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Citation: J. Vac. Sci. Technol. B **17**, 684 (1999); doi: 10.1116/1.590618
View online: http://dx.doi.org/10.1116/1.590618
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Field emission characteristics of diamond films with different surface morphologies

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(Received 20 July 1998; accepted 31 January 1999)

The field emission characteristics of diamond films with different surface morphologies were studied. The diamond films were grown on silicon substrates by chemical vapor deposition technique under different deposition conditions. The nucleation density and surface morphological properties were analyzed by means of scanning electron microscopy and atomic force microscopy. Results from these studies showed that the diamond film with small crystal size and high nucleation densities had better field emission characteristics. In addition, (110) and (111) oriented films exhibited better field emission properties than (100) oriented films. © *1999 American Vacuum Society.* [S0734-211X(99)11502-6]

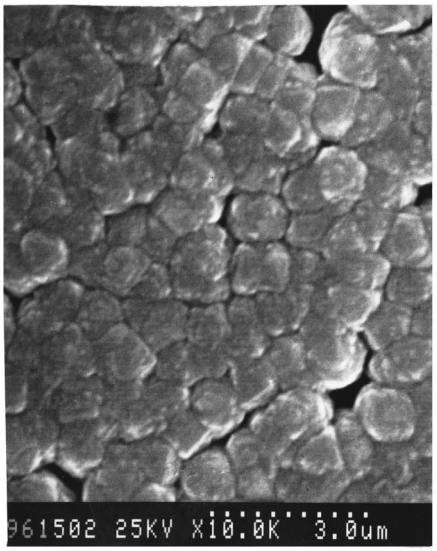
I. INTRODUCTION

In recent years, field emission from diamond films has attracted a lot of attention because of the excellent physical and chemical properties of diamond.[1] The emission property of diamond is influenced by defect doping and surface morphology.[2–4] It has been reported that an island diamond film had a lower turn-on field.[3] This indicated that the surface morphology of diamond films is an important aspect related to the field emission properties. In this work, we carried out an experiment and analytical study of field emission from diamond films of various crystal grain sizes and orientation grown by chemical vapor deposition (CVD).

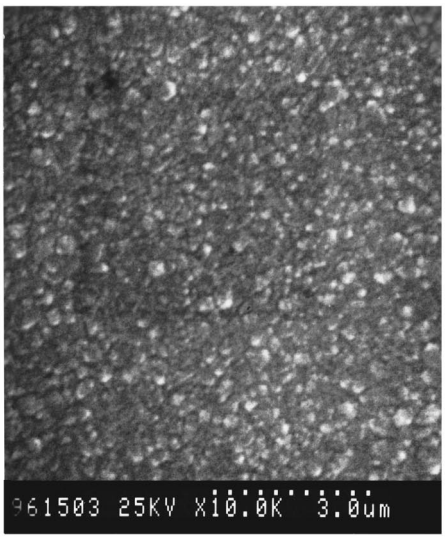
II. EXPERIMENT

Diamond films A and B were grown by microwave plasma chemical vapor deposition at 850 °C on 5×5 mm^2 *p*-type silicon substrates using a gaseous mixture of 2% methane in hydrogen, at a vacuum pressure of 15 Torr. Sample A substrate was abraded with diamond powder (50 μm in diameter) for 5 min and sample B substrate was abraded for 20 min. Diamond samples C and D were grown using a hot filament chemical vapor deposition (CVD) system with a methane–hydrogen ratio of 4/200, at a process pressure of 60 Torr. The substrate temperature was 850 °C for sample C and 950 °C for sample D.

The emission properties were measured at high vacuum ($\sim10^{-8}$ Torr). Indium–tin–oxide (ITO) coated glass plate was used as an anode. CVD diamond film acted as a cathode. The distance between cathode and anode was about 80 μm for samples A and B and 40 μm for samples C and D, respectively. The whole emitting area was 20 mm^2. After the field emission test all samples were operated at a reverse bias voltage of about 1000 V to test the circuit insulation.



(a)



(b)

FIG. 1. SEM micrographs of samples A (a) and B (b).

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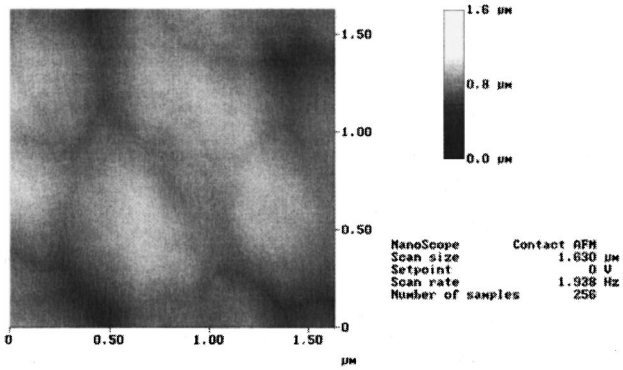


FIG. 2. AFM micrograph of sample B.

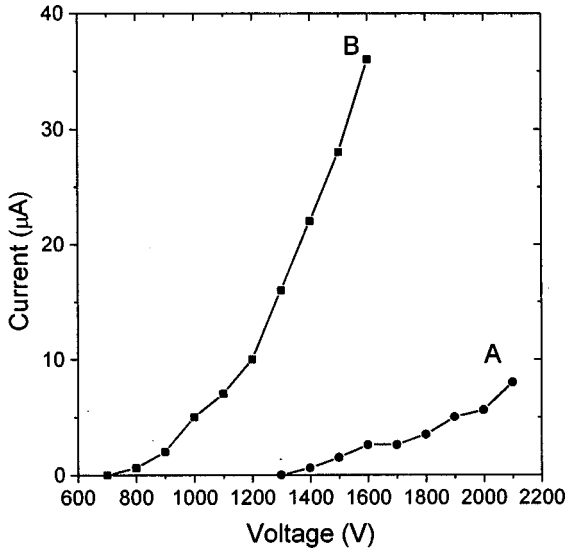


FIG. 3. Field emission $I-V$ curves for samples A and B.

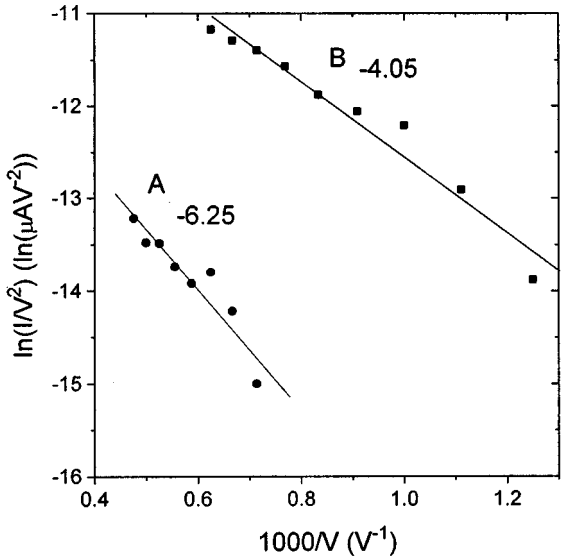
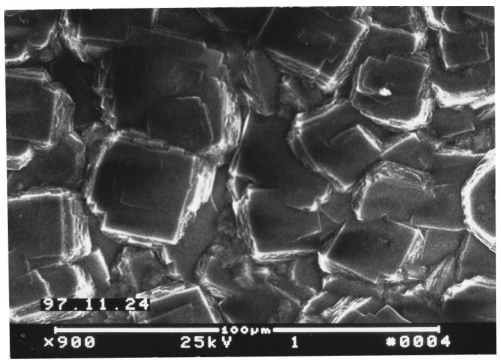
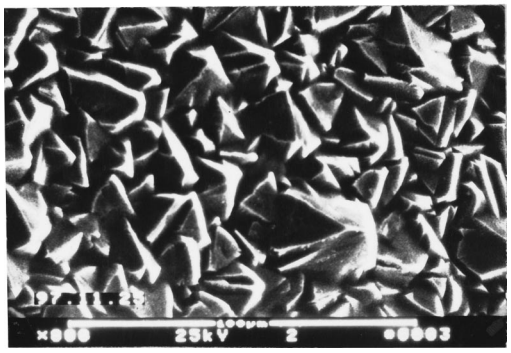


FIG. 4. F–N plots of samples A and B.



(a)



(b)

FIG. 5. SEM micrographs of samples C (a) and D (b).

III. RESULTS AND DISCUSSION

SEM micrographs of samples A and B are shown in Figs. 1(a) and 1(b). Sample A has approximately 1.3-μm-diam crystal grains and low nucleation density, sample B has about 0.3-μm-diam crystal grains and high nucleation density. Figure 2 is an AFM micrograph of sample B. Sample A exhibited the same surface morphology. So, any variation in the emission characteristics of two samples grown under the same conditions can only be influenced by the crystal grain size and nucleation density. Analysis of the field emission property of the diamond films, current–voltage ($I-V$) curves shown in Fig. 3, showed that the emission property of sample B is better than that of sample A. For sample B, the turn-on voltage was 750 V, and current was 38 μA at 16

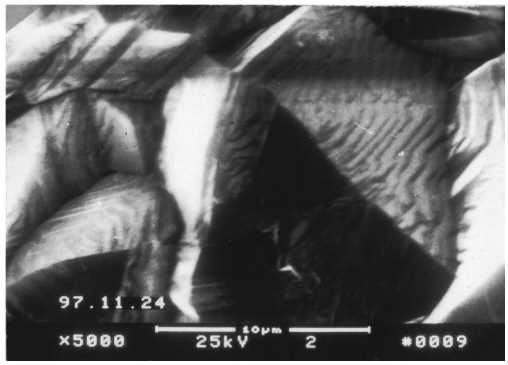


FIG. 6. Surface morphology of sample D.

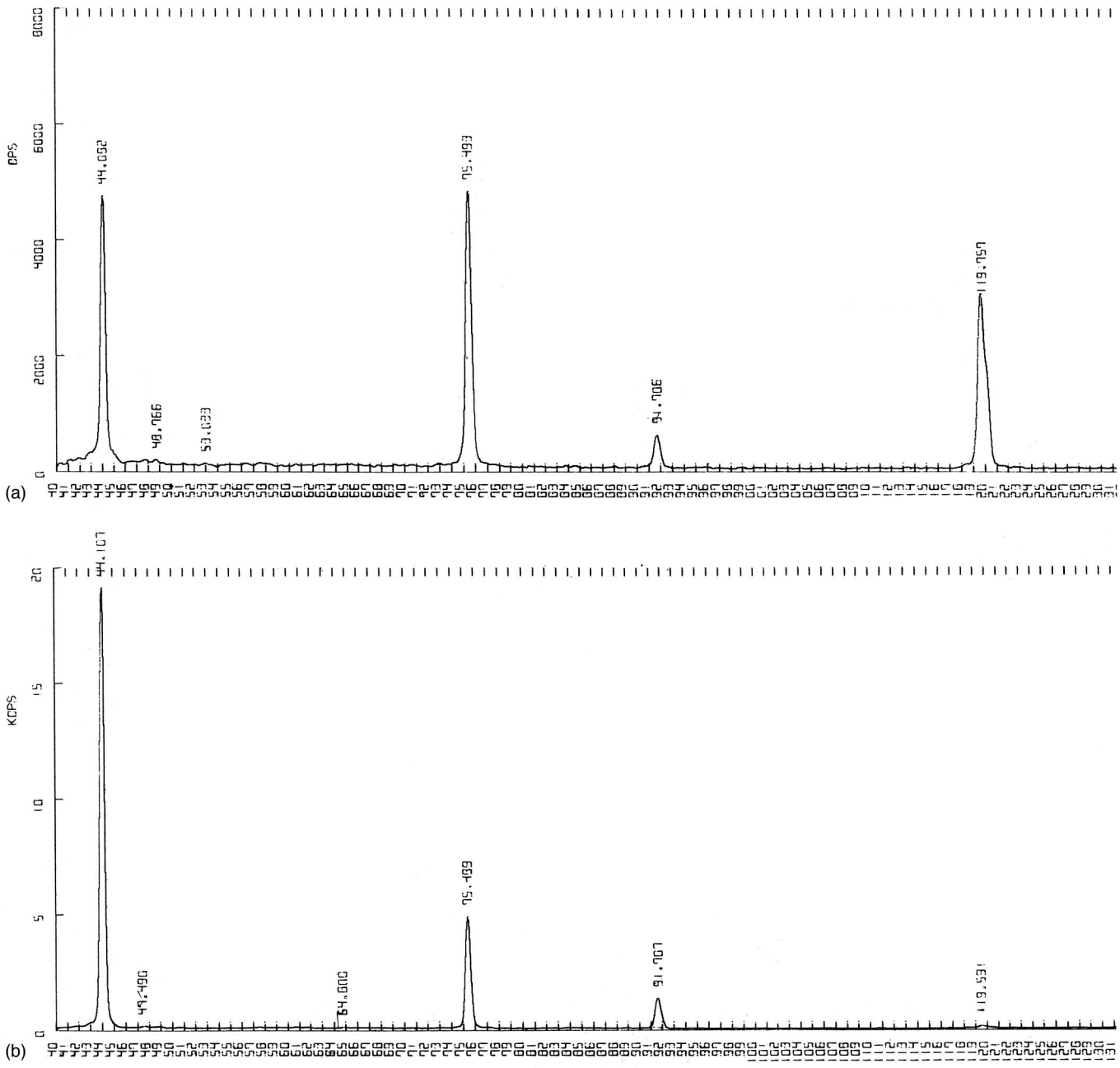


FIG. 7. XRD spectra of samples C (a) and D (b).

V/μm. For sample A, the turn-on voltage was 1350 V, and current was 8 μA at 26 V/μm. The turn-on voltage is defined as the voltage required to produce a current density of 0.001 mA/cm^2.

Fowler–Nordheim theory was used to analyze the field emission results.[5] The F–N theory is shown below:

$$\ln(I/V^2) = a - b/V,$$

where a is a constant, and the slope b is related to the effective work function. So the $\ln(I/V^2)$ and $1/V$ show a linear relation. Figure 4 is the F–N plot of the field emission $I-V$ data presented in Fig. 3 for samples A and B with the slope data listed next to each line. Samples A and B show a linear relation: the slope is -6.25 for sample A and -4.05 for sample B. The ratio of the effective work function is $\Psi_B/\Psi_A = 0.75$, indicating that sample B has a low effective work function. Since both films have the same surface morphology, but sample B has smaller crystal grains and a higher nucleation density, then the higher crystal boundary density of sample B must be the source of the increased emission areas.

It is shown in Fig. 5 that sample C has almost the same crystal grain size and nucleation density as sample B. In addition, the surface of sample C is (100) oriented, while sample D is (110) and (111) oriented. The microstructure of

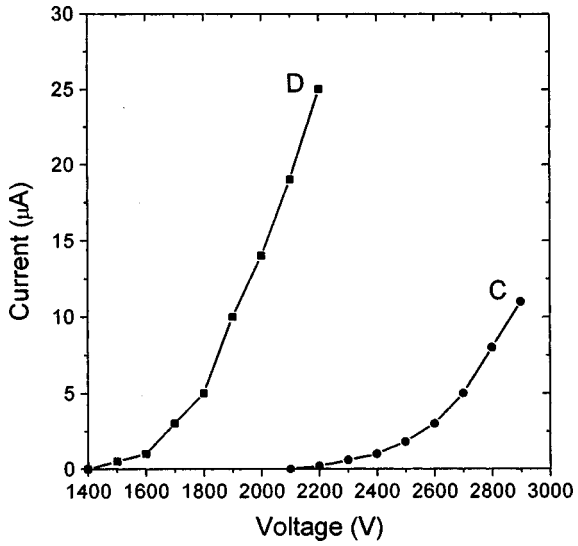


FIG. 8. Field emission $I-V$ curves for samples C and D.

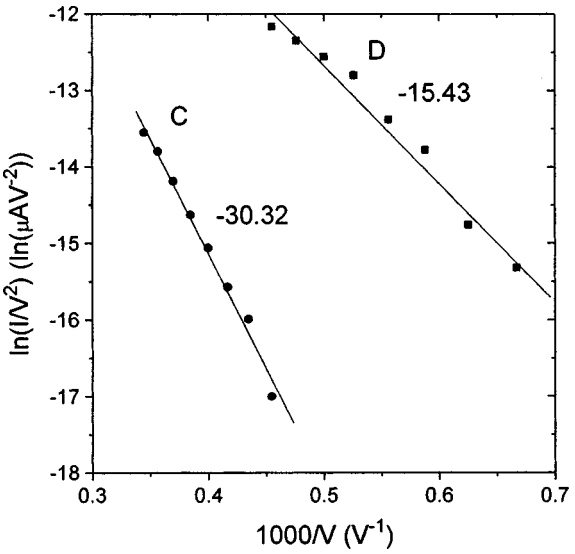


FIG. 9. F–N plots of samples C and D.

sample D is shown in Fig. 6. The texture of diamond films C and D was measured by x-ray diffraction (XRD) technique. As shown in Fig. 7, the resulting 2θ diffraction spectrum peaks 44.1, 75.5, and 119 correspond to (111), (220), and (400) peaks, respectively. The ratio of XRD spectrum intensity is $I(111)/(220)/(400)=100/100/67$ for samples C and $I(111)/(220)/(400)=100/250/0.8$ for sample D. From the $I-V$ curves obtained for samples C and D (Fig. 8), we see the turn-on voltage is 1450 V for sample D and 2200 V. Figure 9 shows the F–N plots of field emission for these two films. The slope about the F–N plot of sample C is -30.32, and that of sample D is -15.43. The ratio of the effective work function is $\Psi_D/\Psi_C=0.64$. This indicates that sample D has a lower effective work function than sample C. From Figs. 5 and 6 we know the two samples have the same crystal grain size and nucleation density, but sample D is (110) and (111) oriented. This indicates that the diamond film with sharp structure has a unique emission property, which may be explained by field enhancement properties associated with such structures.[5,6]

IV. CONCLUSIONS

As discussed above, for diamond films with different crystal size and nucleation density, the film with small crystal size and high nucleation density has a better field emission property than that with large crystal grains and low nucleation density. For diamond films with the same crystal size and different crystal orientation, the field emission characteristics of the diamond film with (110) and (111) orientation are better than that of the (100) oriented diamond film. The surface morphology of diamond films is shown to play an important role in field emission.

ACKNOWLEDGMENT

This work was supported by the High Technology Research and Development Program (program 863) of the Chinese government.

[1]V. V. Zhirnov, E. I. Givargizov, and P. S. Plekhanov, J. Vac. Sci. Technol. B **13**, 418 (1995).
[2]M. W. Geis, J. C. Twichell, and J. Macanlay, Appl. Phys. Lett. **67**, 1328 (1995).
[3]W. Zhu, G. P. Kochanski, S. Jin, and L. Seibles, J. Appl. Phys. **78**, 2707 (1995).
[4]Z. H. Huang, P. H. Cuttler, N. M. Miskovsky, and T. E. Sullivan, J. Vac. Sci. Technol. B **13**, 526 (1995).
[5]G. Yuan *et al.*, J. Vac. Sci. Technol. B **16**, 710 (1998).
[6]M. W. Geis, J. C. Twichell, and T. M. Lyszczarz, J. Vac. Sci. Technol. B **14**, 2060 (1996).