BRIEF REPORTS AND COMMENTS

This section is intended for the publication of (1) brief reports which do not require the formal structure of regular journal articles, and (2) comments on items previously published in the journal.

Emission stability of a diamond-like carbon coated metal-tip field emitter array

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The emission stability of Mo-tip field emitter arrays (FEAs) has been improved. The effect of diamond-like carbon (DLC) films deposited using a layer-by-layer technique using plasma enhanced chemical vapor deposition on the electron emission characteristics of Mo-tip FEAs was examined. The turn-on voltage was lowered from 80 V for Mo-tip FEAs to 65 V for DLC-coated Mo-tip FEAs, and the maximum emission current increased from 140 μA for Mo-tip FEAs to 320 μA for DLC-coated Mo-tip FEAs composed of 900 emitters. An anode current for DLC-coated Mo-tip FEAs and Mo tip of 0.1 μA per emitter was measured at gate voltages of about 87 and 107 V, respectively. The emission current of DLC-coated Mo-tip FEAs is more stable than that of Mo-tip FEAs. © *1999 American Vacuum Society.* [S0734-211X(99)07602-7]

I. INTRODUCTION

Field emitter arrays (FEAs) have shown tremendous progress in recent years for the development of a new generation of flat panel displays and vacuum microelectronic devices, such as high power and frequency amplifiers. However, two important limitations of microfabricated field emitter arrays are their reliability and emission current stability.

Diamond films possessing negative electron affinity (NEA) characteristics[1] have great potential in application as electron emitters in vacuum microelectronics and have produced many studies.[2,3] The interest in diamond-like carbon (DLC) as an emission material results from its unique emission properties: low-field cold emissivity and good emission stability. In addition, its excellent thermal conductivity should allow high maximum currents to be produced from DLC-coated emitters.

Cold cathode electron emitters obtained by depositing diamond films on Si tips,[4] Mo tip,[5] or W tips[6] have been widely discussed. The field strength needed for electron field emission has been reduced to less than 3×10^4 V/cm, which is substantially lower than the 1×10^6 V/cm required for metal-tip FEAs.[7]

DLC films containing a large proportion of sp^3 bonds can usually be grown at markedly lower temperature as demonstrated by Xie *et al.*[7] Chuang *et al.*[8] also showed that the films manifest excellent electron emission characteristics. A layer-by-layer growth technique using plasma enhanced chemical vapor deposition (PECVD) processing is not only suitable for growing DLC films at room temperature, but also useful for synthesizing a film with a large proportion of sp^3 bonds (-60%) with a controlled hydrogen content.

In this work, we fabricated DLC-coated Mo-tip FEAs by a layer-by-layer technique using PECVD, and characterized their electron emission behavior.

II. EXPERIMENT

The Mo tips were deposited on a silicon substrate by e-beam evaporation into 1.5 μm diam holes spaced on 10 μm centers, which included the sequential growth of SiO_2, Mo, and Al layers, followed by patterning of gate layers. The height of the tip relative to the gate is determined by the diameter of the hole and the thickness of the insulating layers.[9] During deposition of the DLC films, the substrate temperature was adjusted to room temperature. The pressure was 20 mTorr. A thin DLC layer of about 5 nm thickness was grown, and then a 200 s CF_4 plasma exposure on the surface was used to remove weakly bonded material, predominantly C–H_n and graphite C–C bonds.[10] The repeated deposition and CF_4 plasma exposure of the surface gives rise to a 20-nm-thick hydrogen-free DLC film.

The electron emission characteristics of the tips were measured using a triode geometry. An anode plate was placed at 1 mm above the gate and was biased at 300 V. The anode and the gate currents were measured using a Keithley SMU 237 at a base pressure of 1×10^{-8} Torr. For all the tests, the device is configured in a common emitter configuration with the emitter grounded, the anode at a positive voltage, and the gate driven positive to turn the device on.

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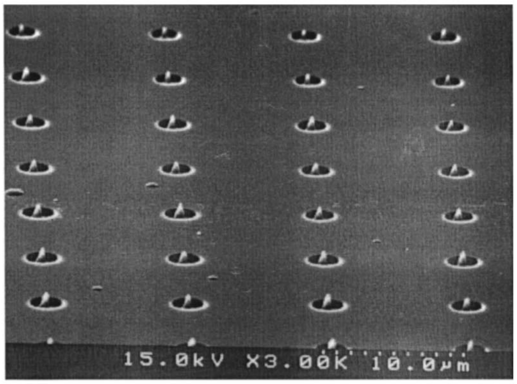
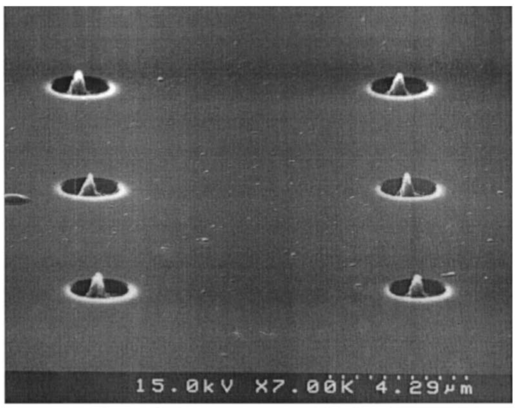


(A)



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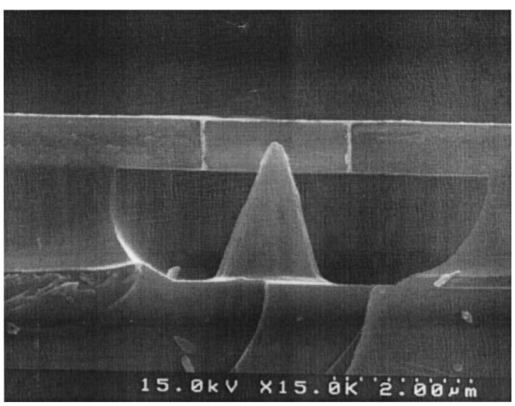

(C)

FIG. 1. SEM pictures of (A) top view of Mo tip, (B) top view, and (C) cross-sectional view of DLC-coated Mo tip.

III. RESULTS AND DISCUSSION

The morphologies of the Mo tip and DLC-coated Mo tips are shown in Figs. 1(A) and 1(B), respectively. The cross-sectional view of the DLC-coated Mo tips shown in Fig. 1(C) reveals that the tips are typically 1.8 μm high with a 1.5 μm wide gate aperture. The thermally grown SiO_2 dielectric layer is approximately 1.6 μm in thickness, and the DLC layer coated on the Mo tips is about 20 nm in thickness.

Figure 2 shows the emission current–voltage characteristics for the 900 tip DLC-coated Mo-tip FEAs and Mo-tip FEAs. The turn-on voltage was 80 V for the Mo-tip FEAs and 65 V for the DLC-coated Mo-tip FEAs. In addition to the decrease in the turn-on voltage, the maximum anode current available also increased from 140 to 320 μA. An anode current of about 0.1 μA per emitter is obtained at 87 V in the DLC-coated Mo-tip FEAs, while the same current level is obtained at 107 V for the Mo-tip FEAs. Thus, the operating voltage is remarkably reduced by using our DLC fabrication process to coat Mo tips. By contrast, the increase in gate current with the applied gate voltage was not significantly altered due to the DLC coating. It should be noted that these Mo- and DLC-coated Mo tips were grown on the same wafers under the same conditions. Thus the modification on the current–voltage property can be completely attributed to the enhancement on the electron emission behavior due to DLC coating.

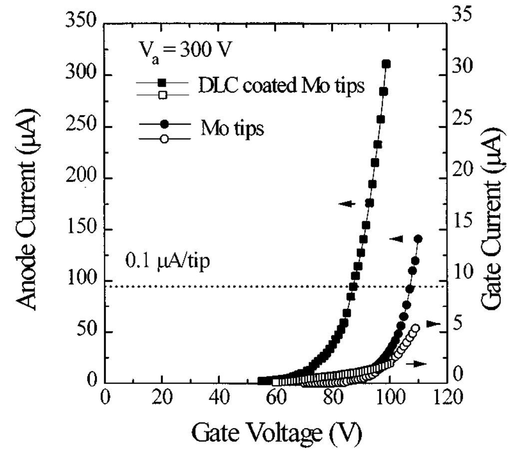

FIG. 2. $I-V$ characteristics of DLC-coated Mo tips and Mo-tip FEAs.

Figure 3 shows Fowler–Nordheim plots of a DLC-coated Mo-tip FEAs and Mo-tip FEAs. The electron emission characteristics of the tips were further evaluated using the Fowler–Nordheim equation.[9] The effective work function (ϕ) and turn-on voltage were estimated from the slope of the

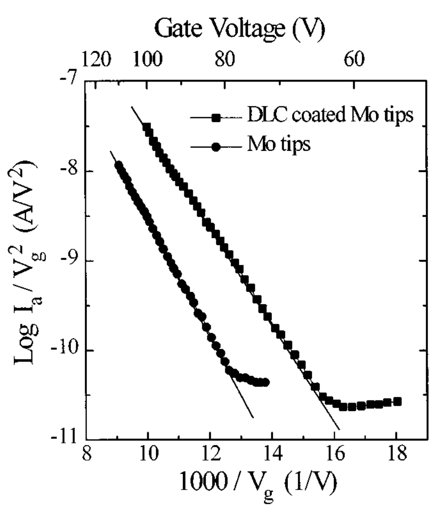

FIG. 3. FN plots of DLC-coated Mo tips and Mo-tip FEAs.

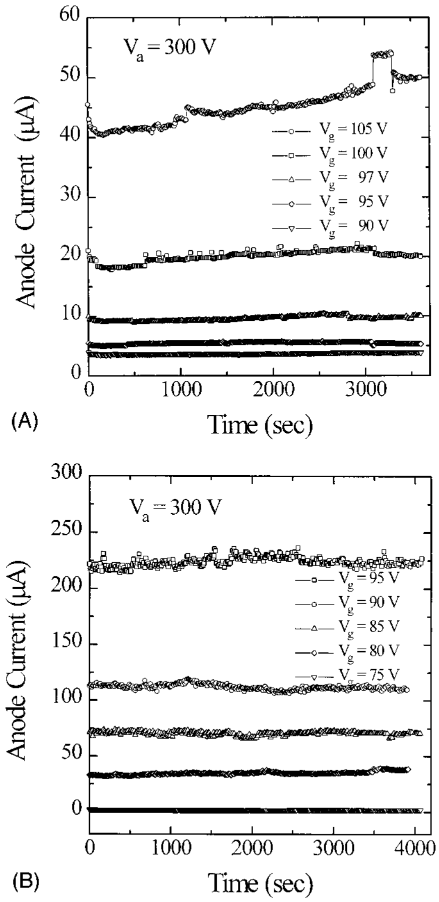

FIG. 4. Emission current fluctuations of (A) Mo tips and (B) DLC-coated Mo-tip FEAs with variable gate voltage.

FN plots and the intercepts of this plot with the abscissa, respectively. The field enhancement factor for these tips was first obtained by comparing ϕ calculated from the slope of the FN plots of the Mo tip with the work function reported for Mo metal (4.5 eV). The calculated effective ϕ value for the DLC-coated tips is 2.60 eV. These results illustrate the significant effect of the DLC coating on lowering the work function for electron emission.

The emission current fluctuations of the Mo-tip FEAs and DLC-coated Mo-tip FEAs with variable gate voltage are shown in Figs. 4(A) and 4(B), respectively. For midlevel currents, the emission current for the DLC-coated Mo-tip FEAs is more stable than that for the conventional pure Mo-tip FEAs. So the performance of DLC-coated Mo-tips FEAs is better than that of Mo-tip FEAs.

IV. SUMMARY

Electron emission characteristics of the Mo tip and DLC-coated Mo-tip FEAs were examined using a triode geometry. DLC coatings markedly enhanced the emission of electrons. The turn-on voltage was reduced from 80 to 65 V, while the maximum anode current increased from 140 to 320 μA, due to DLC coating on Mo tips. The emission current for DLC-coated Mo-tip FEAs is more stable than one for the conventional pure Mo-tip FEAs.

[1]F. J. Himpsel, J. A. Knapp, and J. A. Van Vechten, Phys. Rev. B **20**, 624 (1979).

[2]M. W. Geis, N. N. Efremow, and J. D. Woodhouse, IEEE Electron Device Lett. **12**, 456 (1991).

[3]N. S. Xu, R. V. Latham, and Y. Tzeng, Electron. Lett. **29**, 1596 (1993).

[4]J. Liu, V. V. Zhirnov, and A. F. Myer, J. Vac. Sci. Technol. B **13**, 422 (1995).

[5]W. B. Choi, J. Liu, and M. T. McClure, Proceedings of the 8th IVMC95, 1995, p. 315.

[6]N. Liu, Z. Ma, and X. Chu, J. Vac. Sci. Technol. B **13**, 1712 (1994).

[7]C. Xie, N. Kumar, and C. C. Collins, Proceedings of the 6th IVMC'93, 1993, p. 162.

[8]F. Y. Chuang, C. Y. Sun, H. F. Cheng, C. M. Huang, and I. N. Lin, Appl. Phys. Lett. **68**, 1666 (1996).

[9]C. A. Spindt, C. E. Holland, A. Rosengreen, and I. Brodie, IEEE Trans. Electron Devices **38**, 2355 (1991).

[10]Y. Shimada, N. Mutsukura, and Y. Machi, J. Appl. Phys. **71**, 4019 (1992).