Analysis of Plasma Material Surfaces by Means of Low Energy NRA

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Abstract

Precise investigation for the depth-profiles of the main-isotope on the plasma facing material (PFM) surface is necessary to clarify the mechanism for the fusion fuel recycling in the D-T fusion reactor. For the determination, nuclear reaction analysis (NRA) is valuable to obtain these concentrations and depth-profiles. We have carried out the depth profile analysis of the depth profile of the deuterium, tritium and lithium-isotope on the surface of the JT-60 and TFTR carbon fiber composites (CFC) tile by means of NRA with the JAERI fusion neutronics source (FNS) accelerator. In this paper, we describe the present status of the NRA activity in the JAERI/FNS and especially report the preliminary results of the deuterium and tritium depth profiles for the TFTR tiles.

MEASUREMENT

The measurement has been carried out using the deuteron accelerator of Fusion Neutron Source in Japan Atomic Energy Research Institute (JAERI/FNS) [1]. Figure 1 shows the schematic view of the experimental set-up for NRA. The probe beam is a deuteron beam and its energy and current density are adjusted between 250 and 350 keV and 0.1~ 1μA/cm^2 respectively. In case of carbon samples, the detectable depth is about 1.5 μm by 350-keV deuteron. The beam spot is collimated ϕ 6.5 mm in diameter by an aperture at the upper stream of the beam. The number of incident charges is directly measured from the samples with a positive bias supply (about 150 V). A silicon solid state detector (SDD), with a deposition layer thickness of 200 μm, was used to count high energetic charged particles emitted from the samples. The solid angle for the detection was 1.1 x 10^{-2} sr. The effective area of the detector was covered with a 6-μm thick aluminum foil to suppress scattered deuterons. The incident angle and the detected angle were 45 and 90 deg respectively. The energy resolution was checked with an α-particle emitter (Am-241:E_α = 5.486 MeV) and the *FWHM* was below 40 keV.

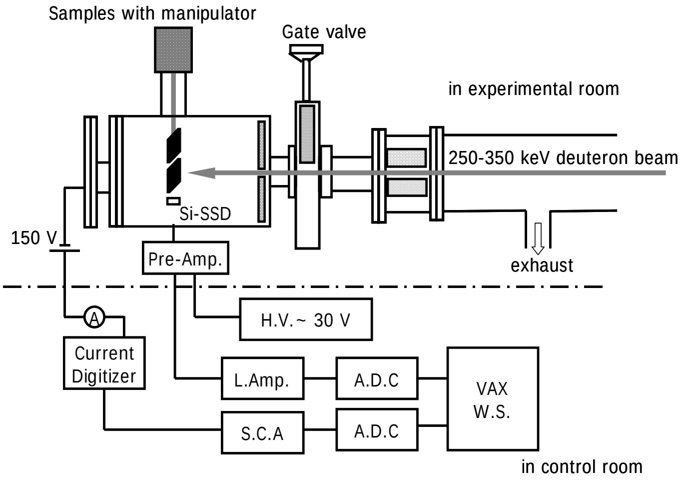

Fig.1 The NRA experimental set-up in JAERI/FNS

SAMPLES

We have used the two plasma irradiated tiles as the sample. One is the JT-60 divertor CFC tile exposed with the D-D plasma and another is the TFTR CFC limiter tile exposed with D-T plasma [2]. Figure 2 shows the used TFTR CFC sample and the location in the TFTR. The sample was a corner peace (about 20 x 15 x 10 mm^3) of a CFC block named KC-16. The KC-16 block was located near the center of the TFTR inner wall in the bay-K area and the role was mainly the limiter of the plasma. The CFC tile was used in the TFTR DT plasma campaign between November 12,1999 and December 9, 1999. In the D-T plasma operation, the lithium pellet injection has been used to After the D-T plasma operation, deuterium and/or helium glow discharge cleaning and air ventilation, baking at 150 °C

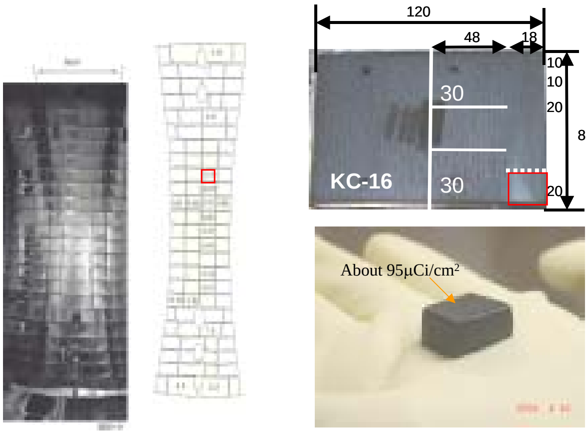

Fig.2 TFTR CFC tile sample and its location

ANALYSIS

D(d,p)T and T(d,αn) are used to measure the deuterium and tritium in the samples. The cross section data of D(d,p)T and T(d,αn) were used the several references housed fusion reactions data Fusion Evaluated Nuclear Data Library (FENDL-2) [3]. From the number of the yield of each spectrum, retentions and depth-profiles can be estimated by the following equations (1)~(3).

$$E_2 = k_{(E,\theta_{out})} \times \left\{ E_0 - \left(\frac{dE}{dx}\right)_1 \frac{x_1}{\sin\theta_{in}} \right\} - \left\{ E_1 - \left(\frac{dE}{dx}\right)_2 \frac{x_1}{\sin(\theta_{out}-\theta_{in})} \right\} - \left(\frac{dE}{dx}\right)_3 \Delta x_2 \qquad (1)$$

$$N_{(x)} = \frac{\int_E^{E+\Delta E} Y dE}{\int_x^{x+\Delta x} \left(\frac{dE}{dx}\right)_1^{-1} dx \cdot \left\langle \frac{d\sigma}{d\Omega} \right\rangle \Delta\Omega \frac{\phi}{\sin\theta_{in}}} \qquad (2)$$

where E_0, E_1 and E_2 = incident deuteron energy, emission-particle energy by nuclear reaction at a depth point x_1 and detection energy, $(dE/dx)_1$, $(dE/dx)_2$ and $(dE/dx)_3$ = stopping powers for each charged-particles in the samples and in the Al (6 μm) screening foil, $k_{(E,\theta\text{out})}$ = kinematics factor taking into account Q-values, x_1 and Δx_2 = depth point from the sample surface and unit depth in the sample taken into account the detector resolution, θ_{in} and θ_{out} = incident angle and detection angle, $N_{(x)}$ = areal density, $d\sigma/d\Omega$ = differential cross sections, $\Delta\Omega$ = solid angle (sr) and ϕ = the number of incident deuterons.

The cross sections of D(d,p) and ^{12}C(d,p) reactions can be described by the following equation

$$\sigma(E) = \frac{S(E)}{E}\exp\left(-31.29Z_1Z_2\left(\frac{\mu}{E}\right)^{-\frac{1}{2}}\right) \qquad (3)$$

where $S_{(E)}$ = astrophysical S-factor in MeV barn, E = incident energy in MeV, Z_1 and Z_2 = atomic numbers of incident and target particles and μ = reduced mass. Since cross the section of T(d,n) has a giant resonance at E_d = 110 keV, we used the experimental cross section value [2].

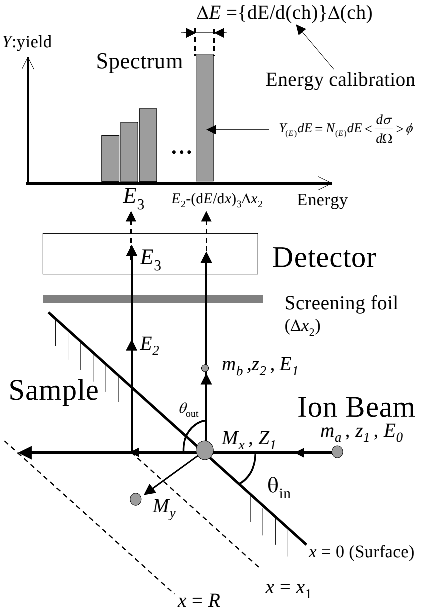

Fig.3 Schematic view for the NRA

RESULTS AND DISCUSSION

Figure 4 shows the energy spectra of the detected charged particles from the TFTR tile sample on 300- and 150-keV deuteron implantations respectively. The Peak at the 10.2MeV is α particles with ^{6}Li(d,2α) (Q = 22.37MeV) reaction and the continuous spectra below 7.5 MeV consists of α particles with ^{6}Li(d, 2αn) (Q = 15.12). The 4.5-MeV and 4.1-MeV peaks are the proton ^{6}Li(d,p$_0$)^{7}Li (Q = 5.03 MeV) and ^{6}Li(d,p$_1$)^{7}Li* (Q = 4.55 MeV) respectively [4]. 2.9-MeV and 0.6-MeV peaks are proton and the triton spectrum from the D(d,pt) (Q = 4.03MeV) and the broad spectrum between 1.2 MeV and 2.5 is α particle with T(d,αn) (Q = 17.59 MeV).

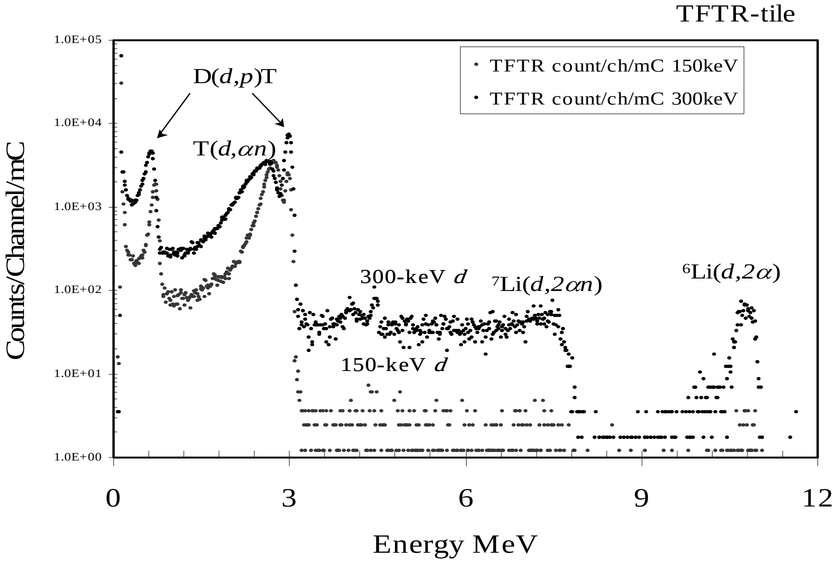

Fig.4 The energy spectra of the detected charged particles from the TFTR tile sample on 300- and 150-keV deuteron implantations

Preliminary, we have obtained the deuterium and tritium depth profile on the JT-60 and TFTR tile surfaces. Figure 5 and 6 show the deuterium and tritium depth profiles for the TFTR tile respectively. From the result of deuterium depth profile analysis, it was founds that the deuterium depth profile of the TFTR tile be uniformly distributed from the surface to 1.4-μm depth and its averaged density value was about 3.8 x 10^{21} deutrium/cm^3. The averaged value was corresponded with about 3% for the typical graphite density. Also it was found that tritium depth profile tend to have the peak of density near 0.5-μm depth and its value. We have to think more in depth about the reason of the tendency of the tritium depth profile as the future works.

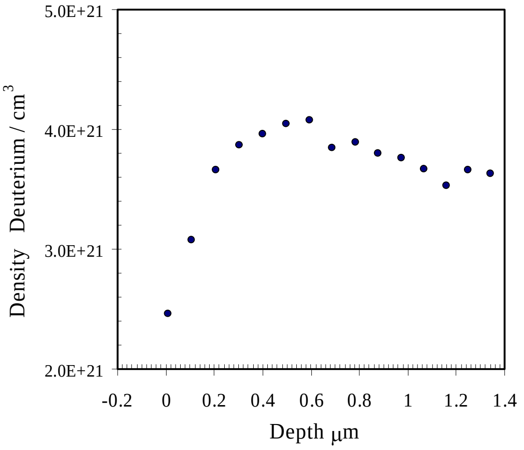

Fig.5 Deuterium depth profile on the surface, the averaged density value is 3.8 x 10^{21} cm^{-2}

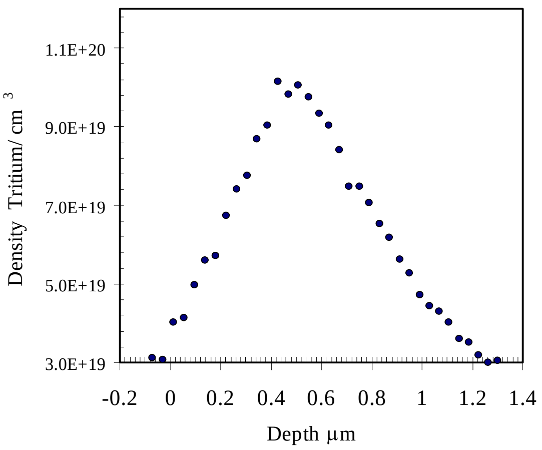

Fig.6 Tritium distribution on the surface, Activity=12.9 MBq/cm^2 Density peak 1 x $10^{20}cm^{-3}$ at near 0.5 μm depth

Reference

[1] *K. Ochiai et al. Journal of Nuclear Materials, Vol. 329-333, Part 1, 2004, p. 836-839.*

[2] *D.K. Owens et al. Journal of Nuclear Materials, Vol. 220-222, (1995) p.62-72.*

[3] For example, National Nuclear Data Center website “*http://www.nndc.bnl.gov/databases/*”.

[4] *Y. Isobe et al Nucl. Instruments and Methods B Vol. 170, 2000, p.171-179.*