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Suppression of Deuterium Absorption in Deuterated Carbon Film by Nitrogen Addition

窒素添加による重水素化炭素膜中の重水素吸蔵抑制

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Issues which control of tritium retention and its removal from the first wall are very crucial for safety and effective use of the fuel in future fusion devices. Nitrogen addition into edge plasmas has been considered and tested as an effective method for the suppression of hydrogen isotope absorption in the deposited films. In this paper the scavenger effect of injected nitrogen into D_2/C_6D_6 plasmas on deuterated carbon film growth has been investigated. It is shown that the key reactive particles with CN and ND bonds to suppress the carbon film growth and hydrogen isotope absorption are much slowly generated.

1. Introduction

Carbon materials have been used as the first wall of nuclear fusion experimental devices so far, but tungsten will be used for ITER diverter materials[1, 2]. Being eroded carbon materials significantly by hydrogen plasma irradiation are generated hydrogenated carbon films. The hydrocarbon particles generated by chemical sputtering of carbon wall containing tritium are transported into scrape off layer (SOL) plasmas and form tritium-containing co-deposits in the cold remote area away from the main interaction area in the diverter plasmas [3]. This has become a problem in safety. Therefore, the control of tritium inventory and suppression of hydrogenated carbon films deposition are very important that carbon materials are considered as the first wall materials in the fusion reactor.

Nitrogen addition into hydrogen plasmas has been examined as effective methods for suppression of hydrogenated carbon films deposition growth [4,5]. Previous experiments shows that $H_2/CH_4/N_2$ plasmas irradiation to silicon targets, that only a few percent of nitrogen addition (N_2/H_2~2%) into H_2/CH_4 plasmas led to significant suppression of deposition of carbon films thickness and number of carbon dust on silicon targets in $H_2/CH_4/N_2$ plasmas [6]. In the experiments using nitrogen as a carbon-radical scavenger, the deposition rate was drastically suppressed by nitrogen addition. It is considered that HCN formation plays an important role to bring a suppression effect [7,8].

In this paper, we have investigated effects of nitrogen addition into D_2/C_6D_6 mixture plasmas on the formation of carbon film and particles using a small helical device Heliotron-DR, which can generate low density and low temperature, and pure D_2 plasmas in steady state condition. These experimental conditions are suited to study the suppression mechanisms of carbon film deposition and the influence of the tritium retention in the carbon film by nitrogen addition in the edge plasmas.

2. Experimental setup

Steady state and low temperature rf plasmas with D-C-N reactive species were generated in Heliotron-DR device [6] with C_6D_6 and N_2 addition into deuterium plasmas. RF power of about P_{rf} ~3.0 kW was launched into plasma using three rf antennas. Gas flow rate of D_2 gas and N_2 gas were 20 sccm and 2 sccm, respectively. In addition, number of deuterated benzene was 3.95×10^{19} [/min]. The operating gas pressure was 0.5-0.8 Pa. Discharge time for deuterated carbon film deposition was 4 hours. The purpose of the experiment is to investigate that the suppression effect of carbon film deposition and the influence of the tritium retention in the carbon film by nitrogen addition and the reaction of the carbon related molecules and dust. Quadruple mass spectrometer (QMS) and optical emission spectroscopy (OES) were used to observe the reactive species generated in D-C-N reactive plasmas. The electron temperature and electron density measured by a triple Langmuir probe were 5-15 eV and $(0.5\text{-}2.4)\times10^{16}$ m^{-3}, respectively. The chamber wall was heated up by a ribbon heater system wound around the outer vacuum vessel. The average temperature of the chamber rose to ~320-345 K.

3. Experimental results and discussion

Figure 1 shows partial pressure of hydrogen isotope generated in $D_2/C_6D_6/N_2$ plasmas. In D_2/C_6D_6 plasmas, partial pressure of D, HD and D_2 decreased compared to those without C_6D_6 addition. In $D_2/C_6D_6/N_2$ plasmas, partial pressure of D, HD increased compared to those without nitrogen addition. It is considered that hydrogen isotope formed a carbon film as deuterated carbon when C_6D_6 added. In addition HD and deuterium atom released from deuterated carbon film when nitrogen added.

Figure 2 shows partial pressure and optical emission intensity of CN generated in $D_2/C_6D_6/N_2$ plasmas. The molecular band spectra of CN radicals were clearly observed strongly in $D_2/C_6D_6/N_2$ plasmas. When nitrogen gas was added, partial pressure of volatile molecules with nitrogen like CN and DCN shows significant increase of volatile nitrogen molecules. Nitride particles such as CN, ND_x show two step increase when nitrogen is added to D_2/C_6D_6 plasmas. First characteristic rise time is short (τ~4 min) and, second characteristic rise time is very long (τ~15 min).

Figure 3 shows chemical reactions in the present experiments. When nitrogen added, porous structures were generated double or triple termination of carbon by nitrogen in the film. Carbon and grow with nitrogen diffusion deeply into the deuterated carbon film. HCN and CN were released from the film through porous structures. Generation of CN and DCN molecules suggests that diffusive penetration and accumulation of the key radical particles, atomic nitrogen, in the deuterated carbon films and a new chemical equilibrium state for CN and DCN formation in the films may have important roles in the suppression of carbon film growth and removal of hydrogen isotope from the carbon films.

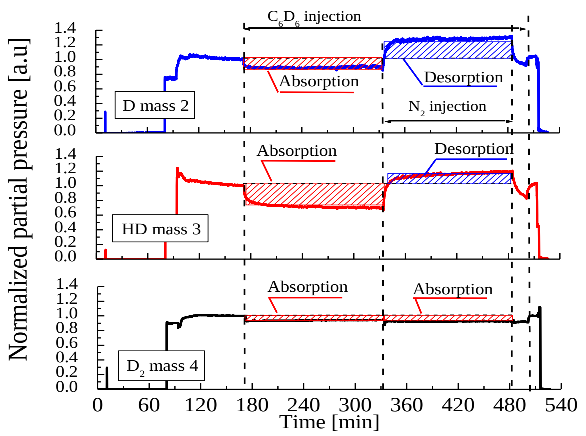

Fig. 1 Partial pressure of hydrogen isotope generated in $D_2/C_6D_6/N_2$ plasmas.

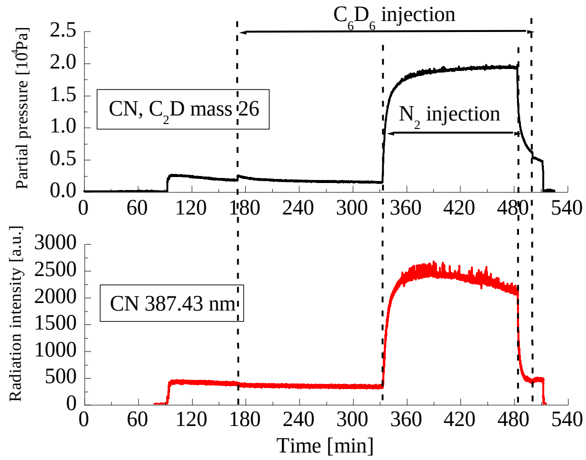

Fig.2 Partial pressure and optical emission intensity of dominant particles in $D_2/C_6D_6/N_2$ plasmas.

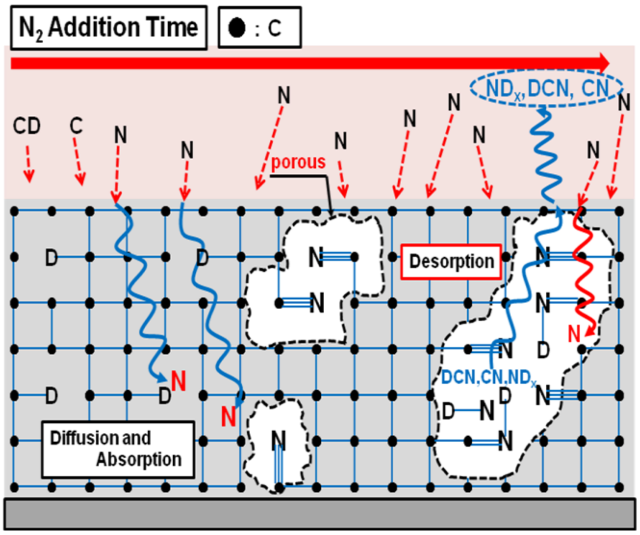

Fig.3 Chemical reactions in the present experiments.

4. References

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