FIRST STEP ANALYSIS OF HYBRID TYPE BORON-DOPED CARBON STRIPPER FOILS FOR RCS OF J-PARC

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Abstract

J-PARC requires thick carbon stripper foils to strip electrons from the H^- beam supplied by the linac before injection into the Rapid Cycling Synchrotron (RCS) [1]. Foil thickness is about 200μ g/cm^2 corresponding to conversion efficiency of 99.7% from the primary H^- beams of 181MeV energy to H^+. For this purpose, we have successfully developed Hybrid type thick Boron-doped Carbon (HBC) stripper foils, which showed a drastic improvement not only the lifetime, but also small thickness reduction, and shrinkage at the irradiated area. In order to know characteristics of the foils, we started to study carbon stripper foils microscopically why carbon foils have considerable endurance for the beam impact by boron-doped. At first step, we made a comparison of ion irradiation effect between normal carbon and HBC by the electric microscope, ion-induced analysis, and so on.

INTRODUCTION

For multi-turn injection of high power proton synchrotron, a charge stripping foil is one of key technology. Typically carbon-based material is used to strip two electrons off the incident H^- beams. Recently high power ring accelerators such as SNS [2] and J-PARC demand much longer lifetime for the stripping foils to reduce beam dead time. J-PARC RCS applied HBC foil developed by Sugai [3]. The foil thickness is about 200μg/cm^2 corresponding to conversion efficiency of 99.7% from the primary H^- beams of 181MeV energy to H^+. The foil size is 40mm$\times$110mm, but the area hit by the beam is about 10mm diameter around the end. At the present time, HBC foil endures our usage of neutron's generation by RCS output beam power of 120kW continuously [4]. We haven't exchanged the first HBC foil by coming to a lifetime yet, that was installed in the beamline after the summer shutdown in 2009. This foil received H^- particles of more than 10^{20} until the present time. However, the final goal of J-PARC RCS is to provide beam output power of 1MW to MLF and MR. We began to study why HBC foil has the much more durability against beam irradiation than a commercial available carbon foil, and how foils are broken by beam damage. In particular, it is important to investigate destruction mechanism by microscopic methods.

In order to reveal the boron-doped effect for a carbon foil made by arc-discharge method against ion beam irradiation, ion accelerators of TIARA(Takasaki Ion Accelerators for Advanced Radiation Application) was used for ion-induced analysis. TIARA belongs in JAEA and have four accelerators, an AVF cyclotron, a 3-MV tandem accelerator, a 3-MV single-ended accelerator and an 400-kV ion implanter [5]. This time we used ion implanter for ion irradiation and 3-MV single ended accelerator for RBS(Rutherford Backscattering Spectrometry) and micro-PIXE(Particle Induced #X-ray Emission). Furthermore, TEM(Transmission Electron Microscope) observation and Raman spectroscopy analyses were tried to compare between normal carbon(NC) and HBC foil before and after ion irradiation.

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SAMPLE PREPARATION

Although typical foil thickness is 200μg/cm^2 for the practical usage, we used foil thickness of 15μg/cm^2 because of ease for these analyses. So we prepared several foils each of NC and HBC foils of about 15μg/cm^2. Ar^+ of 300keV, which we use as irradiated ion from ion implanter in TIARA this time, can deliver the energy deposition by the ion beam into this thickness foil without ion implantation. The ion beam size was about 5mm diameter and much smaller than the target sample foils. Fig. 1 shows details of these prepared foils by a microscope. It is interesting that each surface pattern of the foil is different between NC and HBC. Fig. 2 shows variance of the surface appearances for each of foils irradiated by Ar^+. It seems that surface of HBC flattened out much slower than NC by the irradiation, and HBC was not broken after smoothed out. Although the temperature while irradiating of Ar^+ ion wasn't measured, the visual light from the foil by the energy deposition wasn't observed. So we guess that the foil surface temperature was lower than several hundred degrees C.

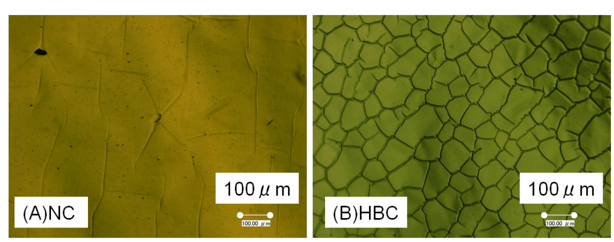

Figure 1: Prepared sample foils :(A)NC,(B)HBC

ANALYSIS RESULTS

NC and HBC foils, as known in the previous section, were analyzed the major atomic composition with RBS. It is possible to obtain the boron to carbon ratio and the foil thickness information. The probe beam was H^+ of 3MeV

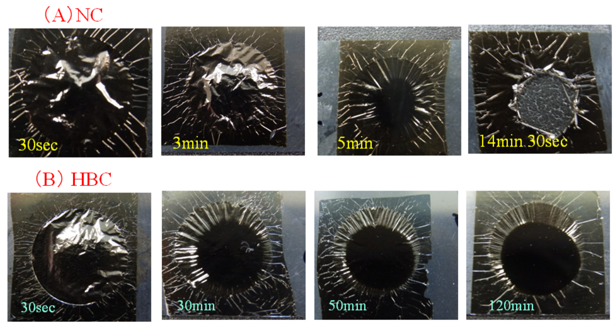

Figure 2: Sample foils irradiated by Ar^+ of 300keV :(A)NC,(B)HBC

from 3-MV single ended accelerator, in which the size was 1mm diameter and the current was about 15 nA on the foil surface. Fig. 3 shows results of RBS for each of NC and HBC. This HBC was made by arc-discharge method, in which the cathode used a boron-doped (25%) carbon rod while the opposite electrode was a pure graphite rod. The conflict of boron-dope ratio between the boron-doped carbon rod and the RBS result and the existence of oxygen requires further study.

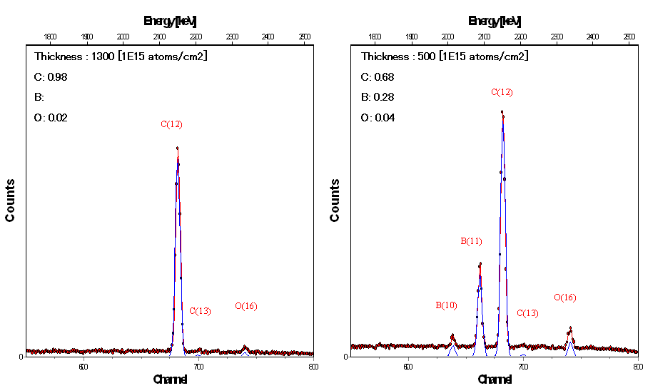

Figure 3: Rutherford Backscattering Spectrometry results for (left)NC and (right)HBC

The presence of impurities such as heavy elements in the stripper foils has significant problem for the uncontrollable beam loss. It is crucial to evaluate the ratio of impurities. We tried to measure impurities of these foils with a micro-PIXE using 3-MV single ended accelerator. The micro-PIXE can provide an atomic composition mapping 100μm square area by using the probe beam of H^+ of 1.7MeV of 1μm diameter. Fig. 4 shows a result of the micro-PIXE for the HBC foil of about 200μg/cm^2. This picture revealed that this HBC foil involved a little impurities of heavy elements such as Na,Al,Fe and so on. In the future, we have to inspect the source of the impurities around the fabrication process.

We have great interest how the irradiated area of the foil changes microscopically. We could get some remarkable informations for NC and HBC before and after ion irradiation with TEM(JOEL JEM-2100F:200keV) and Raman spectroscopy.

- Both NC and HBC had generally amorphous phase, but they involved a lot of micro grains of graphite before irradiation of ions.
- Both were become disorderly by the ion irradiation because of D-band's growth in the Raman spectrum.
- Some large carbon onion were discovered in NC after irradiation.
- There were many boron-rich micro grains in HBC before and after ion irradiation. In particular,it seems that grain size of boron-rich area became much larger by irradiation. These boron-rich grains were covered with graphite structure(Fig. 5).

SUMMARY

We started to investigate the HBC foil as a charge stripper foil with long lifetime. At first step, some results with microscopic analysis methods, such as RBS, micro-PIXE, TEM, Raman spectroscopy and so on, were demonstrated for NC and HBC foils before and after Ar^+ ion irradiation. This time we could obtain effective microscopic techniques adapted to analyze charge stripper foils, and got some remarkable results for transition by ion beam irradiation. We are sure of standing on the first step to reveal destruction mechanism of foils, and to develop charge stripper foils with much longer lifetime.

ACKNOWLEDGMENTS

The authors thank Dr.T.Taguchi in JAEA-Tokai for TEM observation, Dr.S.Yamamoto and Dr.T.Sato in JAEA-TIARA for ion-induced analysis(Ion irradiation, RBS, micro-PIXE), Dr.S.Sakai in JAEA-Tokai for Raman spectroscopy.

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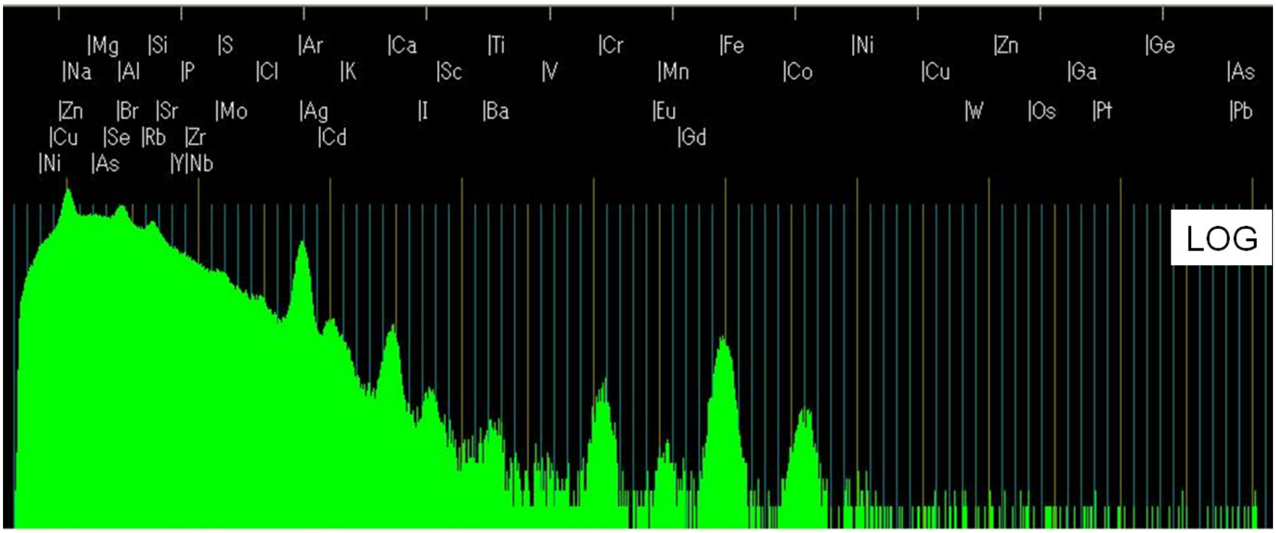

Figure 4: Micro-PIXE results for HBC of 200μg/cm^2

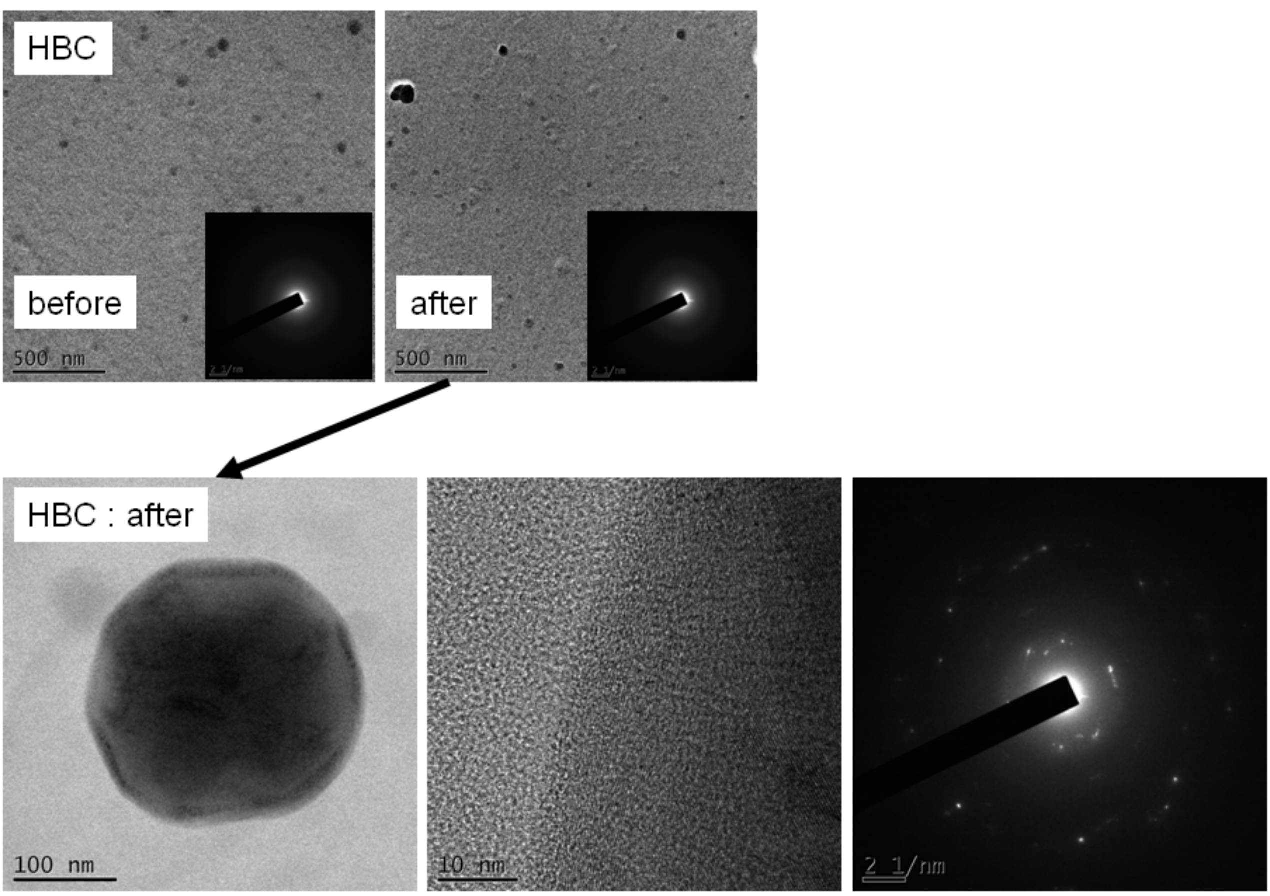

Figure 5: Details of the carbon foil shown in a transmission electron microscope HBC before (left) and after (right) irradiation.