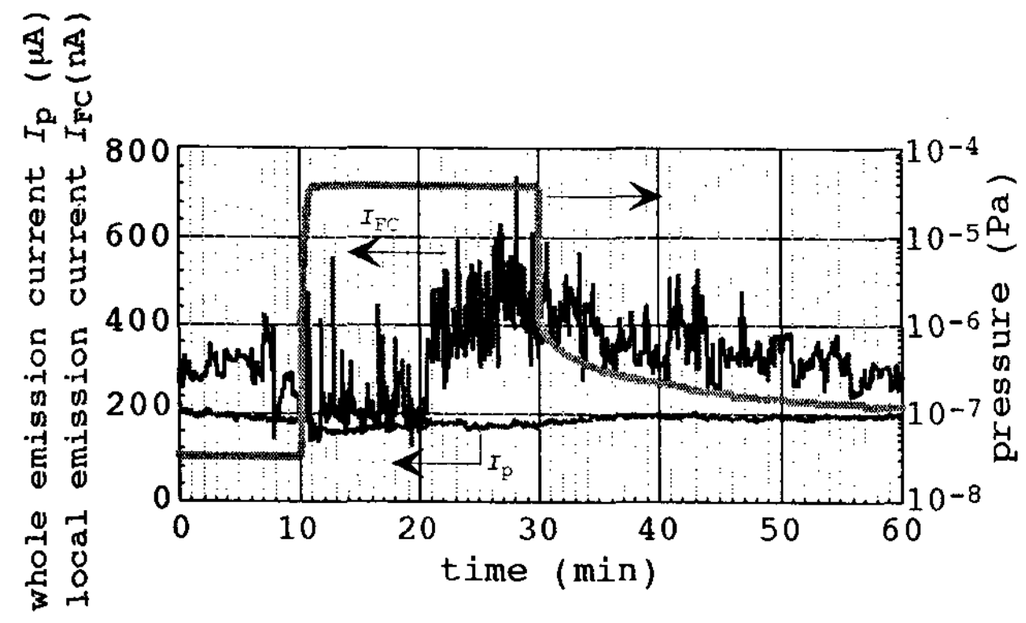


Figure 8 Time profiles of ambient gas pressure, whole and local emission current of an carbon nonotube-based field emitter during oxygen poisoning and recovery processes.

cathode. Carbon surface does not form a thick oxide layer under oxygen gas. Concerning this point, the CNT cathode is essentially distinct from the metal-based cathodes. The behavior in Fig.8 suggests that the reaction between the CNT and oxygen, which may decompose the CNT surface into gas phase of CO or CO_2, leads to morphological change of the emitting point in the sample. This must be the reason for that the CNT-based emitter does not show the simple emission decrease by oxygen poisoning. At the present stage, the special resolution of the CEP is only about 20μm which is defined by the anode-hole diameter, but it is possible to collect the features of field emitters and analyze them under such condition.

5. Summary

Cathode emission profiler (CEP) has been developed in order to evaluate thermionic cathodes and field emitters. This machine enables us to monitor the whole and local emission characteristics and the emission distribution profiles under various conditions. Our results show that evaluation of cathode properties based on whole emission current is sometimes insufficient. In such case, the CEP becomes a powerful tool on the research of cathodes and emitters.

6. Acknowledgements

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7. References

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