

Upgrade glow discharge cleaning system on the Uragan-2M stellarator

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Introduction

Various methods are used to wall conditioning fusion facilities such as tokamaks and stellarators. One of the most common of these is the method of wall conditioning using glow discharge plasma [1-2], as this method is both effective and technically simple. A glow discharge cleaning system (GDC) was developed and implemented on the Uragan-2M (U-2M) stellarator [3-5]. This system was upgraded, and a new anode system was developed and manufactured, which includes two identical anode units.

The paper compares the results of experiments with glow discharge plasma in helium and hydrogen atmospheres. The current-voltage (I-V) characteristics of the discharges are obtained, the plasma parameters are measured, and its composition is determined.

Experimental setup and diagnostics

The stellarator Uragan-2M [3-5], of torsatron type, with a large radius of 1.7 m, radius of toroidal vacuum chamber 0.34 m, volume 3.879 m³ and torus surface area $S \approx 23$ m². The SNA-2-01 dual-channel gas injection system was used to inject and regulate the working gas pressure. Discharge current and voltage were measured with an ammeter and a voltmeter. A triple probe was used to measure plasma parameters. A SOLAR TII SL-40-2-3648 USB spectrometer was used to determine the plasma composition.

The U-2M glow discharge system was upgraded, and a new anode system was designed and built, including two identical anode units (see Fig. 1a). The shape of the anodes is mimicking to that of the anodes of the GDC at the Wendelstein 7-X stellarator. The diameter of the anode (see Fig. 1c) is 130 mm, the thickness is 5 mm, and the height is 20 mm. The material of the electrodes is stainless steel (AISI 321). The mass of one electrode is ≈ 0.49 kg, with an area of ≈ 0.015 m² and a volume of $\approx 6.15 \cdot 10^{-5}$ m³. The anodes have the form of a spherical calotte with an angle of inclination of 10 degrees, both inside and outside.

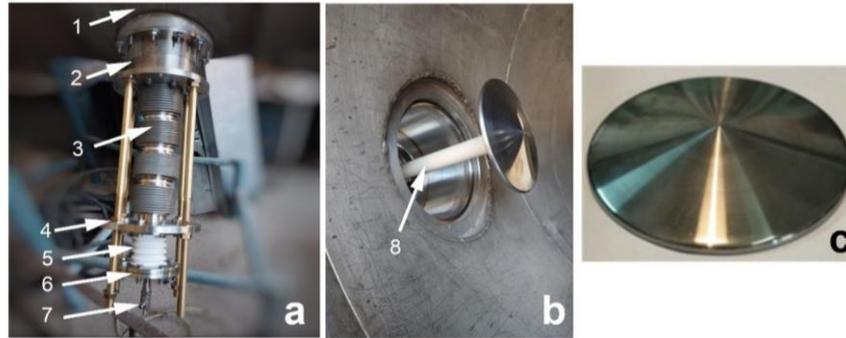


Fig. 1. (a) Anode system: 1 - vacuum chamber U-2M, 2 - transitional vacuum pipeline, 3 - bellows assembly, 4 - anode position control system, 5 - insulator (F4 (fluoroplastic)), 6 - flange, 7 - water cooling system. (b) anode in the model of the vacuum chamber U-2M: 8 - insulator (ceramic). (c) anode.

Experimental results

The experiments were carried out in the pressure range $\sim 0.3 - 13$ Pa, in the discharge current range from 0.1 to 1A. The dependence of breakdown voltage (see fig. 2) in the atmosphere of He and H₂ in the range of 2.41 - 13.4 Pa was measured. In this case, the minimum breakdown voltage for He and H₂ was 514 V and 380 V, respectively, at a pressure of 13.4 Pa. The maximum breakdown voltage for He was 1.44 kV at a pressure of 5.53 Pa, and for H₂ the maximum breakdown voltage was 1.22 kV at a pressure of 2.41 Pa. Fig. 2 shows that according to Paschen's law, the breakdown voltage increases with decreasing pressure.

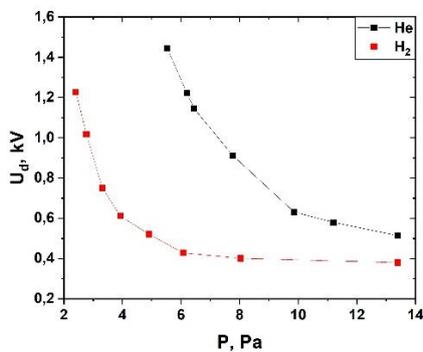


Fig. 2. Dependence of breakdown voltage on the gas pressure He and H₂

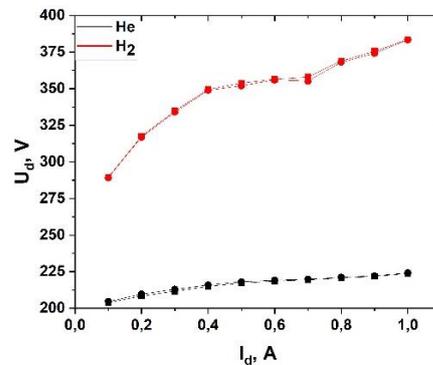


Fig. 3. Voltage current characteristics of glow discharge. He P=6.42 Pa; H₂ P=6.34 Pa

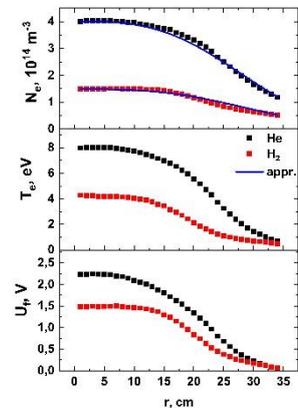


Fig. 4. The radial profile of density, temperature and floating potential. $I_d=0.1$ A; He P=6.57 Pa; H₂ P=6.7 Pa

The figure 3 shows the current-voltage (I-V) characteristic of glow discharge in He and H₂ at a pressure of 6.4 Pa. A tenfold increase in discharge current is observed, with an corresponding increase in voltage across the electrodes of approximately 1.1 times for He and 1.32 times for H₂. Experimentally, the I-V characteristics are similar to the characteristics of the discharge with a hollow cathode [6,7].

The movable triple probe was used to measure plasma parameters (Fig. 4) along the minor radius of the U-2M vacuum chamber. The temperature in the helium plasma was up to ≈ 8 eV and in the hydrogen plasma - up to ≈ 4.3 eV, the plasma density was up to $\approx 4 \cdot 10^{14} \text{ m}^{-3}$ in the helium atmosphere and up to $\approx 1.5 \cdot 10^{14} \text{ m}^{-3}$ in the hydrogen atmosphere, the floating potential was up to ≈ 4.3 V in the helium atmosphere and up to ≈ 2.2 V in the hydrogen atmosphere. The observed plasma parameters characteristic of glow discharge [8], including those in toroidal vacuum chambers [9]. The maximum plasma parameters are observed at the centre of the plasma column, while the plasma density, electron temperature and floating potential decrease from the centre of the vacuum chamber to its walls. The plasma density distribution can be approximated by the formula: $N(r) = N(0) \cdot \exp(((r/R)^A) \cdot \log(B))$, where A and B are variables, for example, for He, A = 3 and B = 0.3 are suitable.

The plasma composition was determined by optical emission spectroscopy. Figs. 5 and 6, the optical spectra of the glow discharge plasma in the range 214 to 673 nm, for He and H₂ are presented. In the optical emission spectrum of the plasma of He, Fig. 5, the lines of excited atoms of He I (He^{*}) are observed. In the spectrum of the H₂ plasma, spectral lines of excited hydrogen atoms H I (H^{*}) and molecular hydrogen are observed, as can be seen in Fig. 6.

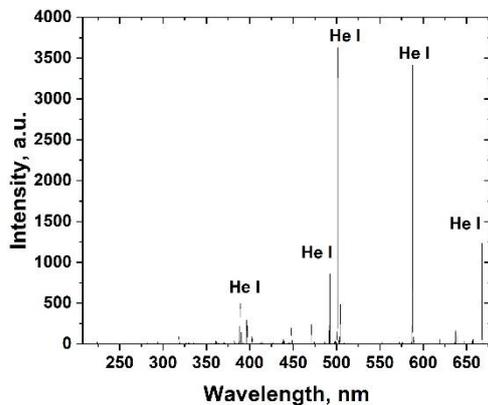


Fig. 5. Emission spectra of glow discharge in helium, at P=6.4 Pa, I_d=1 A

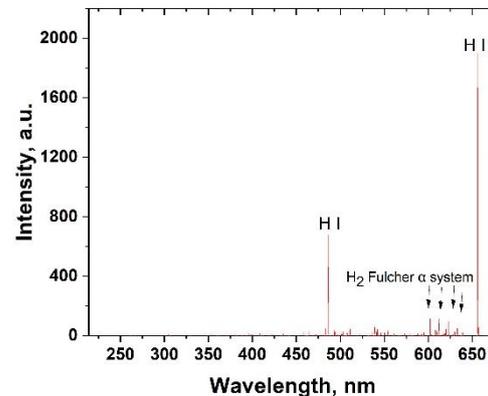


Fig. 6. Emission spectra of glow discharge in hydrogen, at P=6.34 Pa, I_d=1 A

Conclusion

The measured breakdown voltage is observed to be higher in He than in H₂. The glow discharge characteristic curve showed that an increase in voltage leads to an increase in discharge current. Measurements of the radial profile of plasma parameters showed that they decrease from the centre of the vacuum chamber and are higher for He than for H₂. In the optical spectrum of plasma emission, the lines of excited He I (He^{*}), hydrogen atoms H I (H^{*}) and molecular hydrogen are observed.

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