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Deuterium retention of low activation ferritic steel and boronized wall in JFT-2M

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Abstract

Deuterium retention and erosion of F82H exposed to JFT-2M plasmas and the effect of boronization on the deuterium retention were examined based on material probe analysis. The amount of retained deuterium almost saturated after 300 main discharges of deuterium. The retention of helium was clearly observed after helium

glow discharge. The desorption temperature was approximately 600 K. While no significant change in the surface atomic composition was observed after the exposure of main discharges, the mixture layer of carbon, iron and oxygen was observed after the helium glow discharge due to surface erosion and redeposition of eroded particles. After the boronization using trimethylboron, both carbon and boron deposited at the surface. The atomic ratio of B to C was 1/3. The amount of retained deuterium significantly increased, three times larger than that before the boronization, owing to that a large amount of deuterium is trapped in the carbon content.

Keywords: JFT-2M, material probe, ferritic steel, deuterium retention, boronization

1. Introduction

Low activation ferritic steel, F82H (8Cr-2W), is a leading candidate for structure material of a fusion demonstration reactor [1]. In JFT-2M tokamak, Advanced Material Tokamak Experiment (AMTEX) has been performed in order to test the compatibility of the low activation ferritic steel with plasma and study the plasma-surface interaction related to the ferritic steel [2, 3]. Boronization has been performed in order to reduce the impurity influx and to minimize the radiation loss power [4, 5] in addition to the helium discharge cleaning. It is important to investigate the plasma-surface interactions such as deuterium retention and erosion of the ferritic steel during main discharges and/or the helium glow discharge cleanings. The effect of boronization on the plasma surface interaction also has to be clarified.

In the present study, the deuterium retention and the erosion of F82H exposed to JFT-2M plasmas and the effect of boronization on the deuterium retention were examined based on material probe analysis.

2. Experiment

The F82H sample probes mechanically polished were placed on the sample station, which was located the radial position almost same as the ferritic steel plates (approximately 3 cm behind the plates and 50 mm behind graphite guard limiters) in the JFT-2M tokamak, as shown in fig.1. Here, this photograph shows different part of actual position of the sample station. Four kinds of the F82H samples were prepared. Sample A was exposed to approximately 300 deuterium main discharges (Jun.-Jul., 2002). Sample A was also exposed to the helium glow discharge for ~1 h. Sample B was exposed to only helium glow discharges for 6 h. In the helium glow discharge, the

discharge voltage was 320 V, the helium pressure 0.3 Pa, and the discharge current 2 A. Sample C was exposed to approximately 350 deuterium main discharges (Jan.-Mar., 2003) after the boronization. Sample D was exposed to the helium glow discharges in addition to the main discharges after the boronization. The condition of the helium glow discharges after the boronization was similar to that before the boronization. The boronization was conducted using glow discharge with a mixture gas, 1% B(CH₃)₃ (trimethylboron) + He. In every case, the sample temperature was nearly room temperature. The deuterium retention of these samples after the plasma exposure was investigated by using thermal desorption spectroscopy, TDS. The details of the TDS apparatus were described before [6]. The sample was heated from room temperature to 1073K with a ramp rate of 0.5K/s. The desorption rate of deuterium was quantitatively measured using a quadrupole mass spectrometer, QMS [7]. The retained amount of deuterium was obtained by integrating the desorption rates of gases containing D over the heating time. The depth profile of atomic composition was also examined by ex-situ Auger electron spectroscopy, AES, with argon ion etching, in order to investigate the erosion and the deposition due to the plasma irradiation.

3. Results

3.1 Surface modification by erosion and deposition

Figures 2 show depth profiles of atomic composition for Sample A, (a), Sample B, (b), Sample C, (c), and Sample D, (d). Before the plasma exposure, the F82H sample had the oxide layer with thickness of ~10 nm and contamination of carbon at the top surface. After the exposure to the deuterium main discharge (fig.2(a)), no significant change in profile of atomic composition was observed, compared with that before the

exposure. This result indicates that the erosion and redeposition hardly occurred at the region around the sample station during the main discharge. After the helium glow discharges (fig.2(b)), the mixture layer of carbon, iron and oxygen with the thickness of 10 nm was observed at the surface. The mixture layer might have been formed by the surface sputtering, and the depositions of carbon eroded at the divertor and the limiter made by graphite, and iron eroded at the ferritic steel wall. The mixture layer at the surface owing to helium glow discharge has been observed in other fusion devices [8, 9]. After the boronization followed by the exposure to the deuterium main discharges (fig.2(c)), the boronized layer with a thickness of ~40 nm was observed at the surface. The thickness of boronized layer was comparable with that before the exposure of the main discharges (50-60 nm). No significant erosion of the boronized layer was observed due to the exposure of the main discharges. The atomic ratio of boron to carbon, B/C, was approximately 1/3, which was similar to that of the boron film prepared by helium discharge using trimethylboron in RFX [10]. After the boronization followed by the exposure to the deuterium main discharges and the helium glow discharges (fig.2(d)), the thickness of boronized layer after the exposure of the helium glow discharges was approximately 30 nm, which was slightly thinner than that before the exposure. These results suggest that little erosion of boron film due to helium glow discharge occurs.

3.2 Deuterium retention

Figures 3 show thermal desorption spectra of gases containing deuterium atom and helium (He) desorbed from Sample A, (a), Sample B, (b), Sample C, (c), and Sample D, (d). The deuterium retained in the sample was desorbed in forms of D₂, HD, water and

hydrocarbon during the TDS measurement. After the exposure to the deuterium main discharge (fig.3(a)), desorptions of D_2 including with He ($m/e=4$) had two peaks around at 600K and 900K. He desorption of the F82H sample exposed to only the helium glow discharges (fig.3(b)) had peaks around 600K. HD desorption behavior for Sample A and He desorption behavior for Sample B suggest that the peak of $m/e=4$ around at 600K of Sample A is due to He desorption. In the signals of $m/e=20$ and 19, the contribution of hydrocarbon such as CD_4 is included. However, the behavior of these signals was very similar to that of H_2O , so that the contribution of hydrocarbon in these signals may be small.

After the boronization followed by the exposure to the deuterium main discharges (fig.3(c)), the large desorptions of HD and D_2 above 800 K were observed, compared to the case before the boronization (fig.3 (a)). The thermal desorption behavior of the signal of $m/e=20$ and 19 was very similar to that of CH_4 . The contribution of hydrocarbon such as CD_4 to these signal might have been large, compared with the case of the before the boronization. After the boronization followed by the exposure to the deuterium main discharges and the helium glow discharges (fig.3(d)), the desorptions at the low temperature region (~ 700 K) decreased and the desorptions at the high temperature region increased, compared with the case without the helium glow discharges (fig.3(c)).

Figure 4 shows the amounts of retained deuterium in the F82H samples. The amount of retained deuterium in the sample exposed to the main discharges was comparable with that exposed to the deuterium ions (1.7 keV) with high fluence in the ion irradiation apparatus [11]. This result indicates that the amount of retained deuterium in the sample exposed to main discharges almost saturated. The amount of

retained deuterium after the boronization was approximately three times larger than that before the boronization. This is owing to that the deuterium is well trapped in both carbon [11, 12] and boron [13], compared with the steel. The amount of retained deuterium after the boronization followed by the deuterium main discharge and the helium glow discharges was almost similar to that before the glow discharges. This is owing to that the deuterium in carbon is hardly removed [12].

4. Conclusion

Deuterium retention and erosion of F82H exposed to deuterium main discharge and/or helium glow discharge in JFT-2M and the effect of boronization on the deuterium retention were investigated based on material probe analysis. While no significant change in the depth profile of atomic composition was observed after the exposure of deuterium main discharges, the mixture layer of carbon, iron and oxygen was observed after the helium glow discharges due to the surface erosion and redeposition of eroded particles. The boronized layer (thickness: ~40 nm) with a large content of carbon was formed by the boronization. Significant change in atomic composition of the boronized layer was not observed by the exposure of the deuterium main discharges. The deuterium retained in the sample was desorbed in forms of D_2 , HD, water and hydrocarbon during the TDS measurement. Amount of desorbed hydrocarbon increased after the boronization. The amount of retained deuterium after the boronization was approximately three times larger than that before the boronization, owing to a large amount retained in carbon. The amount of retained deuterium after the boronization followed by the deuterium main discharges and the helium glow discharges was almost similar to that before the glow discharges.

5. Acknowledgement

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Figure Captions

Figure 1 Poloidal location of sample station. Actually, sample station was located at different port from this port.

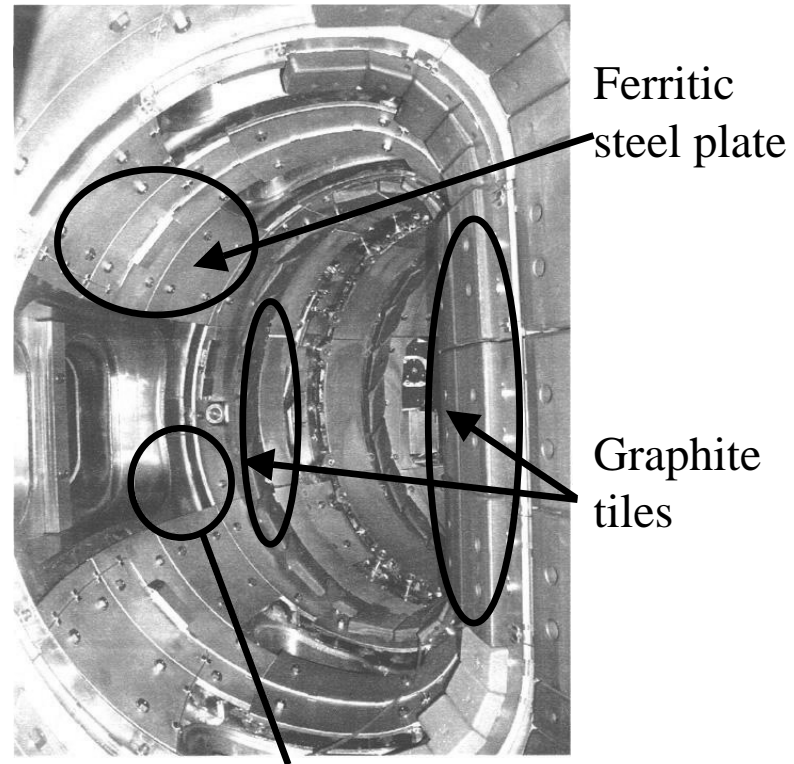
Figure 2 Depth profiles of atomic composition for F82H sample.

- (a) After exposure to deuterium main discharges
- (b) After exposure to helium glow discharges
- (c) After boronization followed by exposure to deuterium main discharges
- (d) After boronization followed by exposure to deuterium main discharges and helium glow discharge

Figure 3 Thermal desorption spectra of gases containing deuterium atom and helium desorbed from the F82H samples.

- (a) After exposure to deuterium main discharges
- (b) After exposure to helium glow discharges
- (c) After boronization followed by exposure to deuterium main discharges
- (d) After boronization followed by exposure to deuterium main discharges and helium glow discharge

Figure 4 Amounts of retained deuterium for the F82H samples after plasma exposures.



Location of sample station

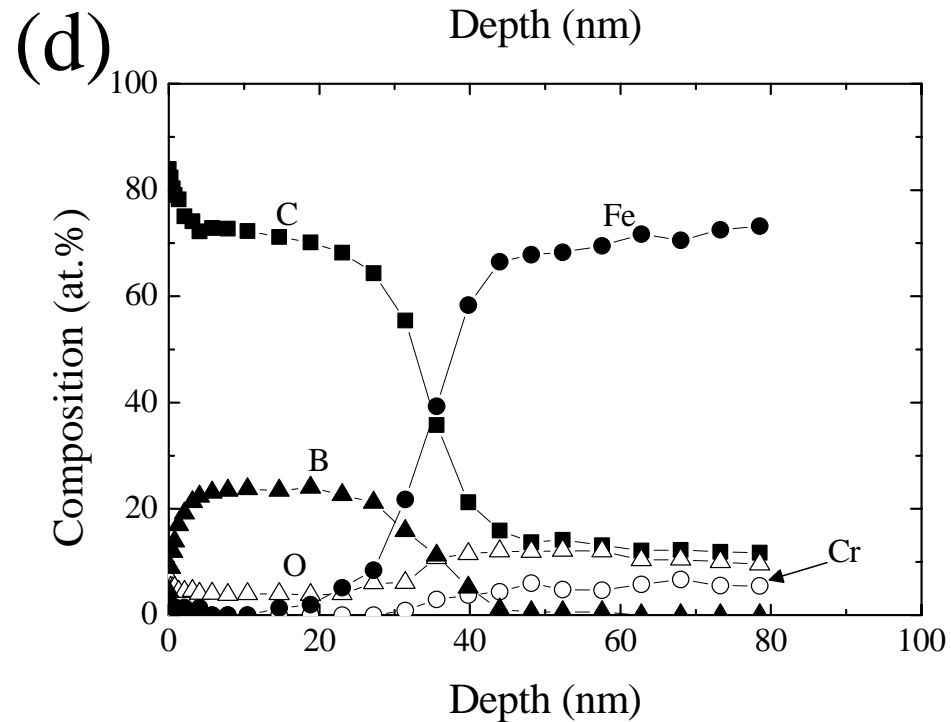
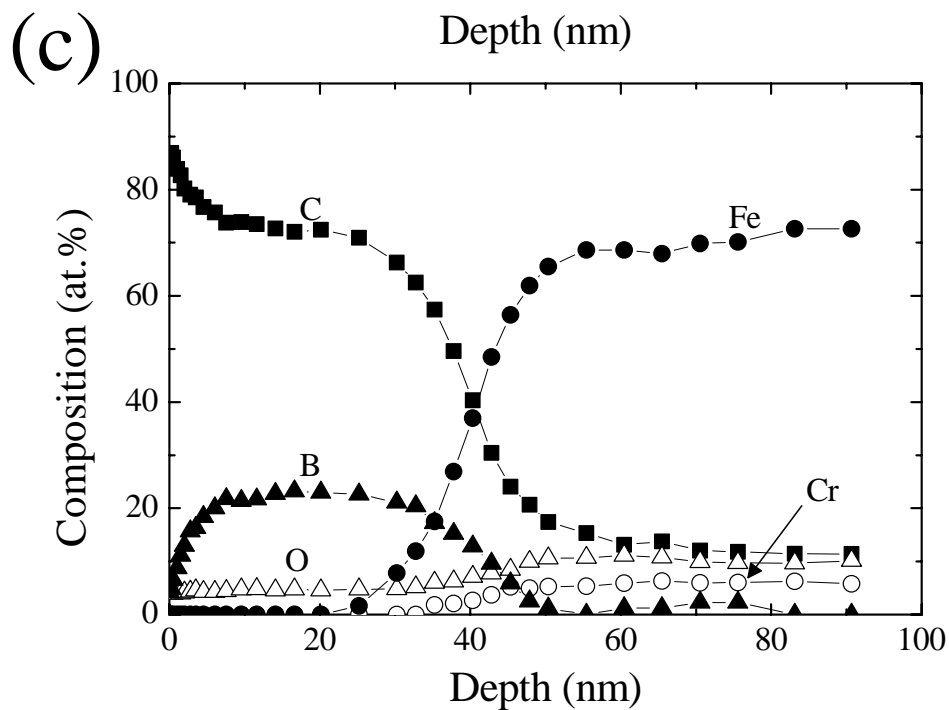
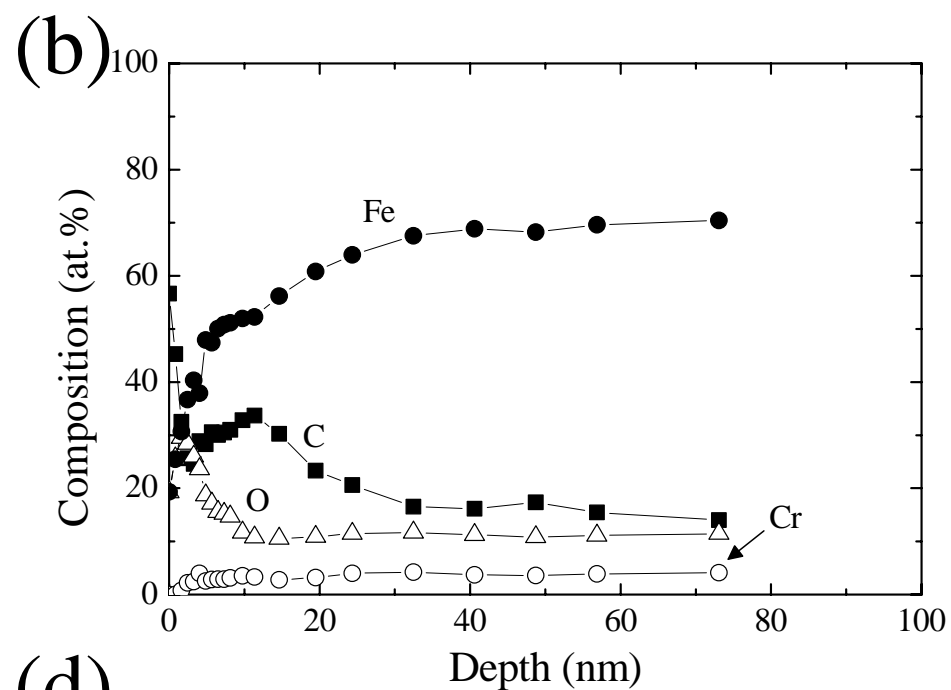
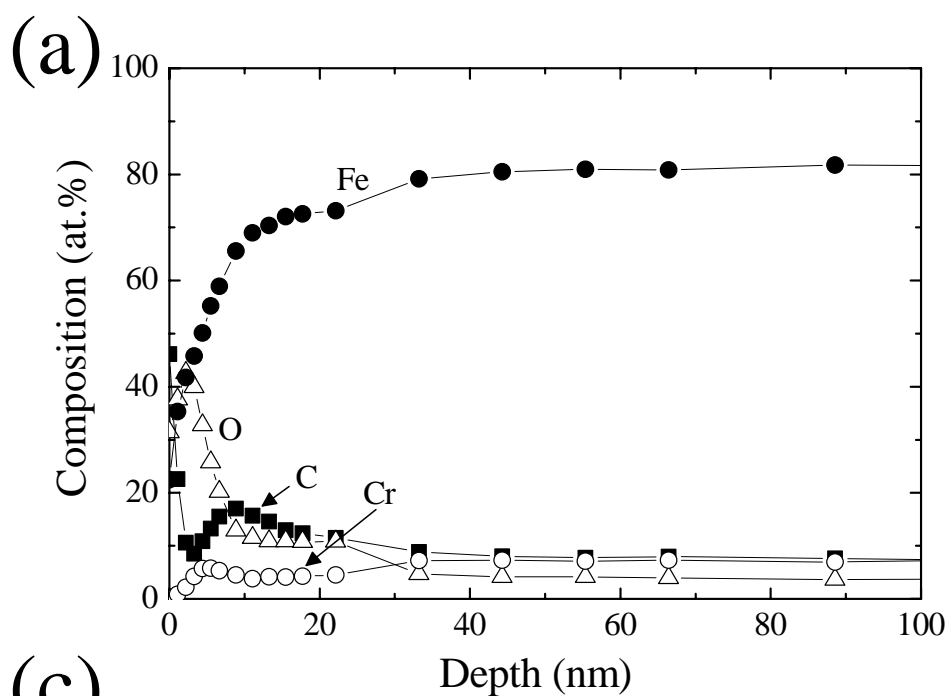


Fig.2 Y. Yamauchi

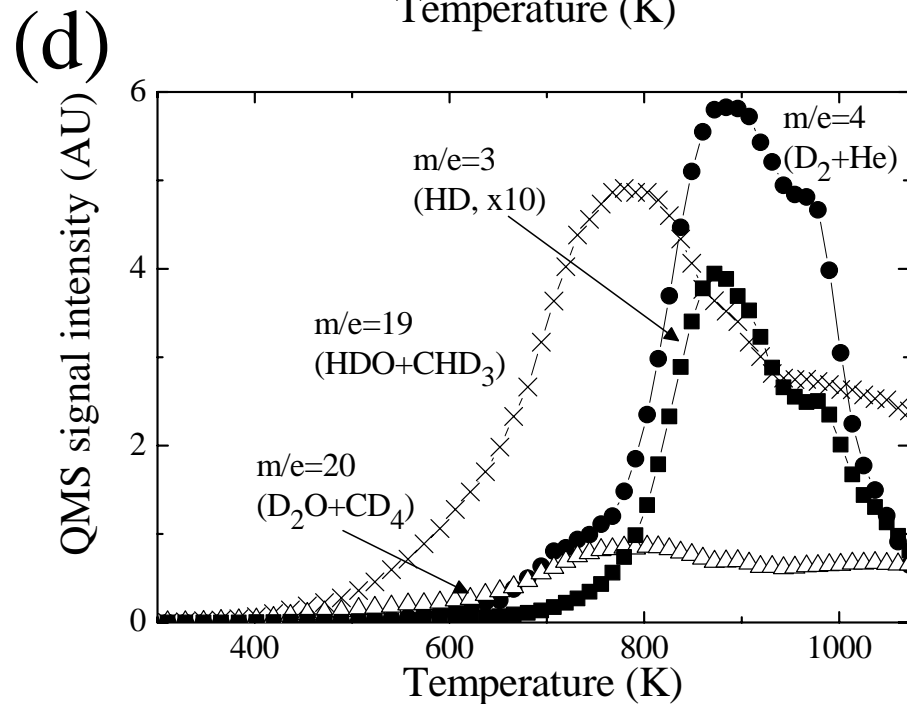
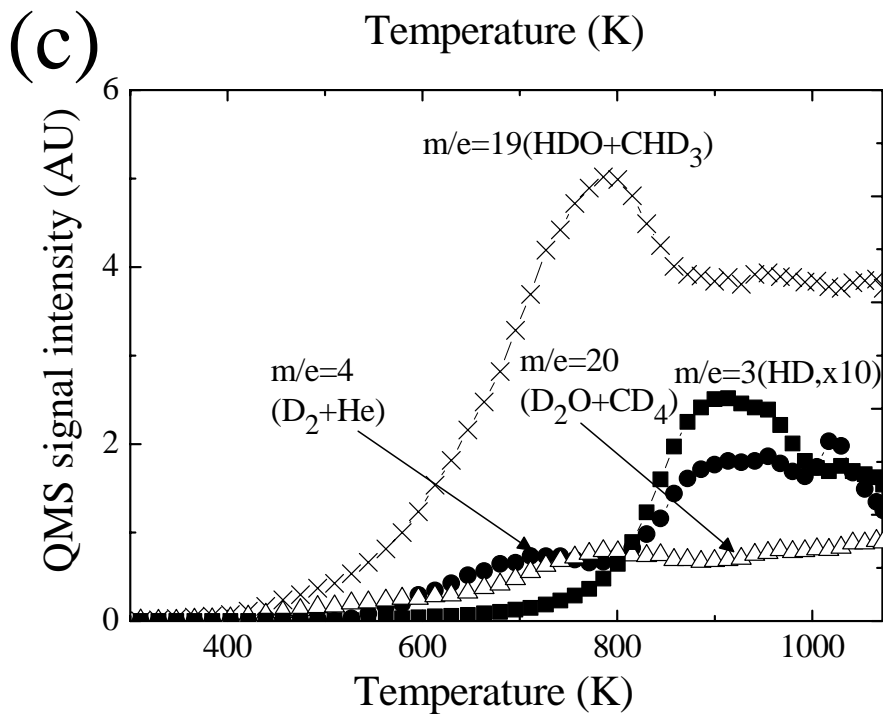
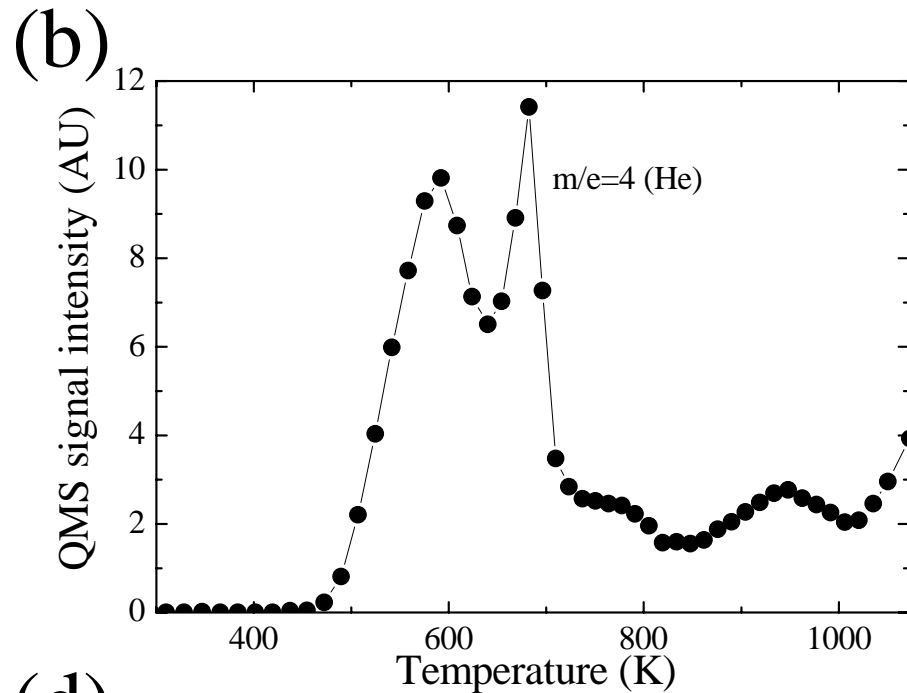
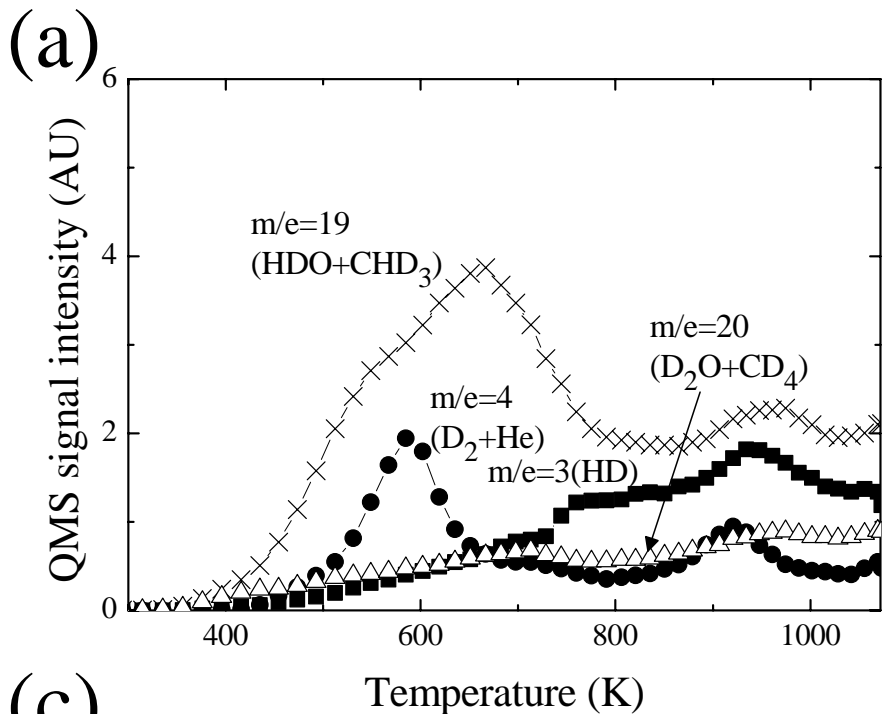


Fig.3 Y. Yamauchi

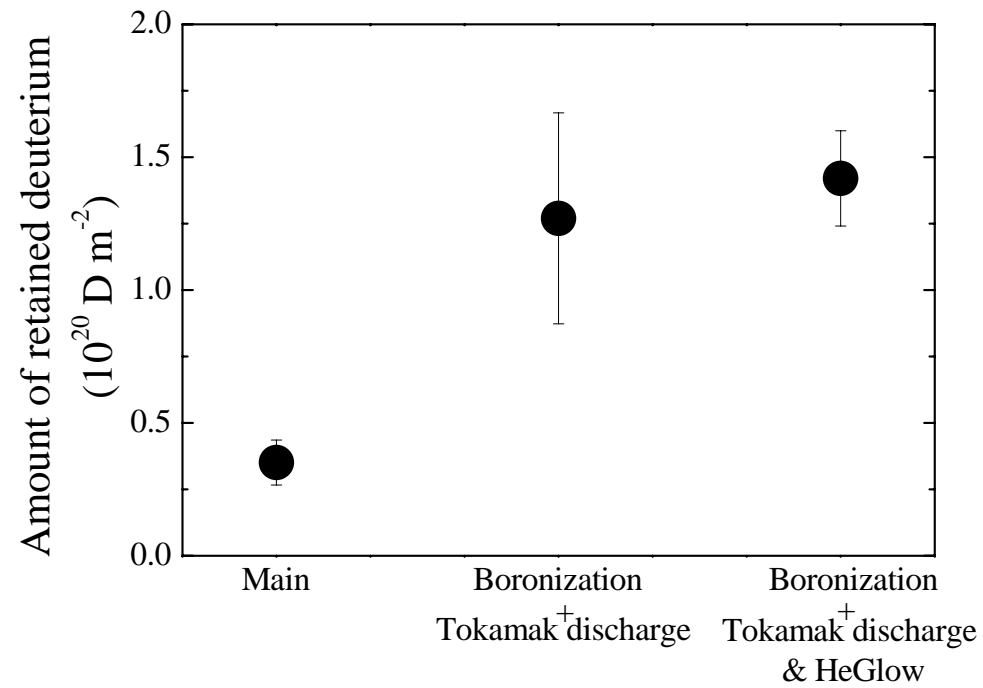


Fig.4 Y. Yamauchi