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Wall conditioning towards the utilization in ITER

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ABSTRACT

Wall conditioning provides an effective means for reducing both impurities and recycling from the plasma surrounding surface. A wide variety of techniques have been developed during the last few decades for conditioning the plasma facing surface. With the presence of magnetic fields, electron cyclotron resonant (ECR) and ion cyclotron resonant (ICR) discharge cleaning techniques have been explored, which could be used for next generation superconducting magnetic confined devices, such as ITER. Efforts have been made on the application of ICR conditioning on many devices and significant progress has been made. A new and simple method for future wall conditioning, high frequency glow discharge cleaning (HF-GDC), has been developed. HF-GDC operates in the presence of strong magnetic field (0.5–2 T) at frequencies of 20–100 kHz stably for a wide range of gas pressures. In this paper, all these techniques are reviewed and their proper application in ITER are discussed.

1. Introduction

Wall conditioning provides an effective means for reducing both impurities, and recycling from the plasma surrounding surface. The experience in present short-pulse tokamaks already indicates that wall conditioning plays a crucial role in achievement of reproducible and clean plasma conditions and improvement on overall plasma performance [1–5]. Some long pulse experiments suggest that the impact of wall condition on the plasma performance could be more serious in ITER with plasma discharge time from 400 to 3000 s. Furthermore, ITER, as a nuclear device, must control the in-vessel inventory of tritium and dust for safety reason.

(1) The objectives of wall conditioning are: reduction of gaseous impurities influx from in-vessel components (the Plasma-Facing Component surfaces and surfaces inaccessible from the plasma) to maintain/improve plasma purity.
(2) Reduction of hydrogenic species influx from in-vessel components to facilitate density control.
(3) Removal of tritium from in-vessel components.
(4) Removal of dust from Plasma-Facing Components.

A wide variety of techniques have been developed during last few decades. Baking of the internal components inside vacuum vessel, glow discharge cleaning (GDC) [6,7], Taylor discharge cleaning (TDC) [8], which were developed in the early days of tokamak experiments, have been demonstrated to be effective, and are still in use today.

With the presence of magnetic fields, electron cyclotron resonant (ECR) and ion cyclotron resonant (ICR) discharge cleaning techniques have been explored, which could be used for next generation tokomaks, such as ITER. Wall conditioning for above mentioned issues has been studied extensively for past few decades and many papers, especially many excellent review papers have been published [3,4,9–14].

The principle of all the cleaning procedures using plasma discharges is to reduce metal or carbon oxides by hydrogenic plasma bombardment to form volatile species, thus depleting the contamination layers on the wall surfaces. These volatile substances, such as water vapour, methane and other hydrocarbons, are then desorbed from the surface, both thermally and by particle impact, and ultimately evacuated from the device via the torus pumping system. Two key factors for achieving a large cleaning effect are the maximum volatile substance formation by plasma discharge, and the effective exhaust of the formed impurities before they are re-ionized, so that these impurity products are not re-ionized, dissociated and redeposited on the surfaces in the cleaning plasma itself. This requires plasmas to have low Te and a low ionization fraction. In addition, high wall temperatures are useful not only for increasing the rates of the reactions leading to the formation of the volatile species on the surface, but also for promoting their desorption from the surface. Furthermore, a large pumping speed is desired for efficient removal of the volatile species from the torus. The essential difference between various conditioning methods lies in the way the atomic hydrogen species are created and interact with the surface. Other effects such as charge exchange

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neutrals, and sputtering due to high-energy ion bombardment may also play a role.

After introduction, GDC will be described in Section 2. ECR and ICR wall conditioning will be given in Sections 3 and 4. A new technique, high frequency glow discharge cleaning will be described in Section 5. Other techniques, such as strike point sweeping, flash lamp and oxidation for effective moving T retention will be given in Section 6. Discussion and summary for future needs and application to ITER will be discussed in last section of this paper.

2. Glow discharge cleaning

The most effective method actually used for surface impurity cleaning is hydrogen or deuterium GDC. One or more anodes are either located in portholes, or moved by a bellows assembly into the main volume of the vacuum vessel. The wall surfaces and limiters are at ground potential. Typical hydrogen pressures, range from 0.1 Pa to a few Pa, the voltage between anode and cathode is of the order of a few hundred volts. Superimposed RF power (~100 W) is often used to ease the breakdown of the glow, and to stabilize the plasma at low pressure.

During D2-GDC, both ions and charge exchange neutrals interact with the first wall surface, and produce by chemical sputtering molecular impurities such as H_2O (D_2O), CxHy (CxDy) and CxOy, which are continuously pumped out during the cleaning process. Simultaneous wall baking is very helpful during discharge cleaning, especially for removing oxygen from the wall. Results from TEXTOR showed that a high wall temperature (over 350 °C) is favourable for quick conditioning of first wall during the GDC process [15]. Oxygen and water contamination can be very effectively removed from the vacuum wall by long glow discharges (~100 h).

He GDC is usually used for devices with a large graphite coverage. The main reason is that large quantities of hydrogen are stored within the penetration range of hydrogen ions. They can be released upon particle impact during a tokamak discharge and make density control difficult, in particular, when the walls cannot be baked to temperatures above 300 °C. For carbon wall, fuel retention is dominated by codeposition. Another reason for fuel retention is the porous structure of graphite that leads to storage of significant amounts of water vapour and hydrogen, rendering recycling control difficult during tokamak discharges. Helium glow discharge conditioning for hydrogen removal has been optimized in DIII-D [16], and routinely used between each tokamak discharge. It has been instrumental in achieving high-performance H-mode plasmas, and a wide operating space in DIII-D where major parts of the surface were covered by graphite.

Tritium removal efficiency with H_2 and He DC glow has been measured in JT-60U by Nakamura et al. [17]. The hydrogen isotope (tritium and deuterium) release rate by H_2 GDC is much larger (by a factor of 2–3) than by He GDC due to chemical processes induced by the hydrogen discharge shown in Fig. 1. The dominant removal processes for the He GDC and H_2 GDC after a few hours can be attributed to physical sputtering and isotope exchange reaction assisted by chemical sputtering induced by the H_2 discharge, respectively. This graph suggests that the removal rate, or the tritium near the surface, could be reduced by three orders of magnitude with a half day of H_2 GDC even at a modest baking temperature of 100 °C.

Its drawback for a machine with superconducting magnets like ITER is that it can be used only occasionally e.g. just during the recovery from a vent or major air/water leak or when the magnets are not turned on (the frequency depends on the build-up rate of tritium inventory and the efficiency of other wall cleaning methods and can range from once a year to once a month). Thus it is excluded from the routine clean-up schemes during operation for a machine like ITER. Another possible drawback is that because the ion energy exceeds the sputtering threshold, erosion of PFCs and coating on the diagnostics mirrors and windows are concern.

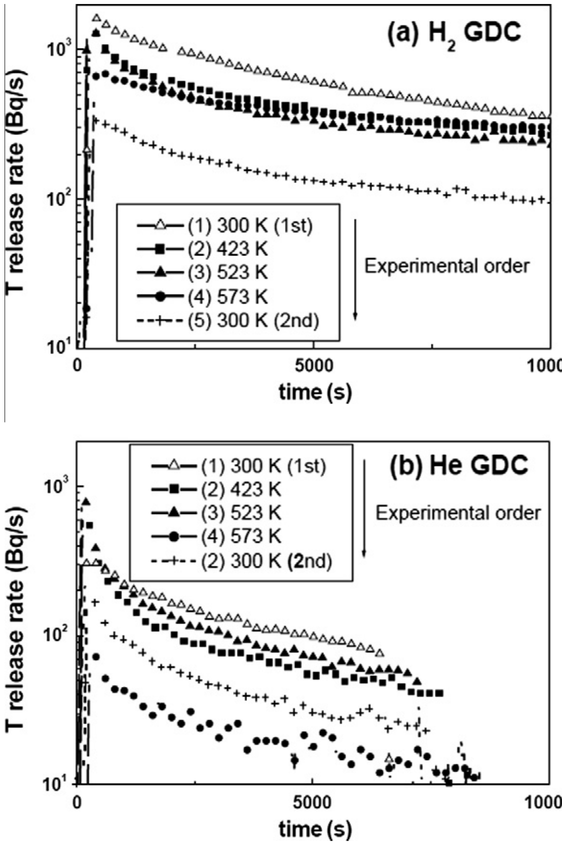

Fig. 1. Tritium release rates from JT-60U vacuum vessel during: (a) H2 GDC and (b) He GDC at various wall temperature [17].

For ITER wall conditioning, GDC is still required when vent to air or during machine non-operation maintenance when there is no magnetic field. For this reason, GDC is still baseline requirement for ITER [18]. The detail of ITER GDC is shown in Table 1.

However, due to the presence of high permanent magnetic fields, conditioning techniques based solely on glow discharges cannot be used. In future superconducting devices, such as ITER, which will be operated over long discharge durations and use deuterium/tritium mixtures, new techniques for wall conditioning are needed, firstly to obtain a reproducible and controlled plasma discharges, and secondly to reduce the tritium wall inventory after each discharge. ECR and ICR conditioning techniques have been developed during the past 20 years, and very good results have been obtained.

Table 1
Glow discharge requirements.

Parameters	Unit	Value
First wall current density	A/m^2	0.1–0.4
Bias voltage	V	300–600
Pumping speed (He, molecular flow)	m^3/s	30–40
Conditioning gas		H_2, D_2, He, O_2
Number of electrodes		6
Operating pressure	Pa	0.01–0.5
Coil currents (TF, PF, CS and CC)	A	0