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P7-6

Fabrication of Carbon Whisker, Pyramid and Steeple Using a Novel Plasma CVD and their Application to Field Electron Emitter

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1. Introduction

Field electron emission using carbon materials such as diamond, diamond-like carbon and carbon nanotube, which has important industrial applications in the field of flat panel displays and high-performance cold cathodes, has been extensively studied for many years [1,2]. Among these materials, carbon nanotubes and nanocrystalline diamond films might be good candidates for field emitters. Carbon films with different structure and morphology can now be fabricated by several techniques. In many cases, plasma enhanced chemical vapor deposition (PECVD) methods with hydrocarbon and hydrogen mixtures (e.g. microwave CH_4/H_2 plasma) are used for the film formation of carbon materials.

In the case of film formation by utilizing PECVD method, it is desirable to supply selectively reactive species suitable for the film growth onto the substrate. Previously we demonstrated the successful formation of diamond crystals using a unique PECVD system, which has the parallel-plate radio-frequency (rf) discharge plasma assisted by the hydrogen radical source [3]. In the present work, by using this system with fluorocarbon gas, carbon nanometer-structured films with unique features were successfully fabricated on silicon (Si) (100) substrate. The film structure was controllable in the forms of pyramids, steeples and whiskers by changing the substrate temperature during the deposition. The field emission characteristics for the carbon films with pyramid and whisker structures were investigated in order to evaluate their applicability to the electron field emitter.

2. Experiment

The experimental system used in this study has been described in detail in Ref. 3. Figure 1 shows a schematic diagram of the rf PECVD assisted by remote radical source, which consisted of three parts: a parallel-plate rf (13.56 MHz) discharge region, a radical source using remote microwave (2.45 GHz) plasma, and a CO_2 laser for

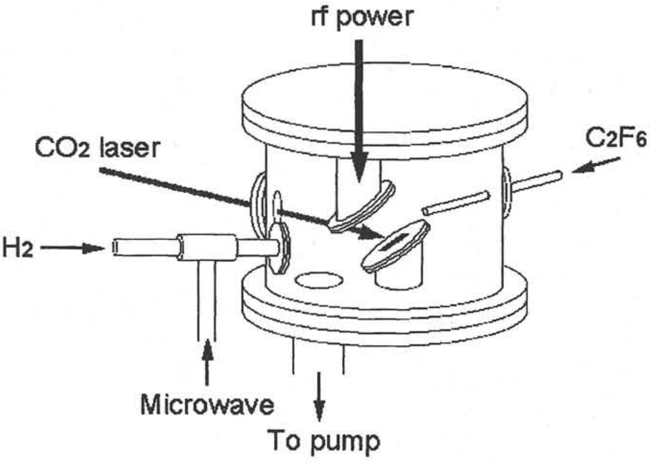

Fig. 1 Experimental setup for the formation of carbon nanometer-structured films.

substrate heating. The main reaction chamber was equipped with circular parallel-plate electrodes with a separation of 4 cm, and an rf voltage was applied to an upper electrode while the lower one was grounded. C_2F_6 was used as a source gas in this case. C_2F_6 was introduced into the rf plasma region. H_2 was fed through the quartz tube equipped with the discharge cavity and excited by microwave plasma. The gas flow rates of C_2F_6 and H_2 were 2.5 and 100 sccm, respectively. The total gas pressure was 100 mTorr.

The deposits were evaluated using a scanning electron microscopy (SEM) and x-ray photoelectron spectroscopy (XPS). The field electron emission characteristics of the films fabricated were measured with a spherical stainless steel anode of 2.3-mm diameter in a vacuum of 10^{-6} Torr. The anode–sample distance was kept at 75 μm.

3. Results and discussion

Typical SEM images for the carbon films deposited in this study were shown in Fig. 2. Surface morphology of the film was drastically changed according to the substrate temperature. As shown in Fig. 2(a), carbon film with pyramid structure (or bud shape) was deposited at a

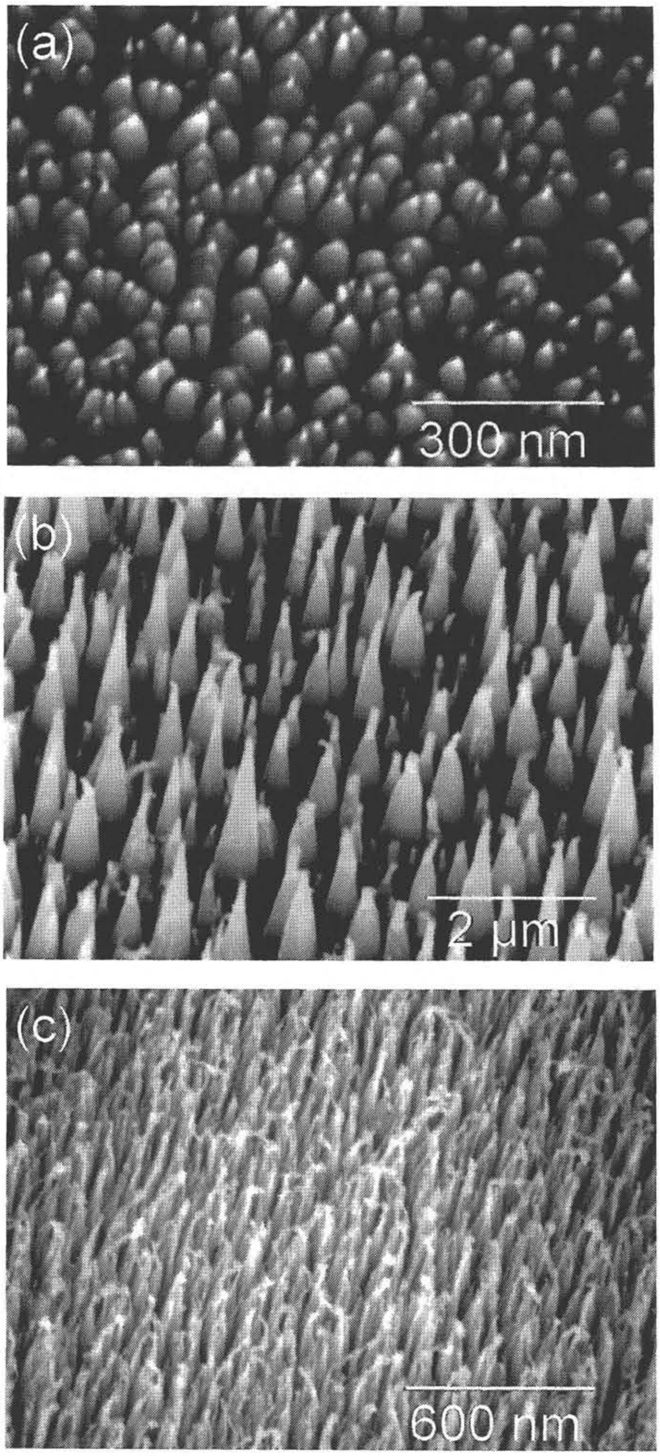

Fig. 2 Typical SEM images of carbon films with nanometer structures. (a)pyramids, (b)steeples and (c)whiskers.

substrate temperature of about 700°C. The film formed at about 600 °C had deposits with steeple structure (Fig. 2b). In the case of deposition at about 500 °C, the film was composed of whiskers with diameters as small as 10 nm (Fig. 2c). From the XPS analysis, fluorine content was not detected in the deposited films, although C_2F_6 gas was used as a source gas.

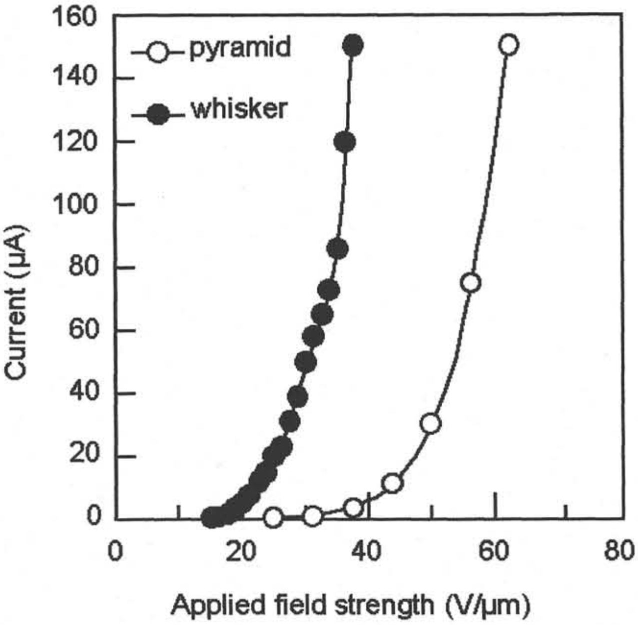

Fig. 3 Field emission characteristics of the carbon films with pyramid and whisker structures.

Field emission characteristics have been investigated for the fabricated carbon films with nanometer structures. Figure 3 shows the characteristic curves of the emission currents as a function of the applied field strength for the carbon films with pyramid and whisker structures. In this case, the applied field strength denotes the applied voltage divided by the anode-sample distance. The onset field of the field electron emission for the film with whisker structure was 15 V/μm. Corresponding Fowler-Nordheim plots were well fitted by the straight lines, indicating that the field emission property can be explained by a tunneling mechanism.

4. Conclusion

The carbon nanometer-structured films with unique features were successfully formed using rf plasma CVD with C_2F_6/H_2. The film structure was controllable in the forms of pyramids, steeples and whiskers by changing the substrate temperature during the deposition. The electron field emission was observed for the carbon films with pyramid and whisker structures.

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