§65. Comparison of Boronized Wall in LHD and JT-60U

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Boronization has been performed in many fusion plasma devices as one of the most effective wall conditioning techniques. It is well known that the major advantages of boronization are (1) covering high Z first wall with low Z materials, (2) oxygen gettering, and (3) quick starting up of wall conditioning after opening the devices to air. The behavior of boronized walls is fairly complicated under physical and chemical processes such as mass transfer and composition changes due to sputtering and deposition of other materials. Therefore, an operation scenario of boronization for next generation devices such as ITER is not optimized yet. For example, in test chambers, there has been measured a capacity of oxygen gettering of B and B/C films exposed to He/O_2 glow discharges. But these exposing times are too short to consider actual fusion devices such as the Large Helical Device (LHD) and JT-60U and an eroded thickness of boron film is quite different between test chambers and actual fusion devices.

In LHD, the first boronization was conducted in the 5th experimental campaign (2001-2002). In this campaign, diborane (B2H6) diluted by helium (He) was injected from only one nozzle. In the 6th campaign (2002-2003), two injection nozzles were added and the boronization was carried out three times using these nozzles with a typical operation time of 7 hours. As a result, oxygen in plasma was reduced and plasma stored energy was increased for the extension of the operational density limit in LHD. Stainless steel 316L samples were installed as material probes on the first wall inside the vacuum vessel and they were exposed to only glow discharge. After about 8 month's exposure, one experimental campaign, these samples were taken out after a vacuum vent.

In JT-60U, two anodes are installed for a GDC on the first wall and 12 gas injection nozzles for the boronization are installed at outer side of poloidal cross-section in JT-60U. A current operation of boronization using deuterated-decaborane ($B_{10}H_{14}$) with He gas started since 2000. A container for polished decaborane is heated to ~ 380K during operation of boronization. A diluted decaborane gas is made from blending He and D_2.

For samples in both devices, the elemental depth profiles were measured with the X-ray photoelectron spectroscopy (XPS) with sputtering by argon (Ar) ions. These results of chemical binding energy for boron are shown in Fig.1. A B_2O_3 bond locates at 193 eV, B-C bond as boron carbide at 189 eV and B-B bond as fresh boron at 188 eV. At just after boronization in JT-60U, fresh boron was kept and boron-oxide concentration is only 2 %. But on this exposed sample, from the top surface to 20 nm, a boron-oxide bond is dominant peak and at depth of 37.4 nm peak of boron carbide was increasing.

At this depth at 37.4 nm, a major bond is boron carbide at 189 eV, an intensity of B-B bond is low. For the actual divertor target tile in JT-60U, it was reported that fresh boron did not remain and shifted to boron carbide.

In LHD, a major boron-oxide peak of chemical bond is observed at the top surface of boron film as same as JT-60U. In deeper region (>3 nm), a fresh boron peak at 188 eV can be observed as shown in Fig.1(b). It was reported the difference between pure B and B/C of oxygen gettering in a test chamber. This result shows that gettering effect of pure B is two times higher than that of B/C. A potential of oxygen gettering in LHD is higher than that in JT-60U. But in the actual experimental devices, an un-estimated other effects such as a thick carbon layer gives influence to the capacity of oxygen gettering. A difference of boron film between in LHD and JT-60U is the thickness of boron-oxide with high concentration. This boron-oxide layer in JT-60U cannot be eroded by glow discharge cleaning for several hours. On the other hand, thin boron-oxide layer in LHD can be eroded easily by GDC. From this reason, a lifetime of oxygen gettering effect is long in LHD.

Then, for long-term operations in JT-60U, high B-O concentration of 90 % was observed at local section and a capacity of oxygen gettering is expected to be saturated. For thick B-O layer with a high B-O concentration on boron film, an additional boronization is needed in JT-60U. In LHD, however, a deposited layer on boron-coated area on the first wall is easily removed by glow discharge and the boron surface can be refreshed.

Reference;

1) N.Ashikawa et al., J. Nuclear Materials 363-365(2007) 1352-1357.

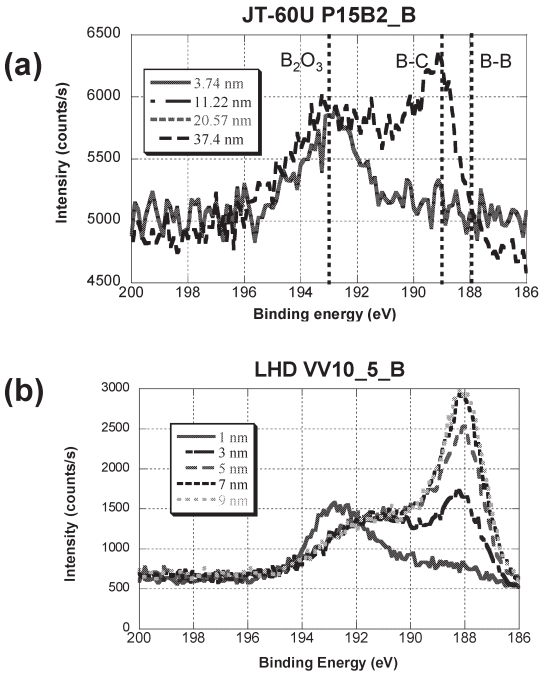

Fig.1 (a) Binding energy of boron film on material probe for each depth of 3.74, 11.22, 20.57, 37.4 nm at P-15 section in JT-60U. (b) Binding energy of boron film on material probes for each depth of 1, 3, 5, 7, 9 nm in LHD. A B_2O_3 bond is indicated at 193 eV, B-C bond as boron carbide is indicated at 189 eV and B-B bond as fresh boron is indicated at 188 eV.