DC glow discharge conditioning of remote areas in fusion devices

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Abstract. Various methods are used for wall conditioning of the vacuum chamber of magnetic fusion devices. Among them, direct current glow discharges in deuterium or helium are used to control the contamination of the plasma by impurities coming from the walls. However, the relatively high energy of the ions on the plasma facing components and the difficulty to extend the glow discharge in remote areas could reduce their attractiveness. We present the results from tests performed in a dedicated reactor, equipped with a narrow cylindrical duct with seven Langmuir probes. A heated cathode, biased at ±40 Volts with respect to the wall, is placed inside the duct. The influence of the pressure on the penetration of the discharge into the tube is shown and discussed. Significant values of ion current and potential in the tube are obtained for pressures two orders of magnitude higher than those currently used in present Tokamaks. The effect of establishing the glow discharge between the anode and the heated cathode was studied. The heated cathode currents can be tuned in such a way that the current measured by the probe increases whereas the potential drop between the glow discharge and the wall decreases and the energy of the ions which are impinging onto the surfaces is reduced.

1. Introduction

In Tokamaks, devices dedicated to the study of thermonuclear fusion by magnetic confinement, the conditioning of the vacuum chamber is a key issue [1]. It is regularly used for three main reasons:

- To limit the flux of impurities coming from the walls, in order to allow plasma initiation and guarantee an acceptable level of contamination of the plasma during the pulse
- To control the desorption of hydrogen and hydrogen isotopes (H,D,T) and hence the isotopic ratio in the plasma (H/D in today’s Tokamaks, T/D and thus the fusion power in ITER)
- To minimise tritium inventory in surface layers of plasma facing components, one of the major emerging issues for Tokamak operation.

Various types of plasma discharges are used to clean in situ contaminated surfaces in existing facilities [1]. Among them, direct current glow discharges (low temperature plasmas, neon type) in a through flow of hydrogen (or isotope) or helium are routinely used for the above reasons. Furthermore, glow discharges in Deuterium or in Oxygen have been proved to be efficient for detritiation treatment [2],[3].
In DC glow discharge conditioning, one or more anodes are located in portholes inside the vacuum vessel of the Tokamak. The wall surfaces and limiters are at ground potential. Since the anode is biased positively with respect to the vessel walls, the latter act as cathodes and are thus exposed to a flux of energetic ions. Typical Deuterium and Helium pressures range from 0.3 to 0.5 Pa, the voltage between anode and cathode being of the order of 500 Volts. Hence typical ion flux densities achieved with present systems in fusion devices are in the range 0.05-0.1 A/m². In JET [4] or in Tore Supra, the He glow current density is a relatively uniform and is about 60 mA/m².

However, some features could reduce the attractiveness of such technique like the relatively high energy of the ions on the plasma facing components and the difficulty to extend the glow discharge plasma in remote area, where amorphous carbon layers containing T seem to exist.

These disadvantages may be overcome by establishing the conditioning glow discharge between heated cathode (-s) and anode (-s) both isolated from the wall which is grounded. In this case, one expects a better control of the plasma potential by varying the voltages on the anode and on the cathode, and therefore a better control of the energy of the plasma ions striking the walls. Furthermore, additional anodes can be placed in the ports which need to be treated.

### 2. Experimental arrangements

A test reactor was modified for the experiments. It is schematically shown on figure 1. The vacuum vessel has approximately a volume of ~ 1 m³, for an inner wall surface of about 5 m². Its grounded walls are temperature-controlled at 150°C. A DC power (3kV – 1A) is supplied to the anode, the aim being to reach a similar level of current density onto the surface with respect to glow discharges current densities. The discharge is operated in He. A tungsten filament is biased negatively with respect to the grounded walls. As a DC current from 10A to 40A is applied to this heated cathode, it emits electrons by thermionic effect.

A flange has been manufactured (figure 2) on which a narrow cylindrical duct (10 cm diameter, 32 cm long) is fixed in such a way that it features a remote area which can not be reached by the usual glow discharge. The duct is equipped with 7 cylindrical Langmuir probes (2.0 mm diameter, 10 mm long tungsten wires) distributed along its length. An eighth Langmuir probe is located at the top of the test tank. The heated cathode (heated filament emitting electrons) is placed at the end of the duct. The pressure, measured by means of a Baratron capacitance gauge, is feedback controlled by variation of the gas flow. A base vacuum of ~10⁻⁵ Pa can be reached. The electrical signals from the probes are recorded with an ADC acquisition board (Texas Instruments SCB68).

### 3. Experimental results and discussion

#### 3.1. Penetration of the glow discharge into the duct
On figure 3 are shown the currents and voltages measured on each probe in the duct with a digital multimeter (hence the probes are at ground potential). The discharge was operated in helium for three different sets of glow discharge parameters. The dashed and dotted lines were obtained without having switched on the heated cathode. The discharge current was set to 1A. At 1Pa (dashed blue line), which is a typical gas pressure for glow discharge conditioning, there are more than 3 orders of magnitude between the currents and the voltages measured with probe #1 and those measured with the deepest probe in the cylinder (#7).

![Figure 3. current (left) and voltages (right) measured at the probes for three different conditions.](image)

The glow discharge burns into the main volume of the reactor and does not penetrate into the cylindrical tube, indicated by the low values of both current and voltages measured. There is practically no coverage of the duct by the glow discharge under “standard” conditions. As the pressure is increased, the glow discharge penetrates into the tube above a pressure threshold which is found to be 22 Pa under the present conditions. The dotted orange curve on figure 3 represents the values obtained at 24 Pa.

3.2. Characterization of the glow discharge in the tube with heated cathode
In this section, the effect of a heated cathode located in the cylindrical tube, on the plasma parameters (electron density, temperature and plasma potential) is shown and discussed. It can be seen on figure 3 (solid red line) that with given cathode operating parameters, the glow discharge penetrates into the tube, even at 1Pa. The currents and voltages measured on each probe of the duct with a digital multimeter are 3 orders of magnitude higher than if the heated cathode is not used.

3.2.1. Determination of the plasma parameters by means of Langmuir Probe measurements
The Langmuir probe diagnostic simply consists of placing a conducting wire into the plasma and measuring the current to it at various applied voltages [5]. Under the discharge operation parameters, the sheath is non-collisional and the mean free paths are much larger than the probe dimensions.

Two examples of a current-voltage characteristics are given on figure 4. The measurement were done with the probe # 1 in a He glow discharge at a pressure of 3 Pa with (in blue) and without (in red) heated cathode. The glow discharge current was controlled to 1A.

The electron current for $V_{\text{probe}} \leq V_{\text{plasma}}$ is given by [6]:

$$I_{\text{probe}} = I_e = 0.4A n_e \sqrt{\frac{k_B T_e}{m_e}} \exp \left( \frac{eV_{\text{probe}}}{k_B T_e} \right)$$

(1)

where $A$ is the probe area, $n_e$ is the charged particles density, $k_B$ the Boltzmann constant, $T_e$ the electron temperature and $e=1.6.10^{-19}$C. Hence the electron temperature $T_e$ is inversely proportional to the slope $p$ of ln($I_e$) at $V_{\text{probe}} \leq V_{\text{plasma}}$. Knowing $T_e$ and the probe geometry, $n_0$ can be easily
determined. In the example given on figure 4 (red curve), the plasma potential measured with Probe #1 is 276 Volts, $T_e=4.15$ eV and $n_e=5.3\times10^{15}$ m$^{-3}$.

3.2.2. Influence of the heated cathode current.

While increasing the cathode current, a decay of the glow discharge in the main volume is observed on the Langmuir probe characteristics shown on figure 4. Both curves were obtained in a He plasma at 3 Pa and a discharge current of 1 A. The blue curve was measured for a heated cathode current of 40 A while applying a bias of -40 V. The red one was recorded without additional cathode. As it can be seen, the first characteristics is shifted with respect to the second one, indicating that the plasma potential drops down. Indeed, in this case, the plasma potential was found to be only 41 Volts, $T_e=4.8$ eV and $n_e=9.4\times10^{15}$ m$^{-3}$. Moreover, the electron saturation current is higher in the first case.

The behavior of the glow discharge and its dependency on the cathode current $I_k$ are illustrated on figures 5 and 6. In all cases, the cathode is biased negatively at -40 Volts with respect to the grounded walls. As shown in figure 5, both the plasma potential and the mean electron temperature decrease with the cathode current in the main chamber, while the electron density remains almost constant below 25 A. At this value of the operating cathode current, the density rises abruptly from $3.10^{15}$ m$^{-3}$ to $5.10^{15}$ m$^{-3}$, while the plasma potential and the mean electron temperature drop down (they are minimum at 28 A and above). As a consequence of operating the heated cathode at such a current, the energy of the impinging ions is reduced due to the potential drop between the glow discharge and the wall.

**Figure 5.** in the main volume: electron density (left) electron temperature (middle) and plasma potential (right) at probes # 1 (He, 1 Pa, 1 A).

**Figure 6.** in the tube: electron density (left) electron temperature (middle) and plasma potential (right) at probes # 6 (He, 5 Pa, 1 A).

In the cylindrical duct (figure 6), the highest values of the mean electron temperature and of the plasma potential could be measured at probe # 6 for $I_k \sim 25$ A. As for $T_e$ and $V_{\text{plasma}}$ in the main volume, they decrease above this value. Note that for values of the cathode current below $I_k \sim 24$ A, the currents collected by the probe are too low to be used for the determination of plasma parameters. The electron density is maximum ($2.6\times10^{16}$ m$^{-3}$) at $I_k \sim 28$ A and remains above $10^{15}$ m$^{-3}$ as the plasma potential drops down.

While further increasing the cathode current above the peak value, a strong negative space charge may develop inside the tube and the measured current and voltage measured drop down.

4. Conclusion.

In this paper, the effect of an additional discharge, created by a heated cathode located in the cylindrical tube, on a DC glow discharge in helium is shown and discussed. The tests were done at pressure and current regimes close to those of conditioning glow discharges in fusion devices. The additional cathode is located at the end of a small cylindrical duct connected to the main vacuum chamber, which features a remote area of e.g. a Tokamak. The main plasma parameters (density, temperature and potential) as well as the current and voltages were obtained from a set of Langmuir probes distributed over its length and in the main chamber. It has been shown that if the glow
discharge is operated in usual conditions (without an additional heated cathode), it can hardly penetrate into remote areas except for gas pressures two orders of magnitude higher than those currently used in present Tokamaks. Using the heated cathode, it is possible to extend the coverage of the glow discharge to the remote area. Significant values of electron density are then found, whereas it was null before. In particular, the current in the cathode could be operated in such a way that the density exhibits a maximum. Simultaneously, the plasma potential is reduced, and thus the energy of the ions striking the walls.

References
[1] J. Winter, Plasma Phys. Control. Fusion 38 (1996) 1503–1542
[2] Federici et al, J. Nuclear Materials, 266-269 (1999)
[3] Counsell et al., Plasma Phys. Control. Fusion 48 (2006) B189-B199
[4] P. Andrew, G. Bosia, R. Claesen, L. Grobusch, J. Harling, J. How and H.S. Jensen. In: The JET Glow Discharge Cleaning System, Fusion Technology 1994, Elsevier (1995), pp. 203–206
[5] Francis F. Chen, “Lecture Notes on Langmuir Probe Diagnostics”, in Mini-Course on Plasma Diagnostics, IEEE-ICOPS meeting, Jeju, Korea, June 5, 2003
[6] L. Schott, “Electrical Probes” in Plasma Diagnostics, edited by W. Lochte-Holtgreven, North-Holland Publishing Company, Amsterdam, 1968, p.668-731.