Microscopic behavior of carbon stripper foils prepared by a mixed ion beam sputtering method under heavy ion beam bombardment

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A mixed ion beam sputtering method has been used for preparing long lifetime stripper foils. The microscopic transformations of these originally amorphous carbon foils under heavy ion beam irradiation are described. The structure changes of the carbon foils, irradiated by 3.2 MeV Ne^+ ion beams, were examined by a 200 keV electron microscope. The larges sizes of grains of the foils were composed of graphite like polycrystallites that had isotropic configurations, with graphite layers nearly perpendicular to the foil surface.

Keywords: Mixed ion beam sputtering; carbon stripper foils; heavy ions beam bombardment; microscopic transformations.

Hemos preparado láminas de carbón de larga vida, para usarse como despojadores en aceleradores, por medio de iones que arrancan el material de una superficie de carbón. Se describen las transformaciones microscópicas de estas láminas de carbón, originalmente amorfo, cuando son irradiadas con un haz de iones pesados. Los cambios estructurales de las láminas de carbón, después de irradiarse con iones de 3.2 MeV, Ne+ se examinaron con un microscopio electrónico de 200 keV. Los granos grandes de la lámina se componían principalmente de grafito al igual que los policristalitos los cuales tenían una configuración isotrópica con capas de grafito casi perpendiculares a la superficie de la lámina.

Descriptores: Erosión de materiales por iones para preparar láminas de carbón; bombardeo con iones pesados; transformaciones microscópicas.

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1. Introduction

Carbon foils are used extensively as electron strippers for ion beams of MeV energies in tandem accelerators, injection linear accelerators, synchrotrons and cyclotrons. A numbers of authors have quantitatively studied the behavior of such foils under bombardment by ions of varying mass and energy [1–5].

Many authors have been investigating micro-structures of carbon foils prepared by thermal evaporation, glow discharge and laser ablation methods [3–5]. The lifetimes of carbon foils of thermal evaporation and glow discharge methods are limited by radiation-induced shrinkage leading to foil rupture. Generally, this shrinkage has been attributed to the rearrangement of the initially disordered structure by radiation enhanced diffusion process. From previous investigations it was suggested that these conventional carbon foils contain a significant proportion of anisotropic bidimensional configuration with graphite layers parallel to the foil surface.

Dollinger et al. have studied the laser ablation method [6]. They have stated that laser ablation produces isotropic carbon structures containing four fold coordination to a large extent, which brings stripper foil lifetime to the physical limit. The foils break when a significant part of the foil has been sputtered away by the energetic ion beam. Lifetime measurement of the laser ablation foils 4 μg/cm^2 thick was reported by [7]. For these measurements, at the Munich Tandem, a 10 MeV $^{127}I^-$ ion beam of 300 nA with 1 mmϕ and 3 mmϕ beam spots were used. The lifetime of 1 mmϕ-beam was 12.2 ± 1.5 μA·min. (6.5 times longer than that of thermal evaporation foils) and the lifetime of the 3 mmϕ-beam was 34 ± 2.0 μA·min. (4 times longer than that of thermal evaporation foils).

Mixed ion beam sputtering has been reported as an effective method for producing long-lived carbon stripper foils [8–10]. Shrinkage of the foil due to irradiation has been almost overcome using mixed gas ions, which has resulted in lifetimes over 100 times longer than those produced by the thermal evaporation method under 3.2 MeV Ne^+ ion beam bombardment [9].

In this work, the irradiation durability of the carbon foils after the bombardment with 3.2 MeV Ne^+ ion beam was studied. Carbon foils were used as electron strippers for ion beams of Mev energies in the irradiation facility of the 4.75 MV Van de Graaff accelerator at Tokyo Institute of Technology [8,9]. Afterwards, the microscopic transformations of these originally amorphous carbon foils were examined by transmission electron microscopy and electron diffraction analysis.

2. Experimental

The focused ion beam sputtering technique was used for producing the carbon foils [8-10]. The production method is capable of rendering foils in the thickness range of 2 – 80 μg/cm^2. Neon and krypton gases were introduced to a duoplasmatron ion source passing through each gas flow meter. The gas mixture used was neon/krypton in the ratio 8/1, using an acceleration voltage of 10 kV. The target material was a block of spectrographically pure graphite (99.999% purity, Poco Co., Ltd. U.S.A.). An aluminum foil (3 cm $\times$ 3 cm, 4 μm in thickness) positioned near the glass slide was weighted before and after deposition, for a thickness measurement, with an electric microbalance (Mettler UM30).

All foils were mounted on 17 mm $\times$ 14 mm stainless steel holders having a hole 10 mm in diameter. Normally, we never use annealing and slackening techniques before irradiation.

Carbon foils were used as electron strippers for ion beams of Mev energies in our Van de Graaff accelerator. After irradiation with 3.2 MeV Ne^+ ion beam our carbon foils prepared by the mixed ion beam sputtering method showed a bright (002) ring and formed random oriented graphitic large grains, shown when examined by a 200 keV transmission electron microscopy and electron diffraction analysis (JEOL, JEM-200CX) at the Research Cooperation Section of the Tokyo Institute of Technology.

The Ne^+ beam spot size was approximately 3.5 mm in diameter. The beam current intensity was maintained and between 3.0 to 5.0 μA ($1.9 \times 10^{18} - 3.2 \times 10^{18}$ Ne^+/m^2s). The vacuum pressure in the chamber was kept at about 1×10^{-4} Pa.

3. Results and discussion

The non-irradiated foils were featureless, having an amorphous surface as shown in Fig.1. Figure 2 shows an electron micrograph and an electron diffraction pattern, observed in an irradiated area of a sputtering carbon foil of 15 μg/cm^2 thickness irradiated for 10 h (7.7×10^{17} incident atoms). The temperature on the carbon foil during irradiation was about 700°C. After irradiation, large crystallites about 0.2 μm in diameter were observed, and the electron diffraction photograph clearly showed a brightest basal plane (002) ring and (100), (110) outer halo rings, evidently due to random oriented graphitisation of the foil.If no (002) rings show up, the foils are anisotropic because no graphite plane is nearly perpendicular to the foil surface. If a sharp (002) ring shows up after irradiation, only the ratio between (002) ring and (100) or (110) ring tells about the anisotropic value of the foil. Figure 3 shows the electron micrograph and electron diffraction patterns observed in the irradiated area of a sputtering carbon foil of 4 μg/cm^2 in thickness irradiated for 3.4 h (2.7×10^{17} incident atoms). In this case, stitch patterned small crystallites were observed. The diffraction photograph exhibited

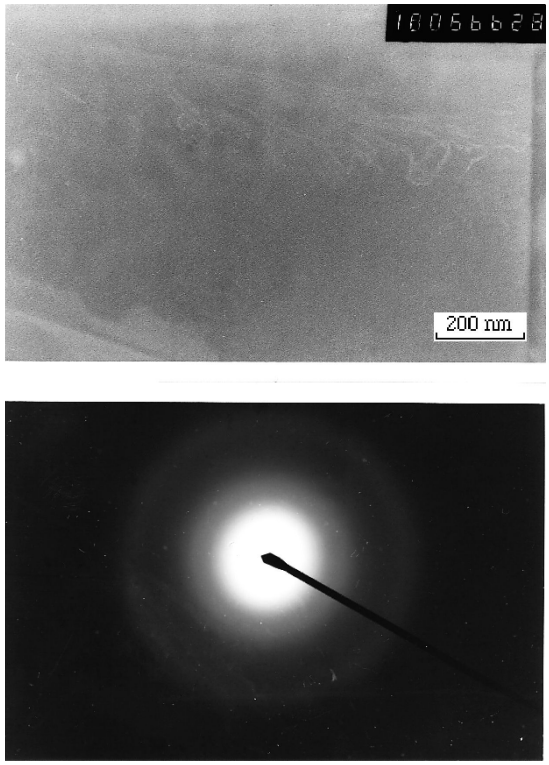

FIGURE 1. Transmission electron micrograph and electron diffraction patterns of non-irradiated sputtering carbon foil 15 μg/cm^2 thick.

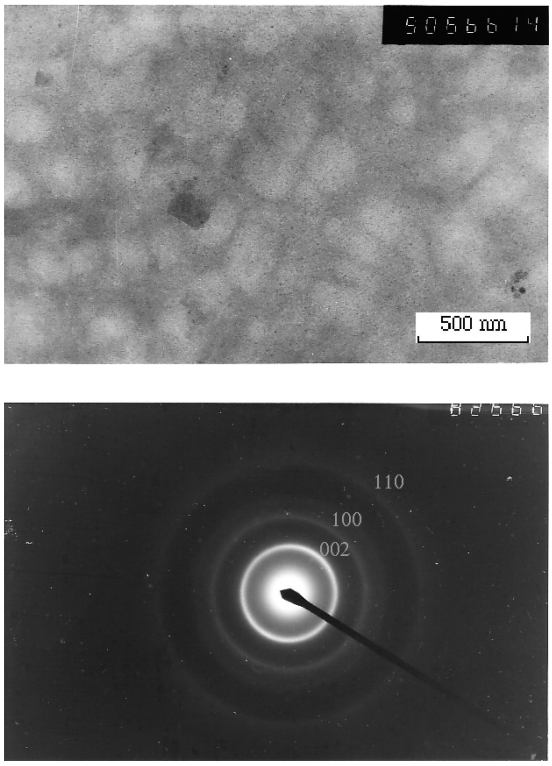

FIGURE 2. Transmission electron micrograph and electron diffraction patterns of sputtering carbon foil 15 μg/cm^2 in thickness after bombardment with a 3.2 MeV, Ne^+ ions (irradiated for 10 hours).

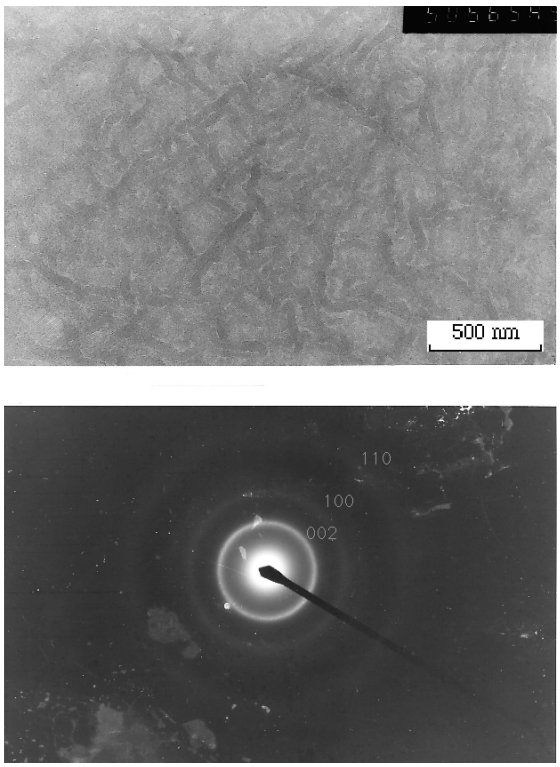

FIGURE 3. Transmission electron micrograph and electron diffraction pattern of 4 μg/cm^2 carbon foil prepared by sputtering method after bombardment with 3.2 MeV, Ne^+ ions (irradiated for 3.4 hours).

central brightest (002) rings even though the foil was considerably thinner and the irradiation time was relatively short. The temperature on the carbon foil was about 350°C. In addition, the mean lifetime of the sputtering carbon foils of 4 μg/cm^{2}in thickness (for 4 measured samples) was $3.2 \pm 0.1 \times 10^{17}$ incident atoms (51.2 ± 4.6 mC, 853.3 ± 76.6 μA·min.), which was 15 times longer than that of thermal evaporation foils.

The main damage presented by our sputtering carbon foils under irradiation was sputtering (thinning) of the beam spot area. The structure of deposited carbon atoms on glass slides during the ion beam sputtering process is amorphous with no structural information, as shown in Fig. 1. For any foil irradiated at high beam currents, a graphitisation takes place due to the high temperature and the atomic transportation induced by irradiation. However, carbon atoms of sputtered foils easily tend to an isotropic orientation, with graphite planes nearly perpendicular to the foil surface during irradiation without much rearrangement of atoms. An irradiated carbon foil of 15 μg/cm^{2}in thickness, prepared by sputtering, presented a large scale of crystals of 0.2 μm. The sputtered carbon particles are thought to have enough energy to manage long range ordering during the preparation process and the texture of the graphite clusters can be arranged nearly perpendicular to the surface, although the foil is mainly amorphous.

4. Conclusions

After irradiation, the electron diffraction photograph of the sputtering carbon foils were always clearly exposed to show central bright (002) rings. The final result of long-lived carbon foils prepared by sputtering was the forming of hexagonal graphite-like configurations ordered in a random oriented graphite layer without a major rearrangement of carbon atoms under high intensity heavy ion beam bombardment.

In a previous study [8] of carbon foils prepared by heavy ion sputtering, we could not understand the reason for the strong durability under heavy ion irradiation. However, from our present study the strong durability under heavy ion bombardment is belived to be due to its long range ordering of carbon particles during deposition that produces clusters arranged nearly perpendicular to the surface of the foil.

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