Behavior of Reversible Hydrogen Getters under the Pulsed Plasma Heat Loads

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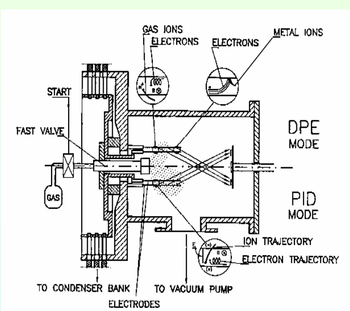
Introduction

Hydrogen getters can be used in fusion devices for the creation of a controlled flow of hydrogen isotopes from the material surfaces to be exposed to hot plasma.
The paper presents results of investigations of hydrogen dynamics under the interaction of pulsed plasma streams with metal-hydrides on the base of Zr55V40Fe5 alloys in conditions of high-heat load.

RPI-IBIS coaxial multi-rod injector



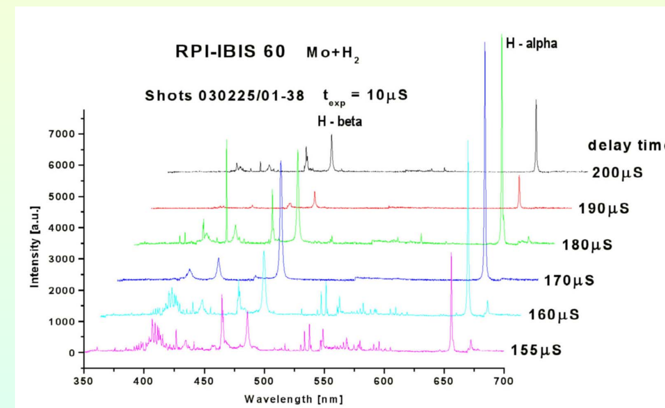
- Pulsed plasma streams were generated as a result of low-pressure high-current discharges performed between two coaxial sets of the multi-rod electrodes.
- initial charging (supply) voltage was 30 kV
- delay time of the high-voltage pulse in relation to the injection of hydrogen into the inter-electrode volume was between 130-210 μs
- distance between the electrode ends and the investigated target was 100 mm
- energy density in plasma stream 14-15 J/cm^2
- energy of ions achieved 10 kV
- pulse duration ~ 1-3 μs

Motivation

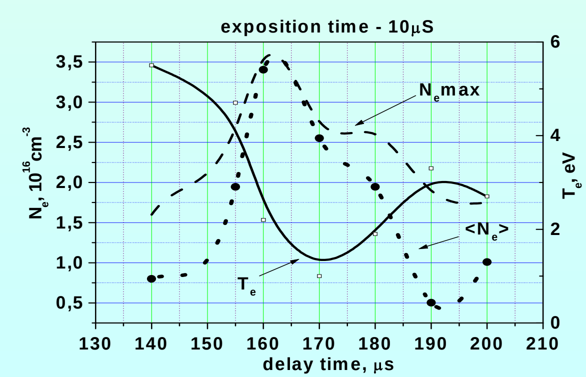
Hydride-forming materials (getters) are considered as rather prospective ones for the improvement of gas discharge cathodes. As the working gases in fusion devices hydrogen isotopes are usually used. Their additional flow, which should be matched with a pumping system, is ideal from the point of view of the providing the low-Z impurities, forming the shielding layer. So, this additional flow from constructional elements does not lead to any complication of the fusion reactor operation. It promotes the creation of a shielding gas target, which considerably screens the plasma energy density delivered to the material surface. One of the advantages of such a protection is that the shielding target is formed not from the target material (already eroded!) and not all time, but by the self-consistent way, i.e. only in the instants when plasma contacts with the material surface. The main aim of this work was to investigate shielding properties of reversible hydrogen getters under their irradiation with high-power plasma streams.

Power flux of the plasma stream used in our experiments was about 14 MW/cm^2, and similar one can be expected for off-normal events in ITER-like tokamaks. The pulse duration of order 1 μs is of course essentially shorter than at tokamak conditions. However, the first instants of the interaction are most important for an energy transfer to the material surface, because (due to the shielding) rather small part of plasma energy will be delivered later on.

Exemplary spectra recorded for different operational modes (various τ)

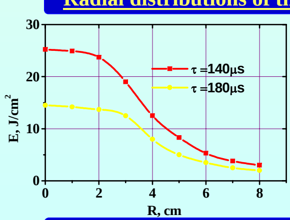


Average values of N_e, T_e for different operational modes



$N_{e\,max}$ reaches peak value $3.7\cdot10^{16}$ cm^{-3} on 165μs and falls to $0.5\cdot10^{16}$ cm^{-3} on 193μs

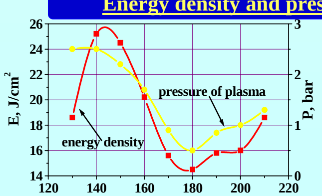
Radial distributions of the plasma stream energy density



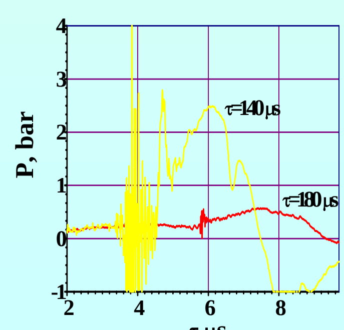
- **DPE-mode: delay time of the high-voltage pulse in relation to the injection of hydrogen –140 μs**
- **PID-mode: delay time of the high-voltage pulse in relation to the injection of hydrogen –180 μs**

Effective radius of plasma steams:
- 2cm for DPE –mode (21-26 J/cm^2)
- 3cm for PID -mode (13-15 J/cm^2)

Energy density and pressure of plasma streams

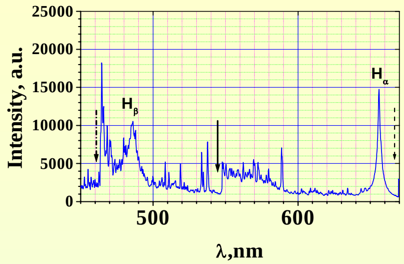


Pressure of plasma streams as well as energy density have been maximum in DPE- mode and minimum in PID-mode

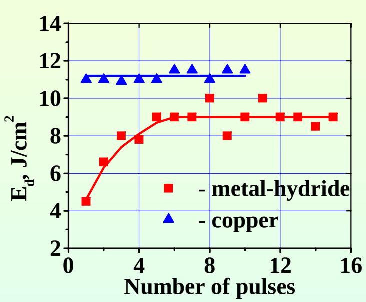


Typical signal of the pressure from piezodetector

Example of the optical spectrum observed in the shielding layer close to the getter surface

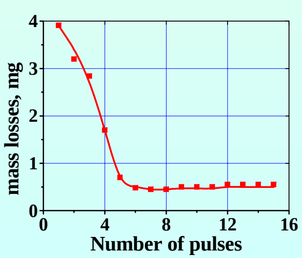


Energy density delivered to the getter surface versus the number of pulses

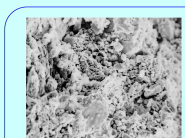


- behavior of the delivered energy curve for the hydrogen getter can be explained by the decomposition of hydrides in a near surface layer of the sample.
- contributions of two competitive processes: the hydrogen doping by the plasma stream and hydrogen desorption from the surface.

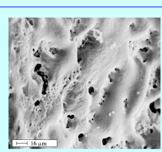
Mass losses of the metal-hydride sample versus the number of plasma pulses.



- After the first pulse the mass losses are maximal, and they rapidly decrease with following pulses.
- the getter material is pressed powder, the decreased heat conductivity between grains can lead to the evaporation of the material, and it can be another reason of additional mass losses.



A



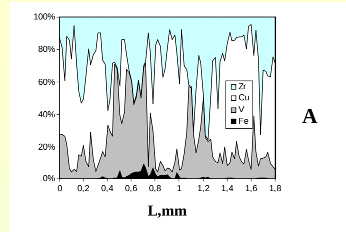
B

SEM images of the getter surface:

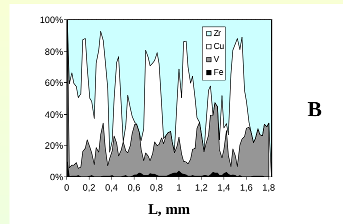
A - before treatment,

B - after the treatment.

Elements profiles along the getter surface: A- before treatment, B - after the treatment.



A



B

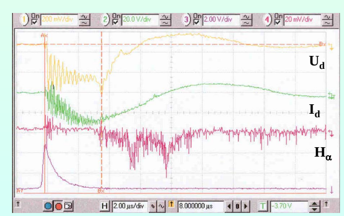
- Irradiated surface is characterized by essential modulation of the copper content from 20% to 80 % with a period of about 0.4 mm.
- behavior of Cu and Zr are quite opposite, i.e. a decrease in the Cu content accompanied by an increase in Zr
- An average content of the main elements along the scanning trace was as follows: Cu-56.7%, Fe-0.7%, V-17.1%, Zr-25.5% before the irradiation, and Cu-32.6%, Fe-0.8%, V-19.1%, Zr-47.5% after the treatment

Conclusions

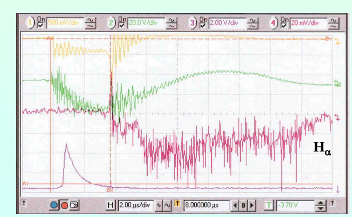
- possibility of the effective shielding of material surfaces by desorbed hydrogen;
- the desorption above 2 x10^{19} particles/cm^2 achieved;
- the intermetallic phase of $ZrCu_5$ is formed during the crystallization;
- the shielding layer formation with density higher than 10^{17} cm^{-3} (close to the sample surface) during parts of microsecond;
- a difference in the delivered energy density, as registered for copper and metal hydride targets within the plateau region, can be explained by an influence of the destruction of the high-temperature hydrides ZrH_2 and $ZrV_2H_{0.60}$;
- hydrogen is desorbed not only from a melted layer but also from a layer thicker than 20 μm, which is estimated to be heated up to such temperatures.

Discharge traces and temporal evolution of the H_α spectral line from the shielding layer, as recorded:

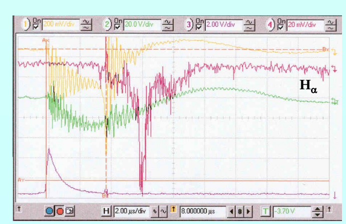
a – for a copper target; b, c and d – for the getter target during the first, fourth and fifth plasma pulse, accordingly.



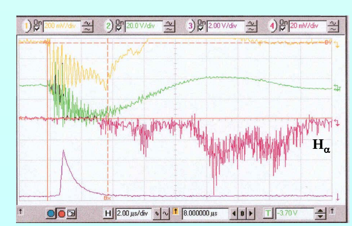
A



C



B



D

- the temporal evolution of the H_α spectral line from the near-surface plasma layer during the irradiation of copper and getter targets.
- the first peak in the H_α curve corresponds to the radiation of a free plasma stream and it can be observed even without the target. The second peak can be attributed to the radiation of the near-surface plasma layer (fig.A).
- interaction of a plasma stream with the saturated getter target is accompanied by a significant increase in the intensity of H_α in the shielding layer formed due to the desorption of previously accumulated hydrogen(fig.B)
- intensity of H_α decreases with following pulses, but the duration of a H_α signal is increased considerably, and it achieves 14-15 μs (fig.C-D).