LOCAL HYDROGEN RECYCLING IMPACT ON OPERATION OF ROD PLASMA INJECTORS

G.P. Glazunov, V.I. Tereshin, E.D. Volkov, A.L. Konotopskiy,
Institute of Plasma Physics of National Science Center „Kharkov Institute of Physics&Technology", 61108 Kharkov,Ukraine, e-mail: glazunov@ipp.kharkov.ua

J. Baranowski, M.J. Sadowski, E. Skladnik-Sadowska, J. Stanislawski, A. Wiraszka
A. Soltan Institute of Nuclear Studies, 05-400 Otwock-Swierk, Poland

The strong influence of hydrogen recycling on the IONOTRON-046 plasma injector operation was found. The transitions were even observed from deposition by pulsed erosion (DPE) regime of the IONOTRON operation, which characterized by strong electrode erosion into pulse implantation doping (PID) regime with low electrode erosion. Physical mechanisms of such behavior are considered using the results of measurements of an outgassing rate from the titanium electrode rods used in IONOTRON-046 by means of mass spectrometry and thermal desorption methods, measurements of current- and voltage-waveforms, and spectroscopic studies of plasma emission. A possible practical use of the observed effects is also discussed.
PACS: 52.58..Lq; 52.40.Hf

1. INTRODUCTION

Hydrogen recycling process plays important role in the operation of different fusion devices with magnetic confinement. The particular attention is given to this phenomenon studies including its active control, in the frame of plasma-material interaction investigations. Also in pulsed plasma generators, e.g. multi-rod plasma injectors (RPI or IONOTRON type of plasma devices), plasma accelerators, etc., which are used for various plasma applications [1, 2], there is needed more detailed information about such processes. The RPI devices are equipped with two coaxial electrodes consisted of many (up to 64) thin rods made usually of molybdenum or titanium. Electrode rods of a RPI device are the main plasma facing component, and, from the one hand, the processes of a gas sorption/release by its surface can influence the plasma machine operation and uncontrollable change properties of modified materials. On the other hand, by a control of the mentioned processes, one can change (select) a required operation regime and perform the modified materials treatment at other conditions. So in this work some imitation experiments were carried out to investigate the influence of hydrogen recycling process (hereinafter we have in view local hydrogen recycling process and local recycling coefficient determined by hydrogen sorption/release from RPI Ti-electrodes) on IONOTRONE-046 plasma performances. Such information can also be useful for understanding of physical mechanisms of hydrogen recycling processes in fusion devices.

2. EXPERIMENTS AND RESULTS

2.1. Outgassing behavior of Ti-electrodes.

As the outgassing from material in vacuum is one of the most important characteristics, which determines gas sorption/release processes and ground pressure, the measurements of outgassing rate in vacuum from the used in IONOTRON-046 Ti-rods were carried out before plasma experiments. A block scheme of the experimental setup used for the outgassing investigations is similar to that described in [3] with some modifications. The setup comprised a thick-wall stainless-steel vacuum chamber, which accommodated samples, a monopole mass-spectrometer, and gauges for measurements of the operating pressure. The vacuum chamber was connected with a turbomolecular pump and a mechanical fore pump. The specimens under studies were Ti-rods of 2 mm in diameter, and 145 mm in length, which were long-time used as external and internal electrodes in IONOTRON-046 under nitrogen plasma operation in DPE regime. For a comparison also investigated were virgin rods made of pure Ti, and samples made of stainless steel rod. The sample holder construction allowed the samples to be heated to required temperatures up to 600°C which were measured by the thermocouple. The experimental system was also equipped with special hydrogen chamber to provide hydrogen saturation of investigated rods to required concentration.

Measurements of an outgassing rate from investigated electrode-rods were performed by means of the thermal-desorption and mass-spectrometry methods [4]. Before those measurements the main vacuum chamber was baked up for 3 hrs, at a temperature of 100 ° C. When the system was cooled down to a room temperature, the final pressure achieved about $(3\text{-}5)\cdot10^{-8}$ Torr. Then the investigated rods were heated to a required temperature with a temperature rise of about 20°/min, and an increase in the total pressure (caused by desorbed gases) was measured. The specific net-outgassing rate (q) was calculated from the equation $q = (p - p_o)S/F$, where the pumping speed S = 50 l/s, F was a surface area of the heated sample, p_o was the initial pressure in vacuum chamber before sample heating, and p was the final pressure at given temperature value.

The mass-spectrum of the gases was registered during the whole desorption process. It was observed that the desorbed gases in 50-350°C range are gases with the ratio M/Ze = 18 (H_2O), 28 (CO, N_2), and 44 (CO_2), that is similar to outgassing behavior of investigated earlier Mo-rods [3]. But under heating in 300-500°C temperature range considerable hydrogen release was observed. It should also be noted that hydrogen release from the used external-electrodes (cathodes) was observed lower than

for virgin rods and hydrogen release from internal electrodes (anodes) visibly higher than that from external electrodes. During the heating of the Ti-electrode rods, which were previously long-time used in the RPI device, the outgassing more than order of value higher than that measured for the virgin Ti-rods and stainless steel samples (Fig.1).

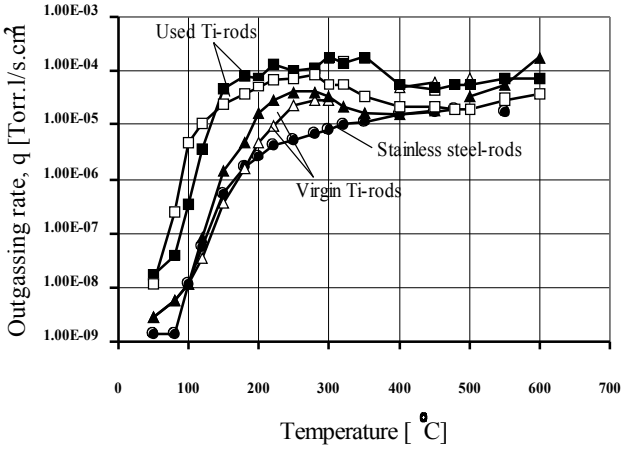


Fig.1. Temperature dependencies of specific net outgassing rate (q) from Ti-rods.

2.2. Current- and voltage-waveforms, spectroscopic studies.

Different experiments are run in RPI with various working gases: hydrogen, nitrogen, etc. A spectrum of the emitted ions depends on the injected working gas and a time delay between the gas puffing and the application of a high voltage pulse. The detailed description of IONOTRON-46 device was given in Ref.[1]. In this work RPI operated with nitrogen plasma in 28kV/16kJ regime with delay time 200μs when so called pulsed deposition mode (DPE) regime is realized, which is characterized by strong electrode erosion. Such regime was of a great interest taking into account its possible technology applications for surface modification of materials. Of course, the regime with low erosion, when working gas plasma is mainly produced, also is interested for hydrogen recycling investigations, and we are going to study it in the next work.

Optical spectra of plasmas, produced by high-voltage discharge between Ti-electrodes, were measured by means of a Mechelle-900 spectrometer within the wavelength range from 300 to 800 nm and 25 μs exposition time duration. Measurements of the emission spectra of nitrogen plasmas have been performed perpendicularly to the symmetry axis of the RPI electrodes at 10cm distance from their ends. Details of method of spectrum measurements and analysis were similar to that in Ref.[5]. Special attention was paid to the H_α, NII, TiII lines.

Four kinds of experiments were carried out in the RPI: with the use of Ti-electrodes long time operated under nitrogen plasma RPI, with the same Ti-electrodes, but after their mechanical cleaning and exposure to hydrogen at pressure 2 atm. during 48 hours, Ti-electrodes with the placing of the additional mono PdH_x-electrode (anode), Ti-electrodes after exposure in situ to hydrogen GD plasma. The typical waveforms and spectra for all above mentioned cases are shown in Fig.2. The spectral lines H_α, NII, TiII intensity evolution in dependence on the number of pulses are presented in Figures 3, 4, 5.

3. DISCUSSION

In order to explain the described outgassing behavior of the titanium electrode-rods, one can suggest possible mechanisms as similar to observed earlier for Mo-electrodes [3]. During the plasma operation regime, electrode surfaces are cleaned by plasma discharges and surfaces value increases due to radiation damages. As a result, the impurity sorbing capability increases during the time between plasma pulses and an exposure to atmosphere (for a comparison with the virgin samples). This impurity source can effect on RPI plasma machine operation and especially, it can be as very important factor for surface modification applications of RPI-plasmas due to possible decrease of investigated sample quality, caused by impurity release from electrode rods. Of course, this impact becomes lower after long time plasma machine operation and without exposure to atmosphere. In this case other effects caused by, so called, hydrogen recycling process can take place. Hydrogen sorption/release by electrode material (in general case by all materials of device) can change its properties, i.e. such as arc ignition probability, erosion behavior, reflection coefficient, electron emission coefficient etc., and can lead to changing of plasma machine performances and, as the result, to change properties of modified materials.

The observed essential hydrogen release from used Ti-rods can be explained by high hydrogen concentration in virgin rods. Even after long time operation under nitrogen puffing there are high hydrogen concentration in electrodes (it is lower in external and higher in internal electrodes). But plasma-activated near surface layer bulk of Ti-electrodes sorbs impurities

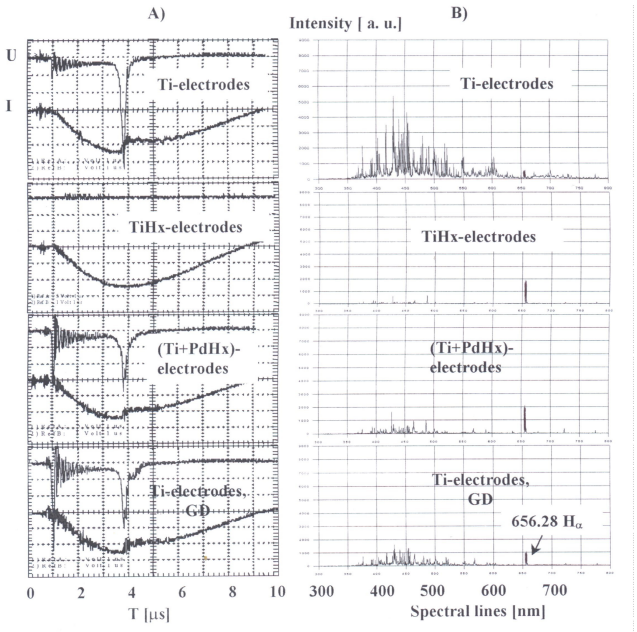


Fig. 2. Voltage(U)-current(I) wave-forms (A) and optical spectra (B) of nitrogen plasma emission in IONOTRON-

046 registered during first shots with the use of Ti (first row)-, TiH_x (second row)-, ($Ti+PdH_x$) (third row)- and hydrogen GD plasma treated Ti - electrodes (fourth row).

between plasma pulses and under atmosphere exposure, therefore we do not observed any influence of hydrogen in rods on device operation under nitrogen puffing (first row in Fig.2). Note, that it is the evidence for the fact that electrode-rod bulk has not been heated to high temperature under plasma impact. The mechanical cleaning of Ti-electrodes and their exposure to hydrogen at pressure 2 atm. leads to cardinal changes in nitrogen plasma regime of the IONOTRON device caused by a transition from low hydrogen recycling coefficient to high hydrogen recycling coefficient (second row in Fig.2). The similar effect with some specificity was also observed, when one hydrogen saturated $PdH_{0.55}$-electrode was placed in multi-Ti-rods system (third row in Fig.2) or when Ti-rods were treated in situ by GD hydrogen plasma of ≈300eV ion energy during 1 hour (fourth row in Fig.2)

If to suggest that spectral line intensity is proportionate to concentration of element in plasma column, one can see in Figures 4, 5, 6 that hydrogen release from electrodes leads to the transition from deposition by pulsed erosion (DPE) regime which characterized by strong electrode erosion into pulse implantation doping (PID) regime low electrode erosion.

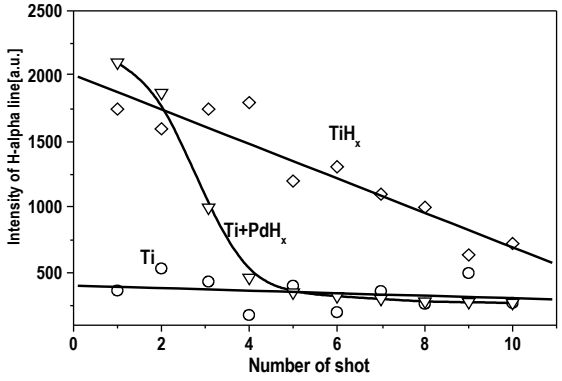
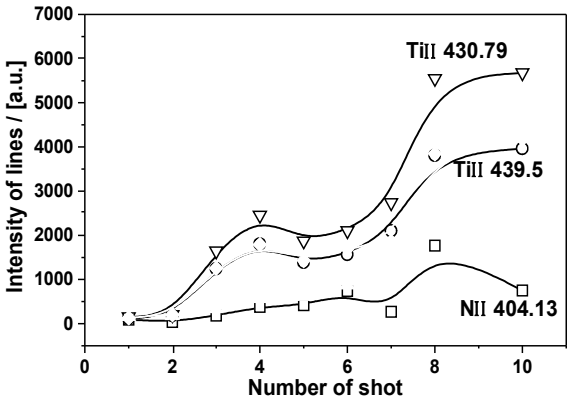


Fig. 3. Evolution of H_α line intensity vs. number of shot for different state of electrodes (high/low hydrogen recycling coefficient).

As seen in Fig. 3, 4, 5, under the use of TiH_x -and ($Ti+PdH_x$) – electrode systems the H_α-line intensity is highest possible during the first shots due to high hydrogen release from the nearest surface layer bulk of the rods. Palladium has high hydrogen mobility even at the moderate temperatures. So only one Pd-rod in electrode system provides H_α-line intensity increase during first pulse more than 64 hydrogen saturated Ti-rods. At the same time Ti-line intensities are the lowest (Fig.4). It means the lowest erosion of Ti-electrodes and that the transition from one operation mode (DPE) to another (PID) is realized due to high hydrogen recycling (additional gas puffing) along whole length of electrodes. After a few pulses (after about ten shots for TiH_x rods) hydrogen concentration in the nearest surface layer bulk of Ti-rods (or in Pd-rod) decreases and the operation regime reverts to the state of DPE mode (Fig.7). So the modification of local hydrogen recycling coefficient in the range of multi-rod electrode system could be as an original method to change operation regime of rod plasma



injectors that could be useful, e.g., for surface

Fig. 4. Evolution of TiII and NII lines vs. number of shot for discharges with TiH_x-electrodes.

modification experiments. In the case of the basic investigation of hydrogen isotope plasmas such method can provide the additional purity and improvement of plasma characteristics.

4. CONCLUSION

The main results of the described study can be summarized as follows. Changing of hydrogen recycling coefficient in the range of electrode system can lead to the transitions from deposition by pulsed erosion regime of the IONOTRON device operation, which characterized by strong electrode erosion, into pulse implantation doping regime with low electrode erosion. Such method could be used, e. g., in material modification experiments and in basic plasma investigations.

The specific net-outgassing rate of Ti rods, which were used in the nitrogen plasma pulse operation regime of the IONOTRON, was about one order magnitude higher than for the virgin Ti rods. The favorable reason of such outgassing behavior could be an enhancing of rod impurity sorbing capability under/after plasma irradiation. At the same time considerable hydrogen release at high temperature was observed from the used Ti-rods due to high hydrogen concentration in virgin Ti-rods.

These results are of importance for applications of IONOTRON-type devices in basic plasma studies and material engineering. It can also be useful for understanding of hydrogen recycling processes in fusion machines.

ACKNOWLEDGEMENT

The described study was performed within the frame of Polish-Ukrainian Scientific Cooperation Program supported by the Polish and Ukrainian governments

REFERENCES

[1] J. Langner, et al., Nukleonika, **45**/3 (2000) 193-197.

[2] V.I. Tereshin. 2nd National Symposium PLASMA'95 "Research and applications of plasmas", Warsaw, Poland, June 26-28, 1995, v.2. Invited papers, p.87-94.

[3] G.P. Glazunov, et al., Proc. of the Intern. Symp. PLASMA-2001 "Reasearch and Applications of Plasmas", Warsaw, September 19-21, 2001, P8-8, p.216

[4] G.P. Glazunov, et al., J. Nuclear Materials. **290-293** (2001) 266-270.
[5] J. Baranowski, E. Skladnik-Sadowska, K. Czaus, M.J. Sadowski. NUCLEONIKA, (2002) to be published.