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Study of field emission of acid treated diamond films

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A electron emission was obtained at as low as about 2 V/μm from acid treated diamond films. An atomic force microscopy study shows there are many protrusions on the surface of the diamond films and their number increased after acid treatment. These results are discussed. © *1999 American Vacuum Society.* [S0734-211X(99)09102-7]

I. INTRODUCTION

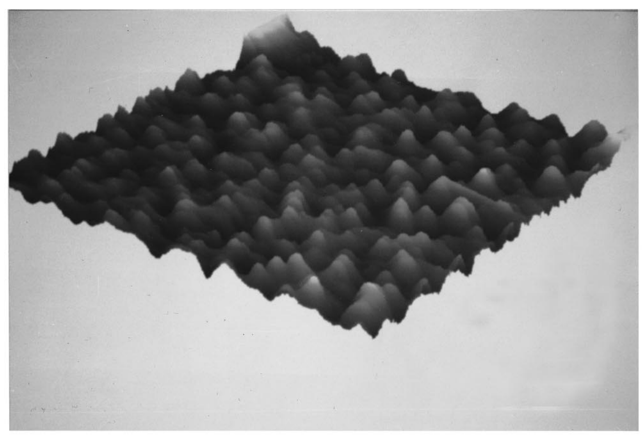
Recently chemical vapor deposition (CVD) diamond films have emerged as potential cathode materials due to their excellent physical and chemical properties such as chemical inertness, high thermal conductivity and negative electron affinity (NEA). But field emission from diamond films shows complex properties and the mechanism for it is not clear. For example, Glesener and Morrish reported that the emission from diamond films is dependent on doping.[1] Some authors report field emission following Fowler–Nordheim (FN) theory,[2] while others do not.[3] Geis and Twichen reported that high emission could obtained at lower electrical field after surface treatment and doping.[4] Usually the surface state including the surface morphology is an important parameter, e.g., NEA. A surface treatment such as acid treatment is a way to change the surface morphology and to obtain higher emission. In this article the effect of acid treatment was studied.

II. EXPERIMENT

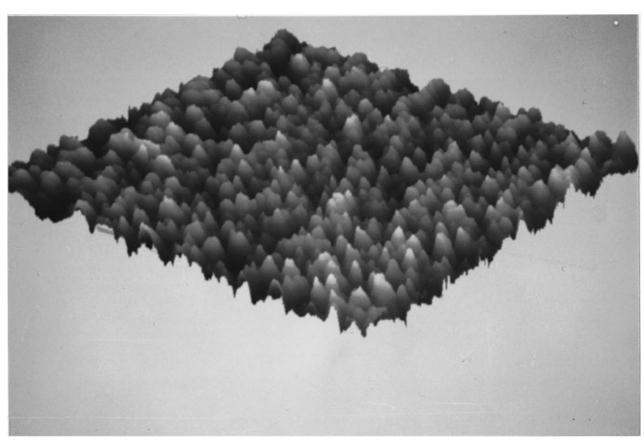
Diamond films were prepared on *n*-type silicon wafers by the microwave plasma CVD (MWPCVD) technique with the following conditions: microwave power 500 W; substrates temperature 900 °C; ratio of hydrogen versus methane 100:2. The deposition lasted 1 h to prepare thin films of about 0.3 μm thickness. Before deposition the silicon wafers were abraded with diamond powder 50 μm in diameter for 10 min. The deposited films were treated with a mixture of sulfuric acid and nitric acid at about 150 °C for 15 min, then washed with deionized water. The field emission was measured in a high vacuum system at 10^{-8} Torr. The distance between the cathode and the anode was 120 μm.

III. RESULTS

Figures 1(a) and 1(b) are atomic force microscopy (AFM) micrographs. Figure 1(a) is a three-dimensional (3D) view of as-grown films; it shows that a continuous films is formed, and that there are some protrusions distributed on the surface. A thin film is necessary to investigate the effect of acid treatment on field emission. Figure 1(b) is a 3D view of the



(a)



(b)

FIG. 1. AFM views of the diamond films. (a) 3D view of as-grown films 12 μm×12 μm in size: (b) 3D view of the acid treated films 12 μm×12 μm in size.

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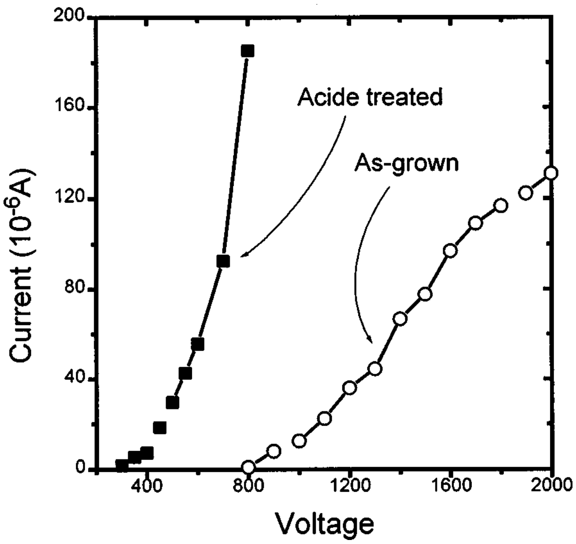

FIG. 2. Field emission plots before and after acid treatment.

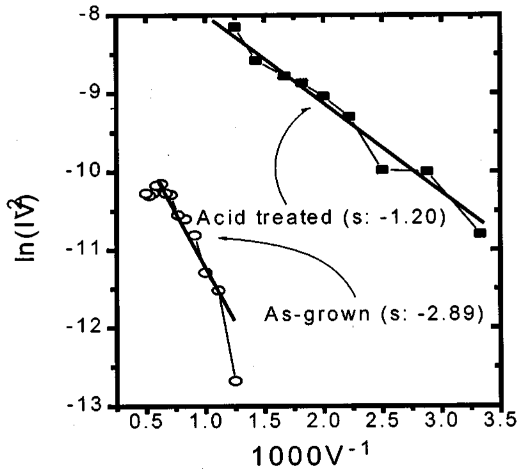

FIG. 3. Fowler–Nordheim plots.

acid treated films. After acid treatment the number of protrusions increased by one or two orders compared with that of as-deposited films, and the protrusions became sharper. Also, the protrusions were distributed more uniformly on the surface.

Figure 2 shows the field emission plots. It shows that the field emission from diamond films is significantly increased after acid treatment, and that the turn-on voltage is reduced.

Figure 3 shows the FN plots. The FN plots are linear and the slope of the acid treated sample is smaller than that of the as-deposited sample. In other words, the effective work function is reduced after acid treatment.

IV. DISCUSSION

Usually because of the effect of electrical field concentration on a sharp protrusion or on the tip of diamond films, the effective work function will be reduced. In other words, the surface morphology of the diamond films will influence field emission. As shown in Fig. 1, the protrusions of the acid treated sample are far sharper than those of the as-deposited films, and the number of protrusions is more than that of the as-grown samples by one or two orders. So there is a lower effective work function and more emission sites for the acid treated sample, and the emission increased and the turn-on field was reduced. But because the acid treated diamond films have low electrical conductivity and a high density of protrusions, the effect of electrical concentration on protrusions upon the effective work function is not so great. The high field emission and low turn-on field from the acid treated sample are attributed to the increased number of the protrusions.

There is a high lattice mismatch between diamond and silicon, and, therefore, in the early stage of the diamond growth, there are more impurities such as graphite and amorphous carbon in the films. After acid treatment the impurities will be removed, so the protrusions become sharper and their number is increased.

It has been reported that there is nonuniform emission from diamond films[5] and that the emission sites increase with the applied electrical field.[6] Probably this is due to a nonuniform distribution and to the sharpness of the protrusions as shown in Fig. 1. For sharp protrusions the electrons can be emitted at lower field (voltage), while higher field (voltage) is necessary for protrusions that are not sharp.

V. CONCLUSIONS

The field emission from diamond films is dependent on the surface morphology of the films. There are many protrusions on the surface and their number can be increased by acid treatment. The high electron emission and low beginning field are attributed to the increase of the number and to sharpening of the protrusions. These results indicate that the geometry of the protrusions on the surface of the diamond films plays an important role for emission.

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