CONTINUOUS WALL CONDITIONING VHF DISCHARGE WITHOUT MAGNETIC FIELD IN A TOROIDAL DEVICE

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Experiments were carried out at Uragan-2M torsaron for wall conditioning without magnetic field. Plasma discharge was created with the same antenna and VHF generator used for weak magnetic field (B_0=100 G) wall conditioning. Experiment was carried out during whole wall conditioning period of Uragan-2M experimental campaign. The dynamics of wall conditioning was obtained alongside with standard plasma parameters measurements.

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INTRODUCTION

The radio-frequency (RF) discharges are used for conditioning of inner walls of vacuum chambers of fusion devices. In the series of experiments on Uragan-2M the Very High Frequency (VHF) discharge [0] is investigated which needs a steady magnetic field. RF wall conditioning without the magnetic field seems is also useful for fusion devices in certain specific cases. It's complicated to switch on and off cryogenic magnetic systems of fusion reactors. For this reason there is a need to have wall conditioning technologies both with and without magnetic field.

In the presence of confining magnetic field, the slow wave which the antenna excites is substantially slowed down in plasma that facilitates its damping. Plasma without magnetic field slows down the electromagnetic waves. To achieve acceptable damping of the wave, high electron-neural collision frequency is needed. Thus, the RF discharge may be sustained at relatively high neutral gas pressure.

The wall conditioning is achieved due to interaction of atomic hydrogen generated in the discharge with the impurities accumulated at the wall surface. The generation rate of hydrogen is proportional to the product of neutral gas pressure and plasma density. Thus, to keep the same rate of atomic hydrogen generation, at higher neutral gas pressure, the plasma density should be lower. This is a positive factor since the probability of ionization of impurities desorbed from the wall is lower in low density plasma.

The wall conditioning without magnetic field was used during the 2016 experimental campaign at Uragan-2M. The same equipment is used as in experiments with steady magnetic field (B_0=100 G).

VHF discharge parameters were measured by means of optical diagnostics and a Langmuir probe. The efficiency of wall conditioning was estimated using the cryogenic vacuum trap.

EXPERIMENTAL SETUP

The VHF wall conditioning was carried out with continuous RF discharge at the frequency of 130 MHz and the power about 3 kW. The RF power is launched into plasma with the small frame antenna (Fig. 1). The small frame antenna is made of stainless steel pipe 1 cm in diameter and is of square shape with side length of 10 cm. Water is pumped through the pipe for antenna cooling. To operate in steady magnetic field, the antenna is placed 2 cm from the last closed magnetic surface.

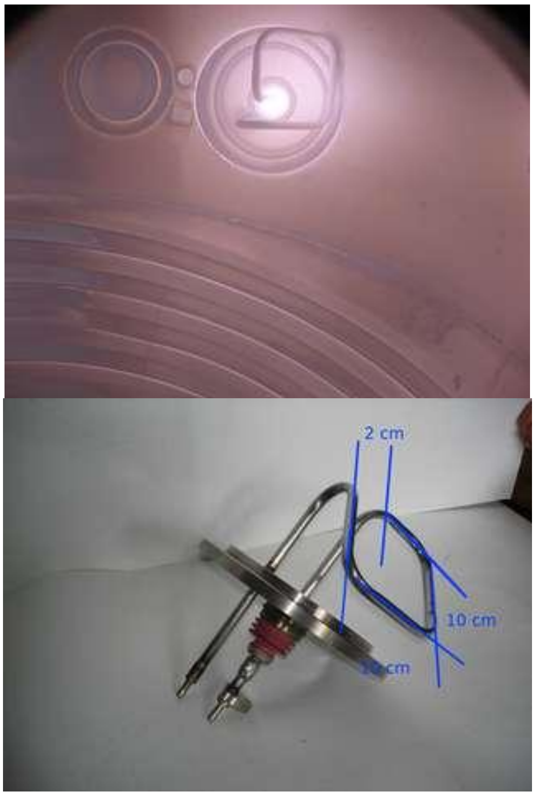

Fig. 1. Water cooled small frame antenna inside torsatron Uragan-2M device during continuous wall conditioning (top). The same antenna before mounting into device (bottom)

When RF power is launched, plasma exists locally only in vicinity of the small frame antenna. The size of such plasma cloud increases with the input RF power, but its luminosity decreases in an order of magnitude at the distance of 1 m from the antenna (along the torus).

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The only scenario fail was the discharge localization inside of the ceramic insulator as at Fig. 1. That caused sputtering of the antenna metallic parts and thin metal film deposition at the inner surfaces of the insulator. The deposition was prevented in further experiments with quartz tube placed onto antenna feed-through; it isolated antenna from the metal vacuum chamber wall and prevented plasma discharge appearance inside of the insulator.

OPTICAL MEASUREMENTS

During wall conditioning experiment at torsatron Uragan-2M, hydrogen, nitrogen and hydrogen-nitrogen mixture were used as working gases. The spectrum of the optical emission for each plasma discharge was measured and the results are presented in Figs. 2-4.

The Langmuir probe measurements of plasma density and electron temperature were made in the horizontal plane of the small frame antenna cross-section.

The electron temperature estimated from optical measurements with the H_2 Fulcher-α band system and H_α intensities is about 2...3 eV, which are in correspondence with the Langmuir probe results given further.

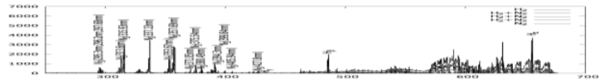

Fig. 2. Plasma discharge spectra for different working gases

Fig. 3. Hydrogen plasma discharge emission spectrum.

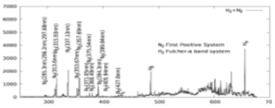

Fig. 4. N_2 and H_2 mixture plasma discharge spectrum with volume gas ratio (50/50)%

The most optimal discharge in hydrogen and nitrogen mixture is for gas volume ratio (50/50)%. The presence of N_2^+ ion line with the wavelength 427.8 nm showed only ionization of nitrogen molecules (see Fig. 4) and the hydrogen spectrum indicated hydrogen dissociation processes.

PROBE MEASUREMENTS

The probe measurements needed pulsed operation, and the pulses were made manually by switching on/off the VHF generator. The Langmuir probe was placed in the same cross-section as the small frame antenna at horizontal midplane at outer part of the torus and could move along radius. The ion branch of the current-voltage characteristic (I-V) was recalculated with the formula (1) to determine the average (equilibrium) local plasma parameters (the electron density, the electron temperature and the floating potential):

$$I(V) \approx I_s \cdot \left[1 - \exp\left(\frac{V - V_f}{T_e}\right)\right], \qquad (1)$$

where *V* is the probe biasing voltage. The ion saturation current can be expressed as

$$I_s \approx 0,5 S_{pr} e n_e \sqrt{2T_e / m_i}\,, \qquad (2)$$

in assumption that $T_e \approx T_i \dfrac{m_e}{m_i}$. Here S_{pr} is the area of the collecting probe surface, m_i is the plasma ion mass.

The Langmuir probe biasing potential was changed from -150 to +100 V to take I-V characteristics. Every probe potential was fixed for 2-3 plasma discharges to get average measured quantity.

It is possible to estimate the plasma density through substitution of different ion masses in the expression (2): m_i was assumed equal 1 amu (H^+), 2 amu (H_2^+), 14 amu (N^+), or 28 amu (N_2^+)

Measurement results are represented as a table:

Langmuir probe measurements

Parameters	mixture of gases		
	H_2	H_2(50%) +N_2(50%)	H_2(<10%)+ N_2(~90%)
Distance of the probe from the chamber wall, mm	87.5	87.5	87.5
V_{fl}, V	50	37	64.5
T_e, eV	2.7	4.1	1.8
n_e (cm^{-3}) by H_2^+ , m_i=2 a.m.u.	$5.1 \cdot 10^9$	$1.8 \cdot 10^9$	$8.6 \cdot 10^8$
n_e (cm^{-3}) by N^+ if m_i=14 a.m.u.	–	$4.8 \cdot 10^9$	$2.3 \cdot 10^9$
n_e (cm^{-3}) by N_2^+ if m_i=28 a.m.u.	–	$6.8 \cdot 10^9$	$3.2 \cdot 10^9$

Radial distributions parameters weren't determined, because 150...200 plasma discharges were necessary to obtain only a single I-V characteristic. All measurements were made in the probe position where the Langmuir probe floating potential was the highest.

The optimal for RF wall conditioning working gas content was the hydrogen-nitrogen mixture with 50/50 % volume ratio, as it provided the highest plasma density. Electron temperature 2...4 eV and of plasma density ~$4 \cdot 10^9$ cm^{-3} were achieved as the most suitable for chosen wall conditioning scenario.

CRYOGENIC TRAP OPERATION

The method of vacuum chamber wall conditioning control described in [0] was used to estimate the conditioning efficiency. This method of conditioning effectiveness estimation and its experimental application is described in detail in Refs. [0,0]

According to this method, the gas pumped from the vacuum chamber was condensed on the liquid nitrogen trap (Fig. 5) inner surface during the RF wall conditioning. Afterwards, the trap was cut off from the vacuum chamber by two vacuum valves and defrosted. The closed volume around the trap was filled with the gas evaporated from the trap surface.

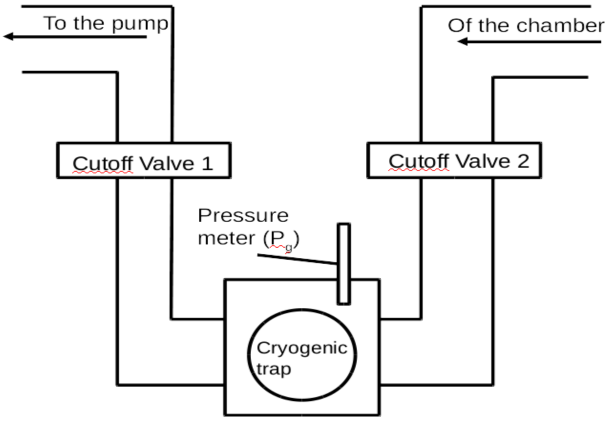

Fig. 5. Scheme of the liquid nitrogen trap

The liquid nitrogen trap volume together with the outlet branch is about 52 l, the liquid nitrogen trap volume is 32.5 l, the cooler (nitrogen) volume is 2.7 l and inner surface area of the trap is about 0.105 m^2. The pressure increases in the cut off volume as the temperature rises and the condensate evaporates from the trap surface.

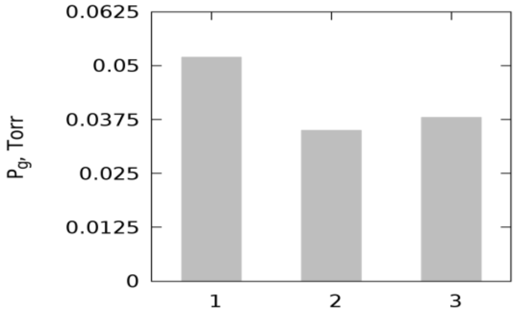

Fig. 6. Pressure in trap volume after 5-minute exposition. Bar 1 is for gas mixture is 50 % hydrogen + 50 % nitrogen, $P_{chamber}=3\cdot10^{-2}$ Torr. Bar 2 is for background level during nitrogen pumping, $P_{chamber}=2.5\cdot10^{-2}$ Torr. Bar 3 is for background level during hydrogen pumping, $P_{chamber}=3\cdot10^{-2}$ Torr

The increment of gas pressure P_g in the closed trap volume is proportional to the gas amount pumped from the vacuum chamber and condensed at the liquid nitrogen trap. The background level of the vacuum chamber out-gassing was determined first, and the amount of condensed gas was measured when there was no wall conditioning and the vacuum chamber was filled with the working gas.

Fig. 6 presents results of P_g measurements without the RF discharge. The exposition time was 5 minutes. The hydrogen pumping background level is higher than the nitrogen one.

Fig. 7 presents P_g values during the RF wall conditioning, bar 1 corresponds to the wall conditioning at the beginning of the experimental campaign and bar 2 – after 45 hours of wall conditioning. It's seen that the initial P_g value is greater by an order of magnitude. This means that amount of desorbed impurities pumped from the vacuum chamber decreased 10 times during the wall conditioning.

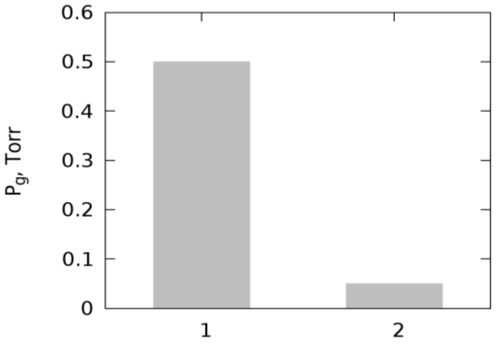

Fig. 7. P_g measurements during RF wall conditioning at the beginning of experimental campaign (1) and after 45 hours of RF wall conditioning (2)

Fig. 8 shows that gas mixtures provide 4 times more intensive volatile substances production than a pure hydrogen discharge.

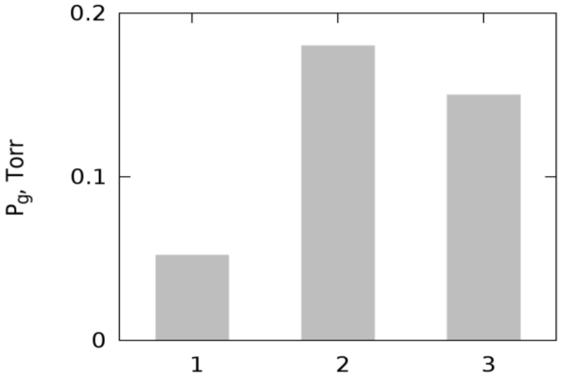

Fig. 8. P_g values comparison for wall conditioning in hydrogen and in 50% mixture of hydrogen and nitrogen. Exposure time was 5 minutes. Bar 1 is for RF wall conditioning in hydrogen, bars 2, 3 are for gas mixtures RF conditioning: 2 – (50/50)%; 3 – (10/90)% (H_2/N_2)

Fig. 9 displays time evolution of the residual pressure, P_{res}, in vacuum chamber during the wall conditioning. P_{res} reached the minimal value $6.2\cdot10^{-2}$ Torr in 25 first hours of the conditioning regime without magnetic field. $P_{residual}$ was not changed until the end of the campaign.

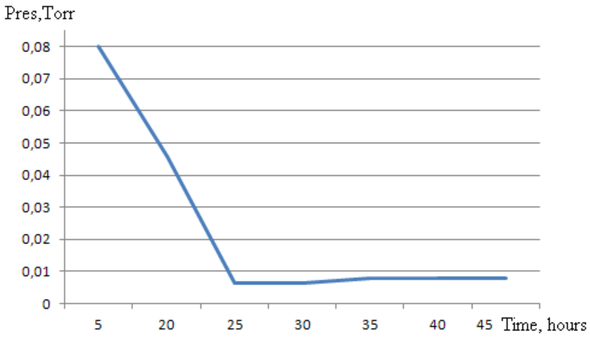

Fig. 9. Residual gas pressure evolution

CONCLUSIONS

The radio-frequency wall conditioning without magnetic field was performed in continuous regime at the VHF frequency 130 MHz and launched power ~3 kW. The discharge existed in high gas pressure 0.1...0.01 Torr, was located near the antenna, and did not spread around the torus. Its parameters were measured using the Langmuir probe and optical diagnostics. The effect of wall conditioning was judged by the amount of substances accumulated at the cryogenic vacuum trap. This amount appeared by the order of magnitude higher than without the discharge what indicates apparently the wall conditioning. Hydrogen, nitrogen and their mixtures had been tried as working gases. The wall conditioning in the mixture (50/50)% was selected as the best.

ACKNOWLEDGEMENTS

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НЕПРЕРЫВНЫЙ ЧИСТЯЩИЙ СВЧ-РАЗРЯД БЕЗ МАГНИТНОГО ПОЛЯ В ТОРОИДАЛЬНОЙ КАМЕРЕ

А.В. Лозин, В.Е. Моисеенко, М.М. Козуля, Е.Д. Крамской, В.Б. Коровин, А.В. Евсюков, Л.И. Григорьева, А.А. Белетский, А.Н. Шаповал, М.М. Махов, А.Ю. Красюк, Д.И. Барон и команда торсатрона Ураган-2М

На торсатроне Ураган-2М был выполнен модельный эксперимент по чистке стенок вакуумной камеры без магнитного поля. Плазменный разряд создавался той же антенной и СВЧ-генератором, которые использовались для чистки в слабом магнитном поле (B_0=100 Гс). Эксперимент проводился на протяжении всего периода чистки во время экспериментальной кампании Урагана-2М. Динамика чистки стенок была получена вместе со стандартными измеряемыми параметрами плазмы.

БЕЗПЕРЕРВНИЙ ОЧИЩУЮЧИЙ НВЧ-РОЗРЯД БЕЗ МАГНІТНОГО ПОЛЯ В ТОРОЇДАЛЬНІЙ КАМЕРІ

А.В. Лозін, В.Є. Моісеєнко, М.М. Козуля, Є.Д. Крамской, В.Б. Коровін, А.В. Євсюков, Л.І. Григор’єва, А.А. Білетський, А.М. Шаповал, М.М. Махов, А.Ю. Красюк, Д.І. Барон і команда торсатрону Ураган-2М

На торсатроні Ураган-2М було проведено модельний експеримент із чистки стінок вакуумної камери без магнітного поля. Плазмовий розряд створювався тією самою антеною та НВЧ-генератором, що використовуються для чистки в слабкому магнітному полі (B_0=100 Гс). Експеримент проводився впродовж всього періоду чистки під час експериментальної кампанії Урагана-2М. Динаміка чистки стінок була отримана разом із стандартними вимірюваними параметрами плазми.