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WALL CONDITIONING RF DISCHARGES IN URAGAN-2M TORSATRON

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The studies of the RF discharges for wall conditioning have been carried out. The goal of the discharge wall conditioning is the removal of adsorbed species from the wall so that they may then be pumped out of the vacuum chamber. The adsorbed atoms or molecules may be removed by the ion or atom impact owing to the momentum transfer or chemical interaction. If during the wall conditioning plasma is magnetically confined, as would happen in superconducting stellarators, the outflow of ions is not intensive and their flux to the wall of the vacuum vessel is not uniformly distributed. Under such conditions, the wall conditioning with chemically active neutral atoms or molecules [1] is advantageous. Such neutrals are produced intensively from a molecular gas in partially ionized plasma when the degree of ionization is low. Such a scenario for wall conditioning is studied for the discharges in hydrogen. In this scenario the cleaning agents are the hydrogen atoms resulting from the dissociation of the hydrogen molecules. They have Franck-Condon energies, about 3 eV. If the electron temperature in the discharge is less than the ionization threshold, 4-10 eV, the dissociation rate is higher than the ionization, and one electron produces a number of neutral atoms during its lifetime.

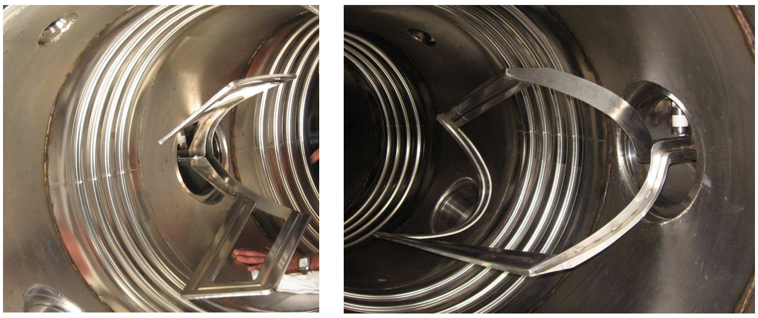

Fig. 1 Antennas of Uragan-2M: double frame antenna (left) and single frame antenna (right).

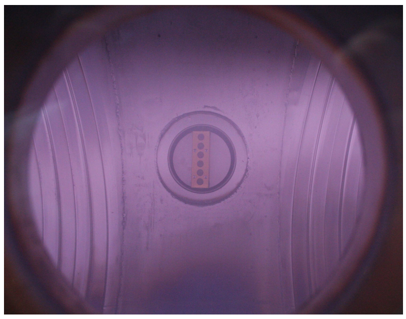

Fig. 2. View of continuous discharge plasma

The experiments are performed at the Uragan-2M stellarator (torsatron) [2]. The machine has the major plasma radius R = 1.7 m, the average minor plasma radius $a \leq 0.22$ m and the toroidal magnetic field $B_0 \leq 2.4$ T. Continuous RF discharges in Uragan-2M torsatron are sustained by the 1 kW RF oscillator in the frequency range 4.5-8.8 MHz. This power is coupled to plasma by a double frame antenna (see Fig. 1). Such a small power creates a plasma with low density up to $n_e = 8\times10^9$ cm^{-3}. The measurements are performed by the optical diagnostics, Langmuir probes and microwaves. Before and after discharges a mass spectrometry is used to analyze the residual gas composition. If the electron temperature is low $T_e < 20\,\text{eV}$, it is calculated following [3] from the ratio of the intensities of the integral emission of Fulcher-α series to H_α line. The concentration of neutral hydrogen atoms $C_H = n_H / n_{H2}$ is calculated from the analysis of the intensities of spectral lines of Balmer series [4]. The key moment here is the separation of the emission induced by the excited atoms and the emission resulted from the dissociative excitation of molecules. Since the plasma density is low the noise-induced error is high for used diagnostics.

It is not possible to measure such a low plasma density with the interferometer. The resonator method, which measures the resonant frequency shift induced by plasma, is used instead.

The discharge (see Fig.2) fills up the whole plasma column and follows the stellarator magnetic configuration. The dependences of the electron temperature and of the neutral atom concentration calculated from the optical measurements are shown on Fig. 3 versus neutral gas pressure and on Fig. 4 versus magnetic field on axis. The decrease of the temperature with rising pressure is higher than expected. The dependences demonstrate that the discharge could be sustained in very wide range of discharge conditions. As it is seen from Fig.4, the optimum magnetic field is B_{0opt} = 600 G, for practical wall conditioning a low magnetic field B_0 = 250 G is chosen.

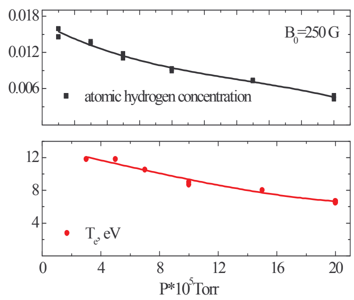

Fig. 3. Dependence of atomic hydrogen concentration and electron temperature on hydrogen pressure.

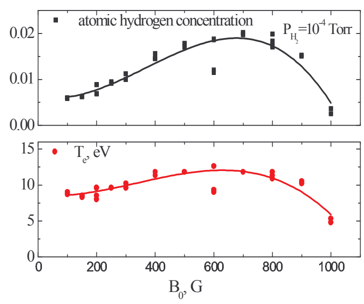

Fig. 4. Dependence of atomic hydrogen concentration and electron temperature on axial magnetic field.

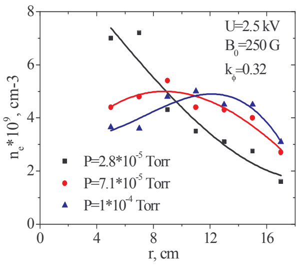

Fig. 5. Plasma density profiles for different neutral gas pressures.

The probe measurements of the plasma density at different gas pressures (see Fig. 5) show that the plasma density has a bulk profile. Plasma density profile is more central for low neutral gas pressures. The maximum density is $n_e = 8\times10^9$ cm^{-3}. On increase of gas pressure the density decreases, but less than in proportion to the pressure.

Measured with the resonator method, the dependence of plasma density on launched RF power for different pressures of neutral gas is shown in Fig. 6. The initial density increase saturates, and this happens earlier for lower pressures.

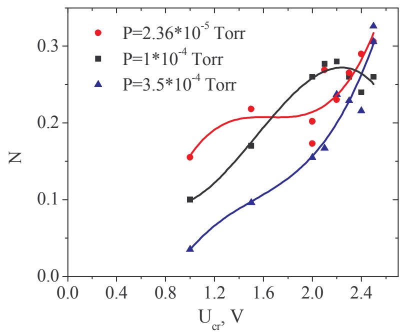

Fig. 6. Normalized plasma density as a function of generator anode voltage at different neutral gas pressures.

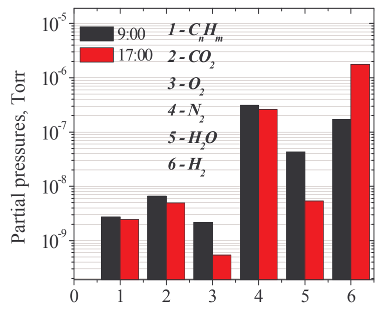

Fig. 7. Mass-spectrometer measurements of partial pressures before and after 6-hour RF discharge.

The wall conditioning is indicated by the behavior of mass composition of the residual gas. The evolution of the gas components for single operation day (see Fig. 7) designates removal of oxygen and water and slow removal rate for hydrocarbons.

The continuous discharge is combined with a pulse discharge with power 100-200 kW, frequency 5.6 MHz, pulse duration 15 ms and the rate 6 pulses per minute. For this discharge the dependence of the plasma density measured by the interferometer and plasma temperature measured optically by the “helium thermometer” (with helium minority puffing) [5] on the neutral gas pressure and the steady magnetic field is given in Figs. 8 and 9. There is an optimum magnetic field for this discharge B_{0opt} = 300 G. It is planned to use further this discharge for wall conditioning.

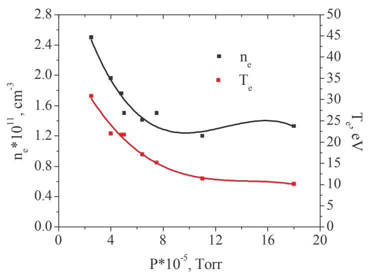

Fig. 8. Plasma density and temperature in combined discharge as a function of neutral gas pressure.

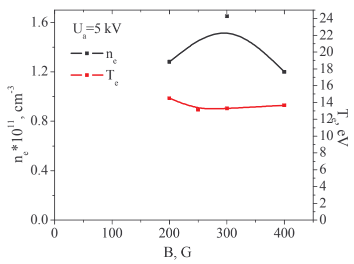

Fig. 9. Plasma density and temperature in combined discharge as a function of magnetic field.

A model of the radio-frequency plasma production is developed which includes the system of the balance equations and the boundary problem for the Maxwell’s equations. The balance of the electron energy includes the RF heating power, energy losses on the vibrational and electronic excitation and ionization of molecules and the heat transport losses. The balance of the charged particles accounts for the ionization and diffusion losses of the particles. The problem is solved in cylindrical geometry. The plasma is assumed to be azimuthally symmetrical and uniformly distributed along plasma column. The boundary problem for Maxwell's equations is solved each time moment for current plasma density and temperature distributions and returns the calculated RF heating power density to the balance equations.

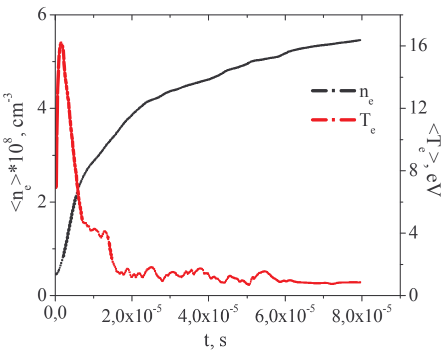

Fig. 10. Time evolution of plasma density and temperature (calculated).

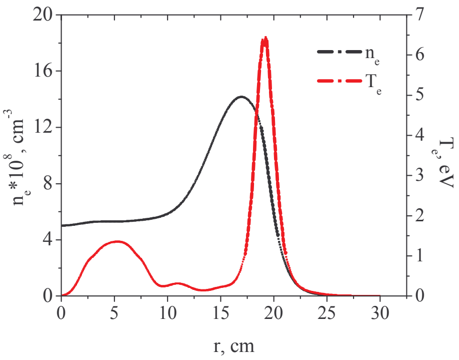

Fig. 11. Radial profiles of plasma density and temperature at time moment t=10^{-4}s (calculated).

An example of the calculations on low power RF discharge in Uragan-2M stellarator with the frame antenna is shown in Figs. 10 and 11. This calculation is done with the toroidal magnetic field B_0 = 250 G and neutral gas pressure is $P_{H2}=6\cdot10^{-4}$ Torr. The RF power is kept constant in time and equal P_{RF}=560 W.

Conclusions

The physical features of the low-power discharges producing hydrogen atoms are studied. The pulsed discharge can be performed in a wide range of neutral gas pressures but has an upper limit in steady magnetic field. The continuous discharge exists in broader range of pressures and magnetic fields. The atypical behavior of the discharge with neural gas pressure variation should be noticed. Both discharges look to be suitable for wall conditioning and, after certain improvements, have a prospect for usage in superconducting stellarators.

Acknowlegements.

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