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The Effect of Irradiation of Fe and Ar Ion on the Surface Morphology of Diamond Thin Film Related to the Magnetoresistance Property

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Abstract

The irradiation of Fe and Ar ion was applied on the surface of diamond/Si thin film to know its effect on the morphology of thin film. The magnetoresistance property was also studied. Ion irradiation treatment using Fe ion followed by argon ion at the energy of 70keV and a dose of 1×10^{15} ion/cm² have been conducted on the surface of two types of thin film, diamond/Si (111) and diamond/Si (100). Both thin films were made by using a CVD method, and the thickness of the thin film is 1000-nm. From simulations using the software called Stopping and Range of Ions in Matter (SRIM), it is known that Fe and Argon ion penetration into the surface of the thin film are respectively 512 and 603 Angstroms. After that the thin film sample was irradiated with ion Fe and Ar, and the property behavior of the morphological change of thin film were studied through Scanning Electron Microscopy (SEM) and Atomic Force Microscopy (AFM). The grain size range of thin film on diamond films / Si (100) was reduced from 115-322 nm to 147-169 nm, suggesting the effect of irradiation on the surface morphology. The magnetoresistance property is approximately 0.15% at room temperature and magnetic field external $H = 0.8$ Tesla.

Abstrak

Efek Iradiasi ion Fe dan Ar terhadap Morfologi Permukaan dari Lapisan Tipis Diamond terkait dengan Sifat Magnetoresistan. Iradiasi Fe dan Ar telah dilakukan pada permukaan lapisan tipis diamond/Si untuk mengetahui efek iradiasi terhadap morfologi lapisan tipis dan kemudian mempelajari sifat magnetoresistansinya. Proses iradiasi dilakukan memakai ion Fe yang dilanjutkan dengan ion Argon pada energi 70keV dan dosis 1×10^{15} ion/cm² ke permukaan 2 jenis lapisan tipis, yaitu diamond/Si (111) dan diamond/Si (100). Kedua lapisan tipis ini difabrikasi memakai metode CVD dengan ketebalan 1000 nm. Dari simulasi memakai piranti lunak yang dinamakan *Stopping and Range of Ions in Matter* (SRIM), diketahui bahwa penetrasi ion Fe dan Argon ke dalam permukaan lapisan tipis adalah berkisar 512 dan 603 Angstroms. Setelah lapisan tipis diiradiasi dengan ion Fe dan Ar, kemudian dipelajari perubahan morfologi dari lapisan tipis memakai *Scanning Electron Microscopy* (SEM) dan *Atomic Force Microscopy* (AFM). Rentang ukuran butiran lapisan tipis pada diamond/Si (100) mengalami penurunan dari 115-322 nm ke 147-169 nm. Hal ini menunjukkan adanya efek iradiasi ion ke morfologi permukaan. Sifat magnetoresistan pada kisaran 0,15% pada suhu kamar dan di bawah medan magnet $H = 0,8$ Tesla.

Keywords: diamond/Si, grain size, ion irradiation Fe and Ar, magnetoresistance, morphology of thin film

1. Introduction

Irradiation of solids with energetic particles, such as electrons or ions, normally gives rise to the formation of atomic defects in the target and spoils the material properties. Historically, the necessity to understand the irradiation-induced degradation of metal and graphitic components of fission and, later on, fusion reactors was

the initial driving force for studying the effects of irradiation on solids [1-3]. However, in spite of the damage, irradiation may overall have a beneficial effect on the target. A good example is the industrially very important ion implantation onto semiconductors [4]. It has been demonstrated that irradiation, especially when combined with heat treatment, can also have beneficial effects on nanostructured materials.

Experiments carried out on the technologically important carbon nanomaterials, such as diamond, nanotubes and graphene, showed that their atomic structure and morphology can be changed in a controllable manner by irradiation [5-10]. Furthermore, recent experiments indicate that ion irradiation can be used to tailor the magnetic properties of nanostructured carbon materials [11-14].

Carbon is a very interesting material because its properties can range from graphitic to diamond-like depending on its atomic bonding. Graphitic carbon is highly electrically conductive and is relatively soft while diamond is hard and is an excellent insulator. Because the properties of carbon can be controlled over such a wide range depending upon how it is grown, it is a very interesting material for thin-film applications. Diamond films are used as coatings because they are extremely smooth, continuous and chemically inert, with surface roughness well below 1 nm. For the last 30 years, diamond has been deposited by sputtering. The application of diamond to actual devices such as electric or magnetic devices requires it to be made into the form of wafers or thin films. The only procedures at present available to this end are low-pressure synthesis methods such as the Chemical Vapor Deposition (CVD). For magnetic thin films such as diamond thin film, roughness may present a problem. Roughness in one layer may create effects in the crystallinity of the next layer. This can have a negative effect on magnetic properties and resistivity.

In this work, we report the effect of Iron (Fe) and Argon (Ar) ion irradiation on the surface morphology of diamond thin film from the view point of roughness by using Atomic Force Microscope (AFM) and its relation to the magnetic properties including magnetoresistance.

2. Experiment

In this study we used a diamond thin film with the thickness of 1000 nm that was deposited on a Silicon (001) substrate using Chemical Vapor Deposition (CVD) method. Before performing the process of ion irradiation, firstly we needed to know the time required for the irradiation process by a calculation using the equation below:

$$D = Q/eA = It/eA \dots\dots (1)$$

which in this case we used Fe and Argon ion with each optimal current value (I) is 10 μ A and 50 μ A, surface area target of ion implantation (A) is 12.56 cm², and an elementary charge (e) is 1.6023 x 10⁻¹⁹ Coulomb. We determined the dose (D) of 1x10¹⁵ ion/cm², so the ion irradiation time (t) will be = DeA/i = 1x10¹⁵ ion/cm² x 1.6023 x 10⁻¹⁹ Coulomb x 12.56 cm² / 20x10⁻⁶ amperes

(Coulomb/second) = 100.48 sec = 1,674 minutes. For a dose of 1 x 10¹⁶ ions/cm², the irradiation time (t) = 1004.8 sec = 16.746 minutes, and so on. Other types of ion also can be calculated in the same way. The amount of ion energy can be obtained by adjusting the acceleration voltage, which in this case is 20, 50 and 70 keV. For a different energy, the penetration depth and concentration distribution will also be different.

In order to investigate the morphology and texture, and to determine some important structural parameters, scanning electron microscopy (SEM: Hitachi S-4800, Japan) was performed using the microscopy system Zeiss DSM 9500. The surface morphology of diamond thin film before and after ion irradiation was observed using an Atomic Force Microscope (AFM: Seiko Instruments Inc.: SPA-350). The magnetoresistance (MR) was obtained by the four point probe method in plane field, with the maximum field of 15 kOe.

3. Results and discussion

Figure 1 and Figure 2 show the SRIM simulation of ion irradiation using Fe and Argon ion on diamond thin film, in order to know the depth of penetration of ion. From this figure, it can be seen that the Fe and Argon ion penetration into the surface of the diamond thin film are respectively 512 and 603 Angstroms.

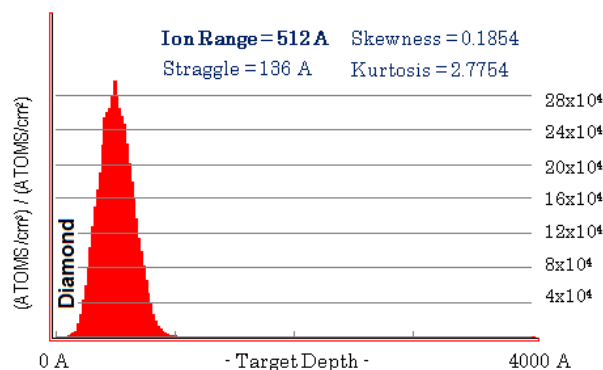


Figure 1. SRIM Simulation Using Fe Ion for Irradiation at E = 70keV on Diamond Thin Film

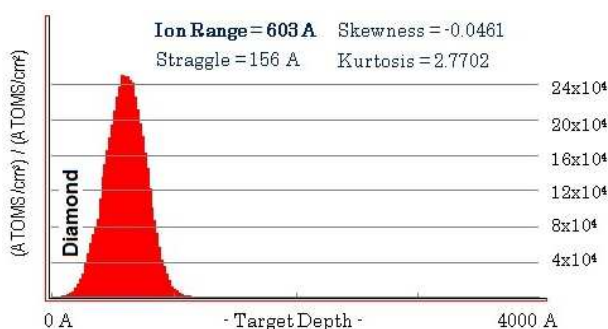


Figure 2. SRIM Simulation Using Argon ion for Irradiation at E = 70keV on Diamond Thin Film

Figure 3 shows scanning electron micrographs (SEM) of CVD diamond films grown on Silicon (100) substrate. Such images, in themselves, do not prove that the films are diamond but monitoring the attendant cathodoluminescence can provide supportive evidence. The coverage of the surface by diamond is above 95%. It indicates that continuous thin films can be obtained from the CVD method. Figure 3 clearly shows the morphologies of triangular faces ($\{111\}$ planes) covering the entire surface. The average grain size was considered to be the mean value of the circle diameter distribution. The film presents grains of approximately 500 nm – 1 μ m in size.

The diamond/Si(100) thin film after ion irradiation showed magnetoresistance properties as shown in Figure 4, with a degree of about 0.2% as applied 70 keV Fe and Ar ion beam irradiation at dose 1×10^{15} ion/cm². This is clearly due to the presence of Fe core granular in the films, which gives rise to magnetic properties, as also reported in the case of Ar ion irradiation to the Fe-Al₂O₃ nano granular films [15].

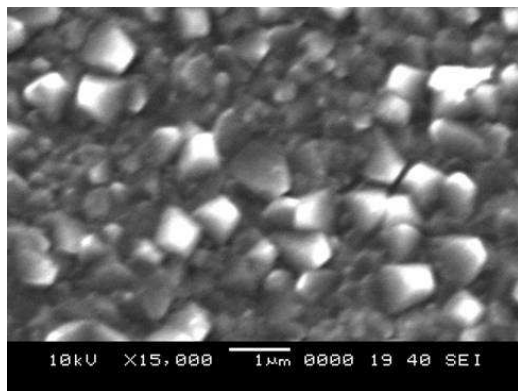


Figure 3. SEM Image of Diamond Thin Film by CVD Method. The Film Morphology Consists Predominantly of $\{111\}$ Facets

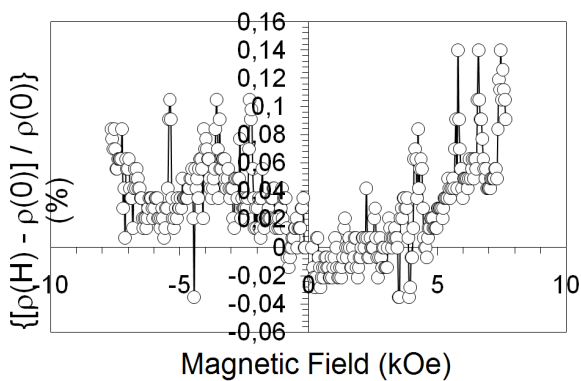
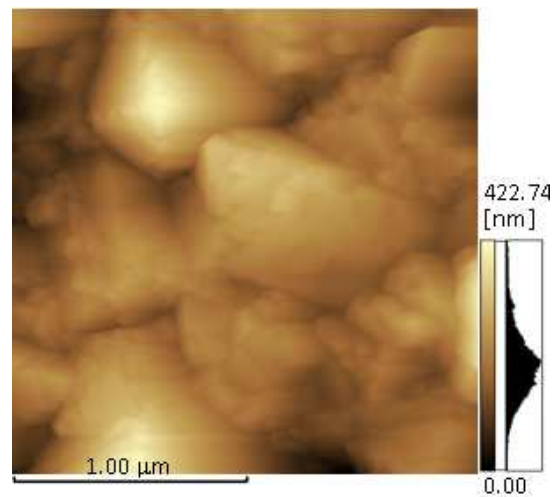
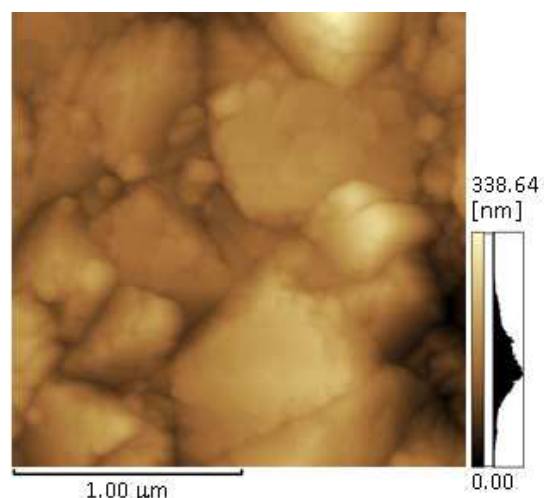


Figure 4. Magnetoresistance Phenomenon in CVD diamond/Si(100) Thin Film after Fe and Argon Ion Irradiation at $E = 70$ keV and a Dose of 1×10^{15} ions/cm².

Figure 5 shows the AFM images of the diamond thin film deposited on a Silicon (100) over the scan area of $2 \times 2 \mu\text{m}^2$ in the case of before (upper image) and after (below image) irradiation by Fe and Argon ion. We can clearly see features with an equilateral triangle shape indicating a possible predominance of the (111) orientation in the structure. These results are consistent with the results shown by SEM observation. As the AFM surface forces are active, the images in the edges and apex of the crystals appear more rounded than those observed by the SEM. The surface of the grains is not very flat but exhibits some corrugations. The upper surface of the triangles is either slightly convex or concave. From these AFM images, it is also clear that the diamond thin film shows continuous island-like structures, and after ion irradiation, these islands become smaller in both lateral and vertical directions (from 115–322 nm to 147–169 nm).



Before irradiation, granular height 115 nm – 322 nm



After irradiation, granular height 147 nm – 169 nm

Figure 5. Magnetoresistance Phenomenon in CVD diamond/Si(100) thin film after Fe and Argon Ion Irradiation at $E = 70$ keV and a Dose of 1×10^{15} ions/cm²

The grain size range decrease in surface roughness with the treatment of ion irradiation indicates that a surface smoothing process is taking place in the surface of the thin films. It can be said that the irradiation induced surface smoothing, which can be explained as follows. Collisions between ions and atoms can enable the atoms hit by the ions to acquire enough kinetic energy to escape from the solid surface of the thin film. However, if the energy of the displaced atoms is smaller than the surface binding energy, the atoms may reach the surface but cannot leave the surface. The atoms only drift parallel to the surface. Surface smoothing happens because of those atoms.

4. Conclusions

This research focused on the effect of Fe and Argon ion irradiation on the surface morphology of CVD diamond thin film using AFM and its magnetoresistance property. Fe and Argon irradiation at energy of 20, 50 and 70 keV were performed with doses of 1×10^{15} and 1×10^{16} ion/cm². The Fe ion irradiation generated the growth of Fe core granular that exhibit the magnetoresistance property of the diamond thin film, which is proved by the GMR result. The continuous thin films with the morphologies of triangular faces ($\{111\}$ planes) was obtained from the CVD method, which covered the entire surface. Fe and Argon ion irradiation reduced the granular height of the surface morphology of the thin film.

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