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Self-Organized Texturing of Nanofibers on DLC Surface using Oxygen RF Plasma Etching

酸素RFプラズマエッチングによる DLC表面上ナノファイバーの自己組織的形成

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Nanosize fibers were formed on diamond-like carbon (DLC) film by O_2 RF plasma etching. DLC nanofibers of about 60 nm and 700 nm heights were found on the DLC film surfaces after etching for 10 and 70 min, respectively. It was found that the top of nanofibers were etched throughout O_2 plasma etching. The etching rates of DLC nanofiber top and the bottom film were 5 and 27 nm/min, respectively. The influence of nanostructures for reactive ion etching process is indicated as the cause for the deformation of DLC nanofibers during O_2 plamsa etching.

1. Introduction

Nanostructural materials are expected to exhibit different characteristics from the original bulk materials. One of the interesting properties deveolped from nanostructures is the enhancement of electron field emission from the surface at low operating voltages, which is expected to be applied to microvacuum devices such as filed-emission display panels.

We succeeded the formation of nanofibers on the surface of diamond-like carbon (DLC) films by O_2 RF plasma etching [1]. In this paper, the formation mechanism is proposed with the object of interactions between plasmas and nanostructures.

2. Experimental Procedure

The fabrication process of DLC nanofibers consists of chemical vapor deposition (CVD) and reactive ion etching (RIE). DLC films were deposited on Si substrates by a conventional RF plasma CVD method. Then the DLC films were etched by O_2 RF plasma. CVD and RIE were carried out using each RF plasma system.

DLC films were grown on the Si substrates flowing acetylene gas under the following conditions; a gas pressure of 5.6 Pa and a self-bias voltage of -1000 V. The growth duration was 10 min and the resulting thickness of the DLC films was 1.3 μm.

RIE was performed by O_2 RF plasma with various of the durations. The etching conditions were a gas pressure of 2.0 Pa and a self-bias voltage of about -600 V.

3. Results and Discussion

Figures 1(a), (b), (c), and (d) show cross-sectional scannning electron microscope (SEM) images of DLC films after etching for 10, 35, 70, and 105 min, respectively. Thickness of DLC films decreased with increasing the etching duration. DLC films were removed completely from Si substrates at the etching duration of 70 and 105 min as shown in Figs. 1(c) and (d), respectively. Nanostructures like fiber were observed on DLC film surface after the etching. It was found that the shape of DLC nanofibers deformed with increasing the etching duration. The length of DLC nanofibers increased with the diameter. The number density of DLC nanofibers decreased.

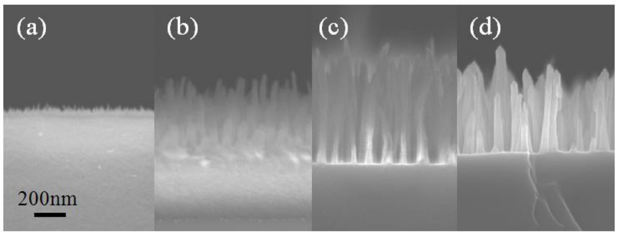

Fig. 1. Cross-sectional SEM images of DLC films after (a) 10 min, (b) 35 min, (c) 70 min, (d) 105 min of O_2 plasma etching at the same magnification.

Figure 2(a) shows a schematic view of the deforming of DLC nanofibers with etching duration and 2(b) shows the thickness of remaining DLC film and length of appeared DLC nanofibers with variation of etching duration. Each dot in Fig. 2(b) shows mean value of measured specimen. The lower and upper bounds shown for each dot in Fig. 2(b) show the minimum and maximum, respectively.

The 3 lines in Fig. 2(b) indicate the etching rates of the DLC on the top of nanofibers and on the flat surface of the remaining film. The remaining DLC layer was constantly etched at about 27 nm/min. The etching rate of the top of nanofibers was 24 nm/min at the beginning. After the formation of longer nanofibers, however, the etching rate of the top of nanofibers decreased to around 5 nm/min. The etching rate of the top of nanofibers was significantly smaller than that of the DLC film remaining under the nanofibers although they were made of the same DLC film.

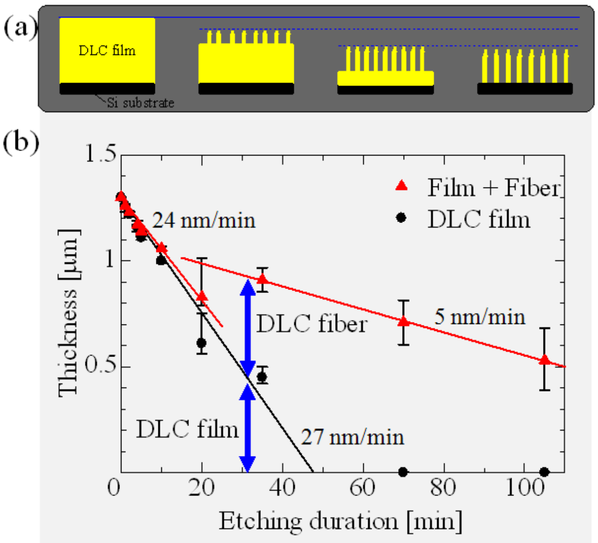

Fig. 2. (a) Schematic view to show the deformation of DLC films during etching and (b) dependence on the etching duration of the original DLC film thickness remaining on Si substrate with the length of appeared DLC nanofibers.

Based on the shape of nanofibers achieved by various of etching durations, Figure 3 indicates possible mechanism for the deformation of DLC nanofibers during O_2 RF plasma etching. DLC nanofibers formed at the beginning will be exposed to ion bombardments from O_2 plasma. While the specimen was negatively charged in total due to the self-bias automatically induced by the RF power, the top of nanofibes will become relatively positive in the specimen due to secondary electron emission. The local charge will modify the surface potential profile and will result in curving of ion's motion from the plasma to the specimen, as shown in Fig. 3. The local charge on the top of nanofibers will prevent the ions from approcaching to the top. The missed ions will attack on the side wall of the nanofibers or will finally fall on the bottom DLC film. Due to the local charge will be enhanced on longer nanofibers, the etching rate of the top of nanofibes will become smaller significantly.

From the fact that the diameter of nanofibers increased with increasing etching duration, it is necessary to consider re-deposition of sputtered carbon, as also shown in Fig. 3. Some of the sputtered carbon atoms will deposit on the side wall of nanofibers and increase the diameter of nanofibers.

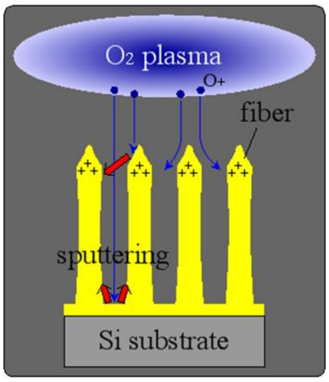

Fig. 3. Schematic representation of the possible mechanism for the deforming of DLC nanofibers during O_2 plasma etching.

4. Summary

Nanofibers were formed on the DLC film surface by O_2 RF plamsa etching. It was found that the etching rate of DLC nanofibers was different from that of DLC film. Due to the smaller etching rate, DLC nanofibers become longer during etching.

It was indicated that the shape of DLC nanofibers were deformed during etching because fine nanostructures formed at beginning influenced ion's motion from plasma.

Acknowledgments

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References

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