Study of glow discharge plasma in a hydrogen and helium mixture on the Uragan-2M

Yu. P. Martseniuk[1], Yu. V. Kovtun[1], O.V. Lozin[1], V. B. Korovin[1], V.S. Romanov[1], S. M. Maznichenko[1], O. Yu. Krasiuk[1], O. V. Yevsiukov[1], D. I. Baron[1], M. N. Makhov[1], A. N. Shapoval[1], S. A. Tsybenko[1], V. Yu. Gribanov[1], V. E. Moiseenko[1,2]

[1]*Institute of Plasma Physics of the National Science Center "Kharkiv Institute of Physics and Technology", Kharkiv, Ukraine*

[2]*Ångström Laboratory, Uppsala University, Uppsala, Sweden*

E-mail: martsenyuky@kipt.kharkov.ua

Introduction

In the research of high-temperature plasma for magnetic confinement fusion, wall conditioning is an important and necessary procedure. There are various methods for wall conditioning, one of which is glow discharge [1-3]. Hydrogen or helium are usually used as working gases in glow discharge. A glow discharge is also used in the boronization procedure [4-7]. In this case, a mixture of helium and diborane can be used, which releases boron upon dissociation. Therefore, it is necessary to conduct research on glow discharge in a mixture of hydrogen and helium.

This research note (хотя в плакате paper) presents the first results of a research study on glow discharge plasma in a mixture of helium and hydrogen, with hydrogen concentrations in the mixture from 25% to 75%. 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 Uragan-2M (U-2M) is a medium-size stellarator (Kharkiv, Ukraine) of torsatron type with a major radius R = 1.7 m, a minor radius of the toroidal vacuum chamber r_c = 0.34 m, a volume $V_c \approx 4$ m^3 and a surface area $S \approx 23$ m^2, and an average plasma minor radius $r_{pl} < 0.24$ m [2, 3, 8]. The Uragan-2M stellarator uses two anode systems and a vacuum chamber serving as the cathode. The anodes are calotte-shaped and made of stainless steel, with a diameter of 130 mm, a thickness of 5 mm and a height of 20 mm [3]. The power supply system for the glow discharge allows voltages of up to 1.7 kV and currents of up to 5 A, which are measured using an ammeter and a voltmeter. The SNA-2-01 system is used for the gas injection and control of working gas pressure. A triple probe is used for measuring plasma parameters, and a SOLAR TII SL-40-2-3648 USB spectrometer gives optical emission spectrum analyzing which the plasma composition is suggested [8].

Experimental results

In the experiments the discharge currents range from 0.1 to 1 A, within a pressure range of ≈ 0.3–14 Pa. The breakdown voltage (see Fig. 1) was measured for a mixture of helium and hydrogen, with hydrogen concentrations in the mixture from 25% to 75%, and compared with that one for 100% He and 100% H_2 reported in [3]. Figure 1 shows that the overall breakdown voltage behavior for mixtures and pure gases is compliant with Paschen's law [9, 10]. In the hydrogen concentration range studied (25% to 75%), a lower breakdown voltage was observed than in pure helium. The minimum breakdown voltage for the He + H_2 mixtures was at the level of the breakdown voltage of 100% H_2 (≈ 380 V) [3] at a pressure of 13 Pa. The breakdown voltage decreased as the hydrogen content in the He + H_2 mixture increased. Thus, at an initial concentration of 25% H_2, the breakdown voltage at a pressure of 2.8 Pa was 1400 V, and at a concentration of 75% H_2, it was 1010 V. Accordingly, the addition of hydrogen to helium leads to a decrease in the breakdown voltage. These dependencies may be related to the behaviour of the first Townsend coefficient and the secondary electron emission coefficient for helium and hydrogen [9, 10].

The figure 2 shows the current-voltage (I-V) characteristic of glow discharge in a mixture of He + H_2, at a pressure of 2.1 Pa. As in pure gases He and H_2 [3], a tenfold increase in discharge current is observed with a corresponding increase in voltage on the electrodes. Experimentally, the I-V characteristics are similar to the characteristics of the discharge with a hollow cathode [8, 11]. Also, in the experiment, an increase in the voltage on electrodes is observed as the hydrogen concentration in the mixture rises.

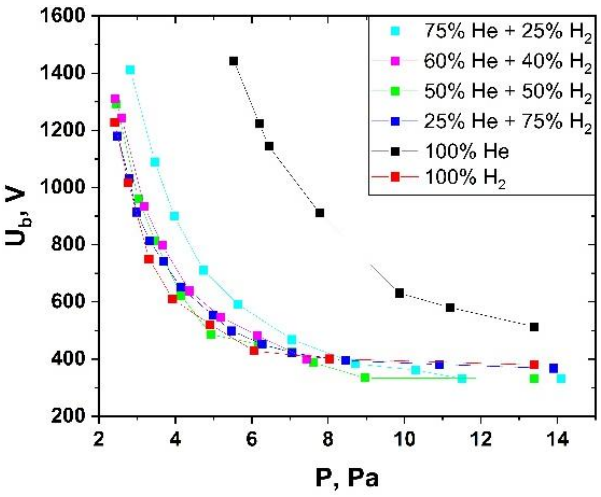

Fig. 1. Dependence of breakdown voltage on the gas pressure He and H_2 and mixture of He + H_2.

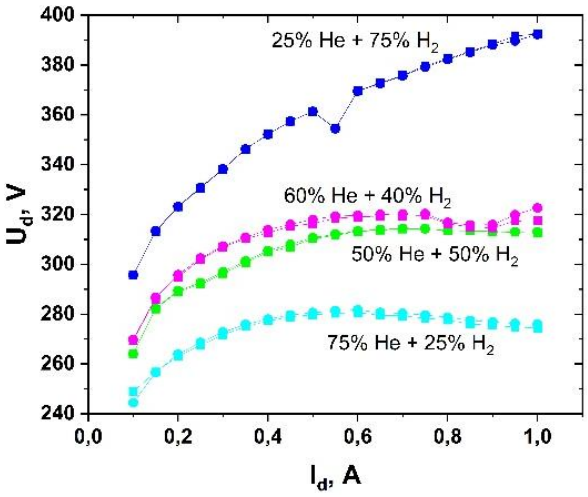

Fig. 2. Voltage current characteristics of glow discharge, P=2.1 Pa.

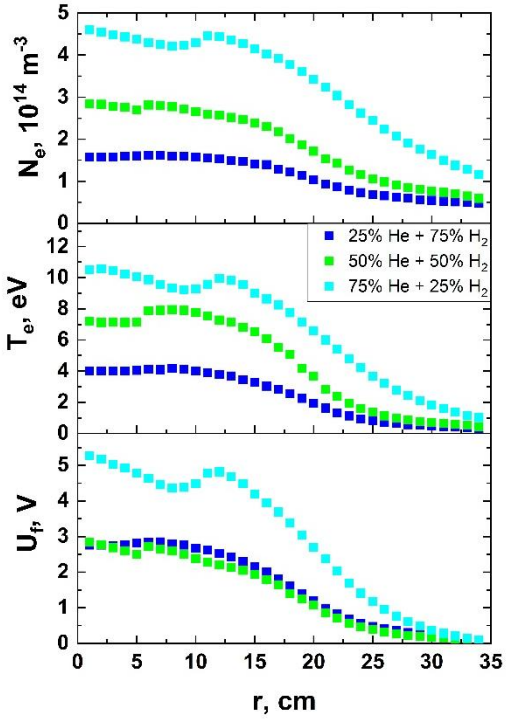

Fig. 3. The radial distribution of density, temperature and floating potential. I_d=0.1 A; 25% He + 75% H_2 P=6.27 Pa; 50% He + 50% H_2 P=6.15 Pa; 75% He + 25% H_2 P=6.15 Pa.

A triple probe installed on the manipulator was used to measure plasma parameters (Fig. 3) along the minor radius of the U-2M vacuum chamber. The density and temperature in He are greater than in H_2, as shown in the last research [3]. In the case of helium-hydrogen mixtures, an increase in plasma parameters is observed as the helium concentration in the mixture rises. For example, at 75% He + 25% H_2, the maximum plasma density was up to $\approx 4.6 \cdot 10^{14}$ m^{-3}, the temperature was up to ≈ 10.5 eV, and in the case when 25% He + 75% H_2 - the values were up to ≈ 4 eV, and up to $\approx 1.6 \cdot 10^{14}$ m^{-3}. The floating potential was highest in the case of 75 % He + 25% H_2 to ≈ 5.3 V, in other cases it was up to ≈ 2.8 V. And also the maximum plasma parameters are observed in the center of the plasma column. Such a picture was observed earlier during studies of the glow discharge [3]. At the same time, the plasma density, electronic temperature and floating potential decrease from the center of the vacuum chamber to its walls. Plasma parameters can be said to be characteristic of glow discharge [9, 10].

In the optical emission spectrum of a glow discharge plasma, in a mixture of helium and hydrogen, with hydrogen concentrations in the mixture from 25% to 75%, in the range from 214 to 673 nm, lines of excited helium atoms He I (He^*) at 502 nm, 588 nm, and 668 nm, and spectral lines of excited hydrogen atoms H I (H^*) at 487 nm and 656 nm are observed.

Conclusion

Investigations of glow discharge on the Uragan-2M stellarator in a mixture of helium and hydrogen, with hydrogen concentrations in the mixture from 25% to 75% have been carried out. The breakdown voltage decreased as the hydrogen content in the He + H_2 mixture increased. Accordingly, the addition of hydrogen to helium leads to a decrease in the breakdown voltage. However, the discharge voltage increases as the hydrogen concentration in the He + H_2 mixture increases. The plasma parameters increase with increasing He concentration in the He + H_2 mixture, and measurements of the radial profile of the plasma

parameters showed that they decrease from the centre of the vacuum chamber towards its wall. In the optical spectrum of plasma emission, in a mixture of He + H_2, the lines of excited He I (He^*), hydrogen atoms H I (H^*) are observed.

Acknowledgement

This work has been carried out within the framework of the EUROfusion Consortium, funded by the European Union via the Euratom Research and Training Programme (Grant Agreement No 101052200 — EUROfusion). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.

The work of the coauthors Yu. P. Martseniuk, Yu. V. Kovtun, V. B. Korovin, V. E. Moiseenko is supported in part by the National Research Foundation of Ukraine (Grant 2023.03/0101).

References

[1] T. Wauters et al. Wall conditioning in fusion devices with superconducting coils. Plasma Physics and Controlled Fusion 62, 034002 (2020)

[2] Y. V. Kovtun et al. Design and Application of Glow Discharge Cleaning at Uragan-2M Stellarator, Problems of Atomic Science and Technology 27, 19 (2021)

[3] Yu. Martsenuik et al. Upgrade glow discharge cleaning system on the Uragan-2M stellarator. 51st EPS Conference on Plasma Physics, Vilnius, Lithuania, July, 2025. 2 P 110.

[4] J. Winter et al. Boronization in TEXTOR. Journal of Nuclear Materials 162, 713-723 (1989)

[5] U. Schneider et al. Boronization of ASDEX. Journal of nuclear materials 176, 350-356 (1990)

[6] U. Schneider and J. Stadlbauer. Boronization on Wendelstein 7-AS. Fusion Technology 1992. North-Holland, 1993. 376-380.

[7] M. Mayer et al. Properties of boron layers deposited during boronisations in W7-X, Nuclear Materials and Energy 41, 101778 (2024)

[8] Yu. P. Martseniuk et al. Glow discharge cleaning on the Uragan-2M stellarator, Fusion Science and Technology 81, 1-12 (2025)

[9] Y. P. Raizer, Gas Discharge Physics, 1st ed., Springer-Verlag, Berlin, 1991.

[10] M. A. Lieberman and A. J. Lichtenberg, Principles of Plasma Discharges and Materials Processing, 2nd ed., Wiley, New Jersey, 2005

[11] A. Lisovskiy et al. Comparing properties of dc discharges in tubes possessing a hollow cathode or anode in an undergraduate laboratory, European Journal of Physics 40, 045203 (2019)