Emission characteristic of diamond-tip field emitter arrays fabricated by transfer mold technique

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Wedge-shaped diamond-tip field emitter arrays were fabricated and characterized. The tip radius of the diamond emitter fabricated by using a silicon mold was about 300 Å. The maximum current density of 800 $\mu A/cm^2$ and the threshold voltage of 600 V were obtained from the diamond-tip field emitter array, which was a better electrical characteristic than that of a flat diamond film. The effects of vacuum pressure upon emission characteristics were investigated. The emission characteristic of the diamond-tip field emitter array was not varied over a wide range of vacuum pressure relatively to the flat diamond film. © *1997 American Vacuum Society.* [S0734-211X(97)03202-2]

I. INTRODUCTION

The evolution of vacuum devices with microstructure depends on the development of a cold electron source.[1,2] Molybdenum and silicon are used for field emitters due to feasible properties.[3,4] A fabrication of a more sharp emitter is possible by the rapid development of thin-film technology. Metal and silicon field emitters, however, have caused some problems due to chemical contamination and physical weakness. In order to compensate these problems, new material systems have been required.

The desirable properties of field emitters are low operating voltage, high emission current density, and mechanical hardness. Diamond is considered as one of the attractive candidates for field emitter materials due to low electron affinity, high chemical stability, and high mechanical hardness.[5–7] However, it is so difficult to form diamond into desirable shapes for field emitter arrays due to chemical stability and hardness of diamond so that the diamond emitter has been generally fabricated in the shape of a flat film. Although electron emission can be obtained from the flat diamond film, a tip-shaped diamond has been expected to have better emission characteristics than the flat diamond film.

In this article, the emission current–voltage characteristics of the wedge-shaped diamond-tip field emitter arrays with different pressure conditions were measured and compared with that of the flat diamond film deposited under the same condition.

II. EXPERIMENT

The diamond-tip field emitter array was fabricated by using the transfer mold technique.[8,9] Figure 1 shows the fabrication procedure of the diamond-tip field emitter array. A 2000-Å-thick SiO_2 film was grown on a (001) silicon wafer by thermal oxidation. SiO_2 islands with 5 μm width and 5 mm length were formed by photolithography. The distance between SiO_2 islands was 3 μm. *V* grooves were formed on the silicon substrate by etching the silicon substrate in ethylenediamine–pyrocatechol–water solution. A polycrys-

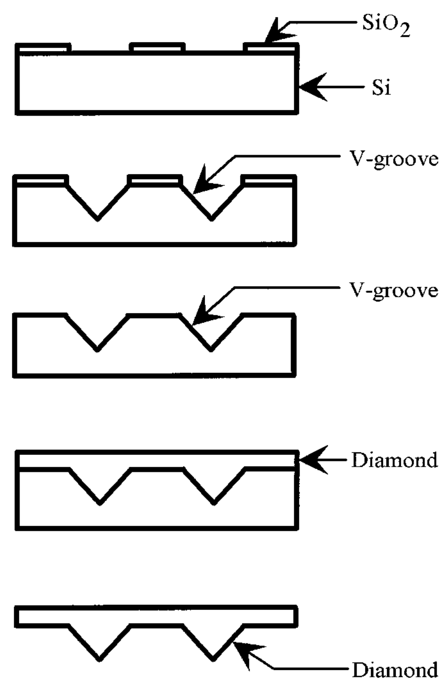

FIG. 1. Fabrication procedure of the diamond-tip field emitter array.

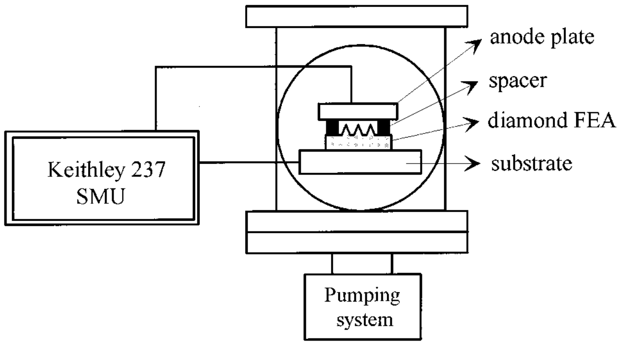

FIG. 2. The schematic diagram of the vacuum test station.

talline diamond film was deposited by plasma-enhanced chemical vapor deposition on the silicon mold. The reactant gas used was 2% CH_4 diluted in H_2 and the substrate temperature was kept at 950 °C. Then, the silicon mold was removed by etching in a $HF:HNO_3=1:1$ solution and the diamond-tip field emitter array was obtained. The current–voltage measurements were performed under the vacuum level of 1×10^{-4}, 1×10^{-5}, and 1×10^{-6} Torr, respectively.

III. MEASUREMENT SETUP

The electrical measurement of the diamond-tip field emitter array was performed in a vacuum test station. Figure 2 shows a schematic diagram of the measurement system. Current–voltage characteristics were measured by a Keithley 237 SMU (source and measure unit), which has a maximum applied voltage of 1100 V. A polyimide film 50 μm thick was placed between the diamond surface and the anode plate as a spacer. The 50-μm-thick spacer used in the measurement showed a leakage current density of 0.3 nA/cm^2 at 1100 V, which was a suitable value for a spacer.

IV. RESULTS AND DISCUSSION

Figure 3 shows the polycrystalline diamond film deposited on the silicon mold fabricated by orientation dependent

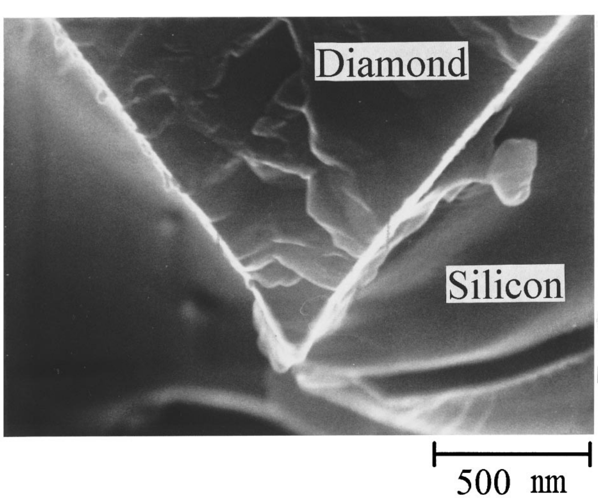

FIG. 3. A cross section of the silicon mold filled with diamond.

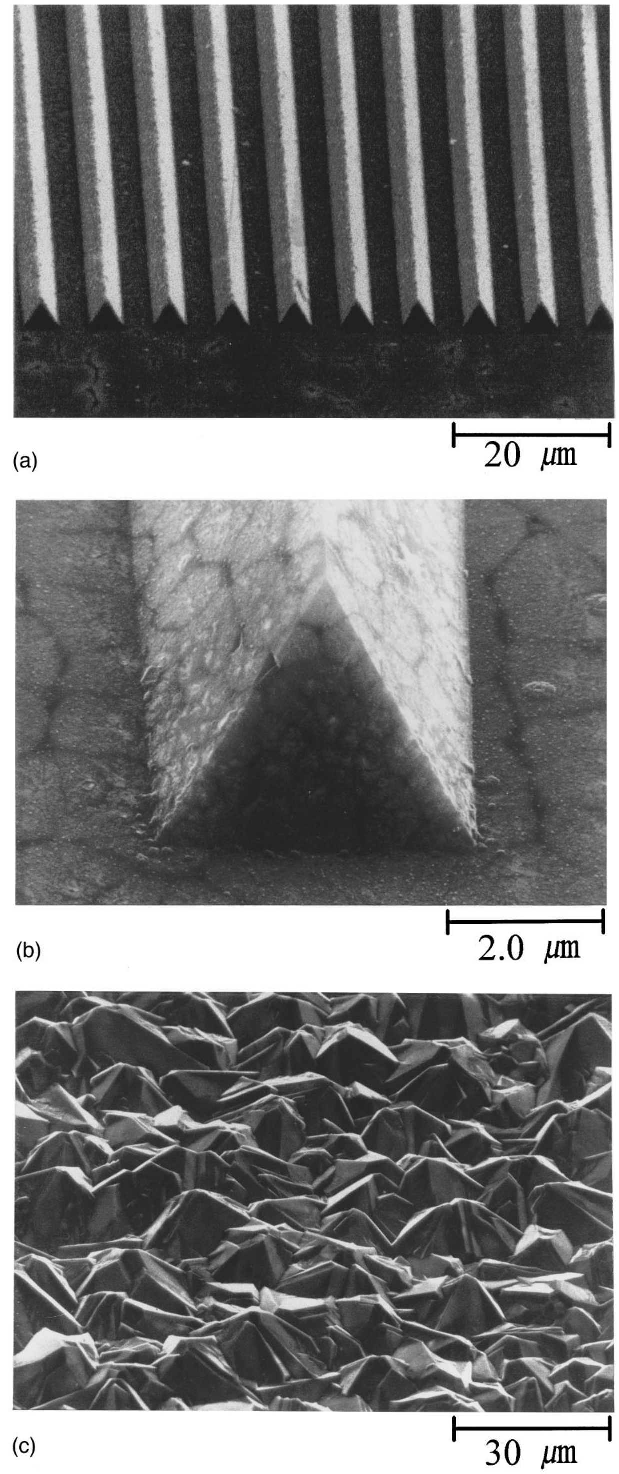

FIG. 4. (a) Scanning electron micrographs of the diamond-tip field emitter array fabricated by transfer mold technique; (b) individual diamond tip; and (c) scanning electron micrograph of the diamond film deposited under the same condition.

etching (ODE). It was clearly seen that the silicon mold was completely filled with diamond. Figure 3 indicates that a diamond tip formed by the silicon mold has very uniform surface such as the surface of the silicon mold, provided the uniform surface is formed after the ODE process.

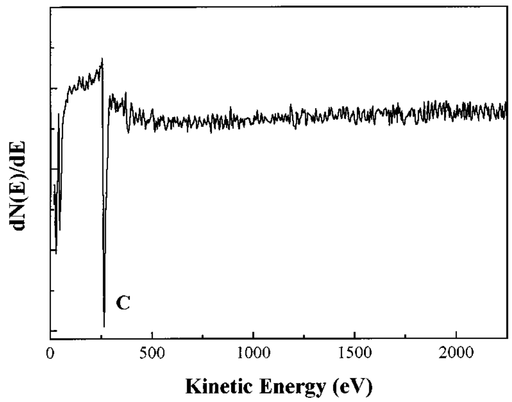

FIG. 5. Auger electron spectroscopy of the fabricated diamond-tip field emitter array.

Figure 4(a) shows the fabricated diamond-tip emitter array after the silicon mold was removed. As shown in Fig. 4(a), a uniform array of the diamond tip could be obtained by the transfer mold technique. Figure 4(b) shows one of the diamond-tip emitters. The tip radius of the diamond emitter was about 300 Å. The surface profile for a diamond film deposited under the same condition as the diamond-tip emitter is shown in Fig. 4(c). It is shown that the diamond-tip emitter has a much smoother surface than the flat diamond film.

Auger electron spectroscopy (AES) was used to confirm if the emitter surface was contaminated by etched reactants. The spectrum that has only a carbon peak shows that no contaminants exist on the emitter surface. The obtained AES spectrum is shown in the Fig. 5.

The qualitative analysis of the diamond emitter arrays was performed by Raman spectroscopy. A typical strong peak of pure diamond was observed at 1335 cm^{-1} as shown in Fig. 6. The fabricated emitter array was identified as pure diamond.

The current–voltage measurements of the diamond-tip

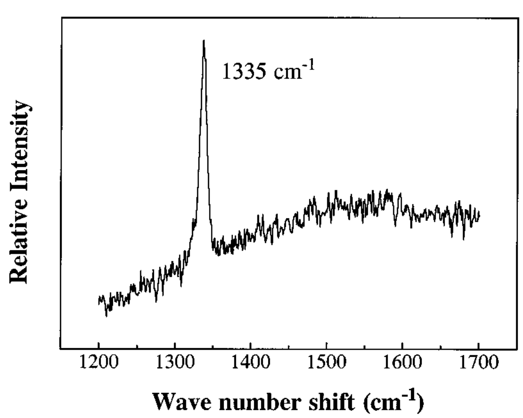

FIG. 6. Raman spectroscopy of the fabricated diamond-tip field emitter array.

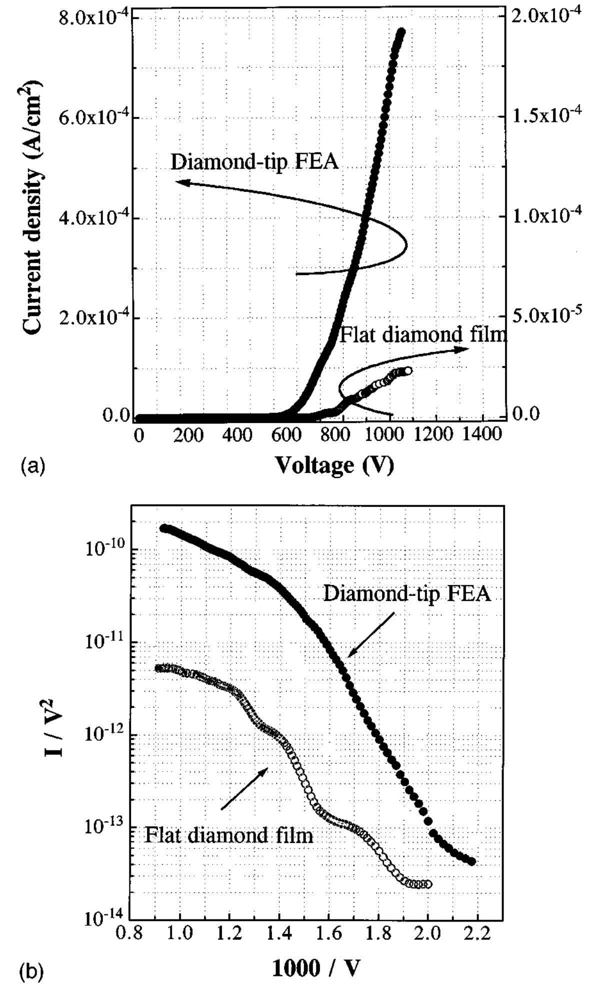

FIG. 7. (a) Current–voltage characteristics of the diamond-tip field emitter array and the flat diamond film and (b) Fowler–Nordheim characteristics of the diamond-tip field emitter array and the flat diamond film.

emitter array and the flat diamond film were performed under the pressure of 1×10^{-6} Torr. As shown in Fig. 7(a), the diamond-tip emitter array has a lower threshold voltage than the flat diamond film, which is in agreement with the expected phenomena. It was also found that the diamond-tip field emitter array has an improved characteristic of higher emission current density as well as lower threshold voltage than the flat diamond film. The obtained result, that a diamond-tip emitter array has much higher current density than a diamond film, has been also reported by another group.[10] Fowler–Nordheim characteristics of the diamond-tip field emitter array and the flat diamond film are shown in Fig. 7(b).

The current–voltage measurement was also performed under a different pressure condition in order to observe the effect of the pressure condition upon the emission characteristics of diamond. Figures 8(a) and 8(b) show the current–voltage characteristics of the different types of diamond emitters measured under different vacuum pressure conditions. The pressure conditions at which the measurement was

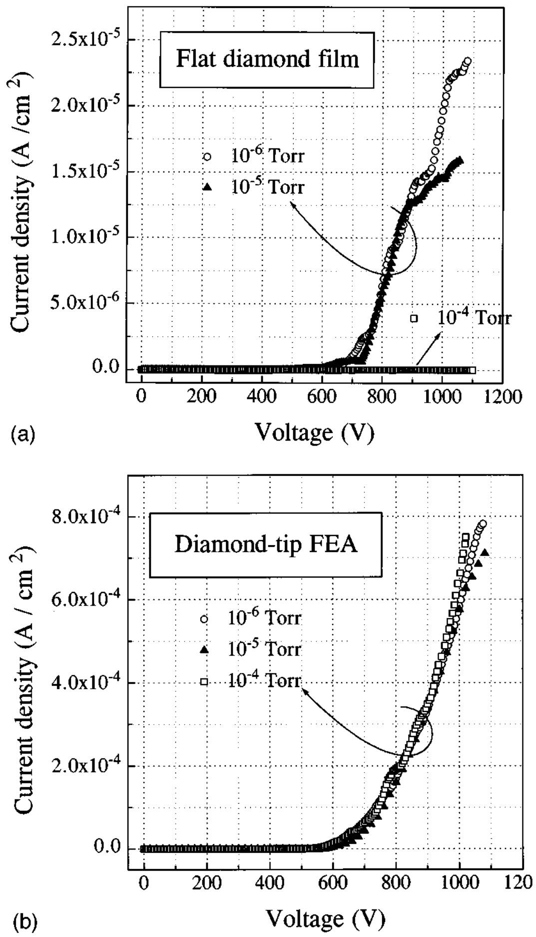

FIG. 8. Current–voltage characteristics of (a) the flat diamond film and (b) the diamond-tip field emitter array measured under different vacuum pressure conditions.

performed were 1×10^{-4}, 1×10^{-5}, and 1×10^{-6} Torr, respectively. In the case of the flat diamond film, no current flow was observed in the pressure of 1×10^{-4} Torr, as shown in Fig. 8(a). Electron emission occurred only under a pressure less than 1×10^{-4}. In contrast to the flat diamond film, the diamond-tip field emitter array showed relatively constant characteristics over the wide range of pressure as shown in Fig. 8(b). There are no drastic differences in the threshold voltages, the current densities, and the slopes of the characteristic curves.

V. CONCLUSION

In this work, very uniform wedge-shaped diamond-tip arrays were obtained by a transfer mold technique. The composition of the emitter was identified as nearly pure diamond from Raman study. It was found that the diamond-tip emitter array has a lower threshold voltage and higher current density than the flat diamond film. From the study on the effect of vacuum pressure upon emission characteristic, it was found that the emission characteristic of the diamond-tip field emitter array was not varied by the operating pressure conditions. The performance of the diamond-tip field emitter array fabricated in this work is suitable for field emission display application. A study on the emission characteristic of diamond emitters with a triode structure will remain as a future work.

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