GRAPHITE EROSION IN CONTACT WITH A HYDROGEN PLASMA AND A COMPARISON TO ION BEAM EROSION DATA

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Introduction

Graphite bombardment by energetic hydrogen ions shows a high erosion yield due to chemical reactions (methane formation). This chemical sputtering depends on the graphite temperature as found in beam experiments /1/. In spite of this significant effect, carbon impurities in a tokamak plasma are not influenced by the temperature of a carbon limiter /2/. Ion flux dependence of the chemical sputtering, metal impurities at the limiter surface and redeposition of sputtered species were considered as the main reason for this discrepancy.

In this work chemical sputtering and its temperature dependence is investigated by an ion beam (flux 1.5 10^{15} cm^{-2} sec^{-1}) and in contact with a plasma (flux 1.5 10^{18} cm^{-2} sec^{-1}). The plasma experiment also shows the importance of redeposited carbon layers created at certain plasma parameters for the net erosion yield.

Experimental

Chemical sputtering with D^+-ions of 50 eV, 100 eV and 200 eV was measured in the IPP high current ion source /3/ and in the plasma generator PISCES /4/. The graphite temperature was varied between RT and 900^{o}C. The sputtering yield was gained by the weight loss method /3/ and the target temperature was measured either by a thermocouple (plasma experiment) or by an imfrared pyrometer (beam experiment). The targets were cleaned in an ultrasonic bath and outgassed well above the operating temperature before each test.

Results and discussion

In Fig. 1 yield data for 100 eV D^+ at normal incidence gained by beam and plasma experiments are compared. Redeposition is avoided also in the plasma experiment by a proper choice of the plasma parameters /4/. The corresponding ion fluxes for beam and plasma experiments are 1.5 10^{15} cm^{-2} sec^{-1} and 1.5 to 10^{18} cm^{-2} sec^{-1}, respectively. In the beam experiment two different types of graphite (Pyrolytic and POCO graphite) are tested. The same POCO graphite samples are tested also in the plasma experiment. For temperatures up to 300^{o}C the beam data are higher by a factor 1.5 which may be explained even by the uncertainties in the data gained from the plasma experiments. At higher temperature the difference is larger and even the beam data for the different types of graphite are different. A possible explanation may be seen in the different bulk structure (dense and porous) for pyrolytic and POCO graphite. However, also for the high ion flux the yield data depend on the graphite temperature.

The lowest yield values are measured at the highest temperature of 900°C investigated in these experiments. This is more significant for lower ion energies as shown in fig. 2. In this figure yield data versus target temperature are given for three different D^+-ion energies (50 eV, 100 eV and 200 eV) measured for POCO in PISCES. The extrapolations (dashed lines) point to the expected values for physical sputtering as methane cannot be formed at these temperatures.

For temperatures above 900°C an increase in the erosion yield by radiation enhanced sublimation has been measured in beam experiments /5/. However, this effect may be small for ion energies below 100 eV /6/.

The net erosion yield is reduced in plasma experiments by redeposition if the ionization length for methane is smaller than the plasma dimensions (in PISCES 10 cm). This is shown in fig. 3. Erosion yields for 100 eV H^+-ions are given for the same flux but two different ionization length (5 cm and $\geq$ 15 cm). Although the ionization length is still larger than the diameter of the graphite sample ($\varnothing$ 1 cm) the yield is reduced up to a factor 2. Experiments with an ionization length of less than one cm gave net erosion yields below the detection limit. However, the surface structure changed significantly due to the redeposited layer.

According to the plasma parameters of scrape-off layers in tokamaks ($n \geq 10^{12}$ cm^{-2} sec^{-1}, Te $\geq$ 10 eV) high redeposition take place at the graphite limiter /7/ and this effect may mask the chemical erosion effect.

Conclusion

The chemical sputtering yield of graphite is not significantly reduced at typical ion fluxes to a carbon limiter ($\sim 10^{18}$ cm^{-2} sec^{-1}) compared to the data gained by beam experiments (flux $\sim 10^{15}$ cm^{-2} sec^{-1}). Also at the high flux the yield depends on the graphite temperature. Such a temperature dependence of the carbon impurities in the main tokamak plasma has not been observed /2/. It is proposed that methane formed in the chemical sputtering process is ionized in the scrape-off layer and redeposited at the limiter. Therefore impurities cannot penetrate into the main plasma. At temperatures above 800° C the erosion yiel is low and reaches values expected for physical sputtering.

References

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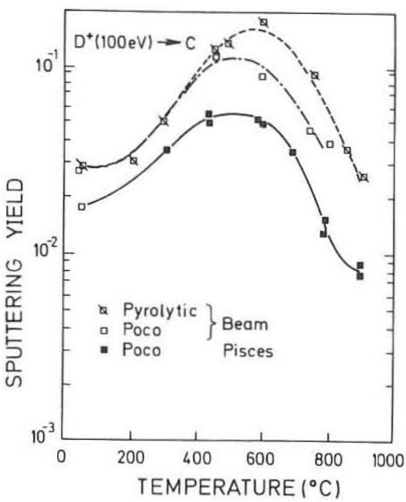

Fig. 1 Chemical sputtering yield versus temperature for 100 eV D^+ ions and two types of graphite

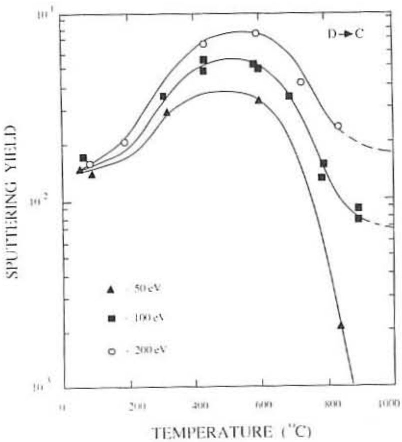

Fig. 2 Chemical sputtering yield of POCO graphite versus temperature for D^+ ions of three different energies

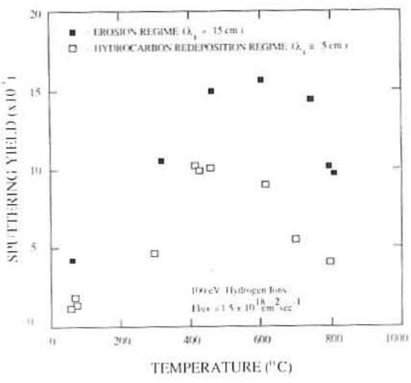

Fig. 3 Chemical sputtering yield of POCO graphite versus temperature for 100 eV H^+ ions in the erosion and redposition regime