§72. Response of Plasma Facing Materials by High Fluence Particle Irradiation

Ueda, Y., Isobe, M., Nishikawa, M.(Fac. Eng. Osaka Univ.)
Noda, N., Sagara, A.

One of the important research subject of the LHD project is to realize long pulse discharges with superconducting magnets. Erosion characteristics and hydrogen retention of plasma facing materials for the LHD must be evaluated by high flux and high fluence beam irradiation. For this purposes, we have measured the erosion rate of graphite and doped graphite with high flux beam generator, the maximum flux of which is comparable to those from edge plasma conditions.

In this study, we tried direct measurements of sputtered particles by using a quadrupole mass analyzer with a differential pumping system to obtain real time information of erosion characteristics. In addition, measurements of chemical bonding of hydrogen with carbon atoms implanted into graphite were made by FTIR-ATR method for the first time.

Experiments were made with a high flux beam irradiation test stand in Osaka University. Irradiation was made with 5 keV H_3 and D_3 beams (effective energy of one atom; 1.7 keV) with the flux of about 10^{22} $m^{-2}s^{-1}$. Maximum pulse length and duty of the beam were about 4 s and 80 s, respectively. Samples were heated by infrared heating device with the maximum temperature of 800°C.

For isotropic graphite, dependence of methane yield on temperature and irradiation flux by chemical sputtering was measured. It was found that a peak temperature at which the yield took maximum shifted from about 600°C to 700°C as irradiation flux changed from 1.0 x 10^{21} $m^{-2}s^{-1}$ to 5.0 x 10^{21} $m^{-2}s^{-1}$. Rise time of methane formation after irradiation to virgin samples is an order of second, which will give some clues to clarify the behavior of hydrogen in graphite materials under high flux irradiation.

Methane yield measurement was also made for boron doped isotropic graphite with boron concentration of 3%, 10%, and 20%. The yield for boron doped graphite decreased by a factor of 2 - 3 compared to pure graphite. The boron yield was almost unchanged with boron content.

For boron thin films on graphite (isotropic and pyrolytic), ion and neutral sputtered particles irradiated by D beam was measured. Boron films were deposited by vacuum evaporation with different deposition rates (0.5 nm/s and 1.5 nm/s). The thickness of boron films were about 1μm which was thicker than conventional boron coating (order of 0.1 μm). The reason to use these thick boron films is why it would be considered necessity of thick boron films for the future long time operation and it would be important to study the characteristics of thick boron coating. Neutral sputtered particle flux was independent of the substrate graphite materials (isotropic or pyrolytic), deposition rates, and time. On the other hand ion flux showed some dependence such that it was larger for isotropic graphite substrate than pyrolytic substrate and larger for low deposition rate than for high deposition rate. Ionization rate of sputtered particles at the surface would be very sensitive to the presence of impurity (especially oxygen). According to ESCA measurements, oxygen content was higher for lower deposition rate, which could account for the dependence of ion flux on deposition rates.

In the field of diamond thin film formation by plasma CVD, it is known that a graphite phase is removed by the reaction with hydrogen atoms; chemical sputtering. In this reaction, concentration of CH bond in graphite grains (SP2 state) and CH bond in methyl groups (SP3 state) change with temperature according to FTIR spectroscopy.[1] In this case, the reaction takes place only on the surface of films and no energetic ion effects exist, while for chemical sputtering of graphite materials by hydrogen ion bombardment the reaction takes place in the bulk and the effects of ion energy cannot be neglected.

In our study, we measured the characteristics of bulk CH bond by FTIR-ATR method for the first time. Since high SN ratio for CH bond signal was necessary to obtain temperature dependent information, pyrolytic graphite with very smooth surface (surface roughness is less than 0.1 μm) was used. An ATR prism of Ge was employed. As the temperature of pyrolytic graphite during irradiation increased over 300°C, SP3 content decreased and SP2 content increased. This means that methyl groups are released over 300°C due to thermal desorption.
This result shows similar temperature dependence to that of diamond thin film.

Reference
1) A. Horn, A. Schenk et al., Chem. Phys. Lett. (1994) 193.