Surface behavior of thin carbon stripper foils under heavy ion beam bombardment

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Results of lifetimes and surface irradiation behavior of thin ($\sim 5\ \mu g/cm^2$) carbon foils prepared by a mixed ion beam sputtering method are given. The mean lifetime of the foils was 57.6 mC (4.6 h), which was about 15 times longer than that of conventional commercial foils under 3.2 MeV, Ne^+ ion beam bombardment. The thin foil was also durable under carbon build-up condition with normal non-bakable chamber.

Keywords: Stripper foils; heavy ions

Se muestran los resultados de tiempos de vida y comportamiento superficial de películas de carbón preparadas por iones que arrancan el material desde algunas superficies. El tiempo de vida de promedio de las películas es de 57.6 mC (4.6 h), lo cual es 15 veces mayor que el de las películas comerciales convencionales. Las películas son también durables bajo condiciones de creciemiento en condiciones normales de hornear.

Descriptores: Intercambiadores de carga; iones pesados

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1. Introduction

A mixed ion beam sputtering method have been developed for producing super long-lived self-supporting carbon stripper foils [1, 2]. The carbon foils of 15 $\mu g/cm^2$ in thickness made by this method were shown to last about 60 times longer than commercially available foils during a 3.2 MeV Ne^+ ion beam bombardment. For the surface behavior of the carbon foils of sputtering method, it was made clear that the lifetime of the carbon foils had a great dependence upon the thickness. Thickening and thinning behavior of carbon foils under heavy ion bombardment can be understood within the microscopic theory of ion induced alterations in carbon foils [3]. The irradiation damage mainly contains slackening, thickening and shrinkage during irradiation. In our measurements the sputtering process was remarkable and no thickness increase had been observed for the thicker foils. However, the thin foils showed different behavior under heavy ion irradiation in comparison to the thicker foils. The thin carbon foils always showed constant average thickness or slight thickening during irradiaton [2]. The increased energy loss under ion irradiation has often been ascribed to carbon build-up from the result gas. Many authors attributed the observed energy loss variation to foil thickening caused by carbon deposition [4–6]. In this paper the influence of carbon build-up for the lifetime of the thin carbon foils is reported.

2. Carbon foil preparation

Carbon foils produced by the mixed ion beam sputtering method were produced by the well known ion beam sputtering technique [1, 2, 7]. Typical running parameters of the mixed ion beam sputtering method are shown in Ref. 1. The production method is capable of producing in the thickness range of 2–80 $\mu g/cm^2$. Neon and krypton gases were introduced to a duoplasmatron ion source passing through each gas flow meter. Source gas purity was 99.999%. The gas mixture used was neon/krypton in the ratio 8/1 and acceleration voltage was 10 kV. Focusing voltage (einzel) was 1.5 kV and total ion current was 2.0 mA. Target material was Carbon graphite (99.999% purity, Poco Co., USA). Vacuum gauge reading in the preparation chamber was 10^4 Pa.

Carbon foils were deposited on the surface of a glass slide covered with a release agent (Johnson and Sons Co., Ltd. CREME COTE). An aluminum foil (3 cm×3 cm, 4 μm in thickness) positioned near the glass slide was weighted before and after deposition for a thickness measurement. This was done by means of an electric micro-balance (Mettler UM 30). All foils were mounted on 17 mm×14 mm stainless steel holders having a hole of 10 mm diameter.

3. Experimental

For lifetime measurement, we constructed and installed a beam line on the 4.75 MV Van de Graaff accelerator at the Tokyo Institute of Technology as mentioned in previous papers [1, 2]. The pressure in the irradiation chamber was kept about 10^{-4} Pa. All measurements were made using a 3.2 MeV, 3.5 μA Ne^+ ion beam over an area of 9.5 mm^2. Transmitted ion beam was collected in a Faraday cup located downstream from the foil and monitored by a current integrator.

The lifetime of a foil is given as the total charge incident (milli-coulomb) on the foil necessary to cause its rupture as

TABLE I. Lifetimes of the carbon foils of 5 $\mu g/cm^2$ in thickness made by the mixed ion beam sputtering method with those commercially avaliable.

Foils	Number of samples	Lifetimes [mC]
Sputtering method	4	57.6 ± 5.2
Commercial	4	3.7 ± 0.5

indicated by a sudden decrease in the transmitted current to the Faraday cup. At intervals during irradiation, the change in the carbon foil was monitored by detecting scattered neon ions from the irradiated carbon foil by a solid state detector positioned at a laboratory angle of 22.5° [2]. In addition, commercial foils prepared by thermal evaporation (Arizona Co. Ltd.,) of known thickness (5 $\mu g/cm^2$) were used as standards for determining the thickness of the other foils.

4. Results and discussion

Table I shows the lifetimes of the carbon foils of 5 $\mu g/cm^2$ in areal density made by the mixed ion beam sputtering method with those commercially available. The mean lifetime of the sputtering carbon foil was 57.6 mC (3.6×10^{17} incident ions), which was about 15 times longer than that of a conventional commercial foils. During the irradiation shrinkage of the carbon foil of sputtering method was very slow and radial stress lines appeared at the peripheral region of the beam spot in the last phase of the bombardment. The rupture of the foil always took place near the edge of the foil [2].

The thickness increase causing increased multiple scattering was reported by many authors [8–10]. In our vacuum environment, we had different kind of background gases such as hydrocarbons. However, carbon build-up is limited by surface temperature and does not take place at sufficiently high temperature [8]. Figure 1 shows the average thickness as a function of incident ions for the carbon foils prepared by the mixed ion beam sputtering method irradiated by 3.5 μA and 1.2 μA.

In the case of 3.5 μA no thickness increase has been observed during beam irradiation. On the other hand, in the case of 1.2 μA, foil thickening and slight decrease in transmitted intensity was observed. The mean lifetime of the carbon foil with high intensity beam was shown to last 57.6 mC which was about 5 times longer than that of the foil with carbon build-up. The mean lifetime of the low intensity foils was 11.8 mC (2.7 h, 7.4×10^{16} incident ions). In the both high and low intensity beam irradiation number of measured samples was four. In addition, the mean lifetime of the commercial foils with low intensity beam was about 1.5 mC ($\sim$ 20 min, 9.4×10^{15} incident ions). The shrinkage and the total concentration of a commercial foil during irradiation was so great that the additional materials such as hydrocarbons drawn into irradiated area caused greatly increased beam scattering and a reduction in the transmitted beam.

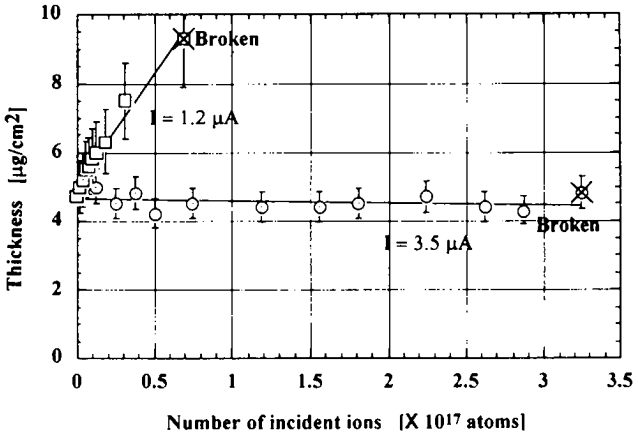

FIGURE 1. Average thickness as a function of incident ions for the carbon foils made by the mixed ion beam sputtering method irradiated by 3.5 μA and 1.2 μA, both of similar thickness (5 $\mu g/cm^2$). In the 1.2 μA (12.5 $\mu A/cm^2$) case a carbon deposition rate of 40 ng/(cm^2min) was determined.

From the experimental observation of the color of the bombarded foils, the temperature of the foil irradiated by 3.5 μA beam at the beam spot was estimated about 400° C. In the case of 1.2 μA, we could not estimate the surface temperature because no color change was observed during irradiation. In the case of 1.2 μA we could not estimate the surface temperature because no color change was observed during irradiation. Therefore, we calculated the surface temperature using the Stefan-Boltzmann law [11]:

$$T = \left[\frac{\phi(dE/\rho dx)\rho d}{2\varepsilon\sigma} + 300^4 K^4\right]^{\frac{1}{4}}, \qquad (1)$$

where $dE/\rho dx$ is the stopping power taken from the tables of Northcliff and Schilling [12], ϕ is the particle current density in units of $cm^{-2}s^{-1}$, ε is the total hemispherical emissivity of the foil, ρd is foil thickness in units of $\mu g/cm^2$ and σ is the Stefan-Boltzmann constant. For our case that the $\phi = 7.8 \times 10^{13}$ $cm^{-2}s^{-1}$, Ne^+, 3.2 MeV ion beam with $\rho d = 5 \mu g/cm^2$ we obtained $T = 546.6$ K (273.5° C). While, in the 3.5 μA case $T = 703.8$ K (430.8° C) was obtained from Eq. (1). Of course, this estimation is only quantitative, so this value must be measured accurately in further developments.

In the terminal of the Tandem Accelerator of the Centro Nuclear de Mexico carbon stripper foils of 5 and 10 $\mu g/cm^2$ in thickness are used. in our daily operation with duoplasmatron ion source or SNICS (Source of Negative Ions by Cesium Sputtering) the vacuum gauge reading of the acceleration tube is $5.0 \times 10^{-4} \sim 10^{-3}$ Pa.

Generally, in order to prevent the hydrocarbon build-up which is bringing out serious multiple scattering, hydrocarbon-free vacuum chambers have been used by several laboratories. However, bakable chamber and the high vacuum systems cost a large amount. From our data annealing of the surface of carbon foils during beam irradiation

may have important role to hold back the hydrocarbon build-up, even though, with normal non-bakable chamber.

5. Conclusions

These results have shown that a great enhancement of the lifetimes of the thin carbon stripper foils prepared by the mixed ion beam sputtering method. Improvements in lifetime of the 5 $\mu g/cm^2$ carbon foils at least a factor of 8 have been achieved by comparing with the conventional commercial foils even with carbon build-up condition.

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