*29th EPS Conference on Plasma Phys. and Contr. Fusion Montreux, 17-21 June 2002 ECA Vol. **26B**, P-1.020 (2002)*

Influence of High-Power Plasma Streams Irradiation on Properties of Reversible Hydrogen Getters.

V. N. Borisko[1] , V. V. Chebotarev[2] , I. E. Garkusha[2] , J. Langner[3], V.I. Lapshin[2]
N.S. Poltavtsev[2], M. J. Sadowski[3] , V. I. Tereshin[2], I.Yu. Zavaliy[4]

[1] *Kharkov National University, 61108, Kurchatov Av. 31, Kharkov, Ukraine*
[2] *Institute of Plasma Physics of the NSC KIPT, Kharkov, Ukraine*
[3] *The Andrzej Soltan Institute for Nuclear Studies, Swierk, Poland*
[4]*Physical-Mechanical Institute of NASU, L'viv, Ukraine*

1. Introduction

It is known that one of the reasons for erosion of first wall in tokamaks is sputtering by hydrogen isotopes with energy $\varepsilon \le 300$ eV. From the other side, under the disruptions conditions high heat loads up to 20 MW/cm^2 can be reached due to the plasma streams impact on the surface. Naturally, without additional methods of erosion processes control any existing material can not be protractedly used in such conditions. Therefore, besides of creation of erosion resistant construction elements, it is necessary to search the ways for materials erosion control. In this paper it is proposed to use hydrogen flow from getter material surface for creation of shielding gas target which considerably screens the plasma energy delivering to the material surface and, therefore, increases the efficiency of the surface protection against its contact with a plasma.

2. Results

The getter hydride-forming alloys $Zr_{55}V_{40}Fe_5$, $Zr_{50}V_{50}$ and $Zr_3V_3O_{0.6}$ [1] are used in our experiments. The samples were initially saturated with pure hydrogen. The specific content of accumulated hydrogen was varied in the range of 180 –250 ncm^3/g. Materials provided pressure of hydrogen letting in the range of 10^{-1}-100 Pa for heating temperatures varied from 150 to 450 ^{o}C. The typical curve of hydrogen thermodesorption for getters being in use is presented in Fig.1. Desorption under the pressure of 0.01 Pa starts at 50 ^{o}C and continues up to 700 ^{o}C. At that, three maximums of desorption rate are observed: $(dx/d\tau)_{\max}$ = 2.5 ncm^3/(g·min) for 128 ^{o}C, 2.1 ncm^3/(g·min) for 208 ^{o}C and 1.8 ncm^3/(g·min) for 542 ^{o}C respectively. In temperature range of 250-450 ^{o}C the desorption occurs with approximately constant rate of 0.5 ncm^3/(g·min) under the hydrogen pressure above the sample surface of about 10 Pa.

Experiments were carried out in three experimental installations. Impact of particles with energy $\varepsilon \le 300$ eV at the getter surface was investigated with steady-state planar magnetron discharge providing the necessary energies of sputtering atoms and ions and their

total dose of irradiation. In addition, experiments on irradiation of getters with high-power nitrogen and hydrogen plasma streams were carried out with use of pulsed plasma accelerators PROSVET and IBIS described in details in [2].

Experiments on sputtering of multicomponent hydrides in conditions of hydrogen isotopes desorption from the materials surfaces under the irradiation with ions of argon and hydrogen with energy below 1 keV and current density up to 100 mA/cm^2 have shown essential decrease of erosion in comparison with sputtering of the same materials without desorption. There was observed also interdependence between the processes of sorption-desorption and energy flux value to the surfaces of used getters. Thus, it was shown that materials on the base of reversible hydrogen sorbents have the properties of self-regulated desorption. This is positive factor for creation of gas-dynamic shield of material surfaces.

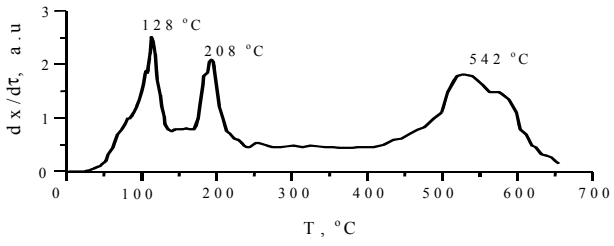

Fig.1. Curve of hydrogen thermodesorption from saturated sample.

The system of equations (1-4), describing the interaction of getter hydride-forming material with plasma flows, with boundary condition (5-7) was used for analysis of obtained experimental results. The fluxes of heat and particles are considered as steady-state ones. It is supposed exponential attenuation of the flux $J_b = J_0 \exp(-x/l)$ with characteristic scale l and constant heat conductivity coefficient χ in the bulk of material.

$$\frac{d}{dx}\left(J_b - D(T)\frac{dN}{dx}\right) = 0, \quad (1) \qquad \chi\frac{d^2T}{dx^2} + \frac{w}{l^2}x\exp(-x/l) = 0, \quad (2)$$

$$\frac{2\alpha P(1-\theta)^2}{N_S\sqrt{2\pi MkT_0}} - \theta^2\nu_{dS}\exp\left(-\frac{2E_{dS}}{kT_0}\right) + \frac{D(T_0)}{N_S}\left(\frac{dN}{dx}\right)_{x=0} = 0, \quad (3) \qquad D(T) = D_0\exp\left(-\frac{E_D}{kT}\right). \quad (4)$$

$$T\big|_{x=L} = T_\infty, \quad (5) \qquad -\chi\frac{dT}{dx}\bigg|_{x=0} = -\sigma\left(T_0^4 - T_\infty^4\right), \quad (6) \qquad N\big|_{x=L} = N_m. \quad (7)$$

Here N- density of hydrogen atoms in the volume of crystal lattice of material, w – energy density delivered to the material surface with a flux of high-energy particles, N_S – maximum density of hydrogen atoms adsorbed at the surface, θ – packing rate of adsorbed hydrogen atoms at the surface, P – hydrogen pressure above the metal-hydride surface, M – mass of hydrogen molecule, k – Boltzmann constant, T_0 – surface temperature of metal-hydride,

ν_{dS} – desorption frequency, E_{dS} – activation energy of desorption, σ – Stephen-Boltzmann constant, T_∞ - wall temperature of the vacuum chamber, E_D – energy of activation. On the base of solution of that system of equations the expression for the flux of hydrogen atoms diffusing was obtained:

$$-D(T_0)\left.\frac{dN}{dx}\right|_{x=0} = N_S\nu_{dS}\exp\left(-\frac{2E_{dS}}{kT_0}\right) - \frac{\sigma l}{\chi k T_0^2}\left(T_0^4 - T_\infty^4\right)\left[J_0 E_D\left(\frac{L}{l} + \exp\left(-\frac{L}{l}\right) - 1\right) + \right. \quad (8)$$

$$\left. + N_S\nu_{dS}\frac{L}{l}\left(2E_{dS} - E_D\right)\exp\left(-\frac{2E_{dS}}{kT_0}\right)\right].$$

Substitution of values typical for our experimental conditions:

$$L = 1cm,\quad l = 3\cdot 10^{-7}cm,\quad T_0 = 900K,\quad T_\infty = 300K,\quad N_S = 2\cdot 10^{15}cm^{-2},\quad \nu_{dS} \approx 10^{13}s^{-1},$$

$$\chi \approx 0.45\left[W/cm\cdot K\right],\ E_{dS} = 0.4\,eV,\ E_D = 0.2\,eV,\ k = 8.625\cdot 10^{-5}\left[eV/K\right],\ \sigma = 5.67\cdot 10^{-12}\left[W/cm^2K^4\right]$$

had shown, that the flux of diffusing the hydrogen atoms is directed from the bulk of material to the surface. This flux is equal to one of hydrogen particles desorbed from the metal-hydride surface into plasma. Equality of those fluxes is provided by the equation of balance (3) with $\theta \approx 1$.

As result of these calculations, the linear dependence between fluxes of hydrogen desorbed from the surface and flux of plasma particles, bombarding the surface, was obtained. This dependence is in agreement with experimental data.

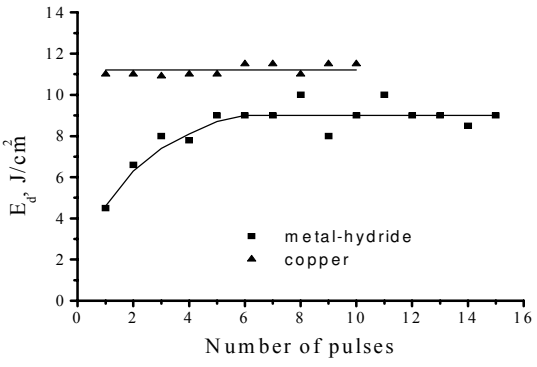

Fig.2. Energy density delivered to the sample surface versus the number of plasma pulses.

Material behavior under the pulsed heat loads was investigated in pulsed plasma accelerators PROSVET and IBIS, generating the nitrogen and hydrogen plasma streams with ion energy 2 keV and 10 keV, plasma density 2.10^{14} cm^{-3} and 10^{15} cm^{-3} accordingly. Specific power of plasma streams with the pulse length of 1-5 μs achieved 15 MW/cm^2. The main aim of these experiments was investigation of the role of desorbed hydrogen in shielding of material. For a comparison a copper sample of the same diameter was also investigated. Fig.2 shows the energy density delivered to the sample surface in IBIS facility as a function of the number of pulses. It is obtained that in the case of the copper target about 78 % of the plasma stream energy density

is delivered to the target surface, and this value remains unchanged with an increase of the pulse number. Melting of the copper surface was observed as result of the plasma stream interaction. For the getter target only 32% of the plasma energy density is transferred to the target surface during the first pulse. In this case the value of the delivered energy density increases with an increase of the number of plasma pulses. The saturation, which is visible on the curve for the getter, was achieved after 5 plasma pulses, but even in that case the value of delivered energy is about 60% of plasma energy (i.e. lower than for the copper target). This is the result of pulsed heating of the surface and the formation of the shielding layer of hydrogen stored initially in the surface layer. The fact that the value of energy delivered to the getter surface is still lower than that for the copper sample can be explained by the influence of a reverse process of the hydrogen doping into the melted layer from a plasma stream during the pulse end phase. So, one can observe the balance between two competitive processes: the hydrogen doping by the plasma stream and hydrogen desorption from the surface. Similar results were obtained under getter surface irradiation with pulsed plasma in PROSVET device.

Phase structure of initial and irradiated surfaces was determined from diffractograms assignment of indices. Lattice periods of hydride-forming intermetallic phases, namely Laves phase λ_2–$Zr(V,Fe)_2H_X$ and phase $Zr_3(V,Fe)_3OH_X$, are higher than periods of initial intermetallides (0.7396 nm and 1.2156 nm respectively), but they are lower than the lattice periods of completely saturated hydrides (0.7886 nm and 1.2656 nm). Comparison of the obtained results with the literature [3] allows to estimate the degree of saturation of a Laves phase by hydrogen as 72 % before irradiation and 64 % after irradiation. The data for the η–phase are 49% and 30 % respectively. It testifies that intensive desorption of a hydrogen from these hydride phases takes place during bombardment.

3. Conclusions

The obtained results have shown the possibility of the effective protection of material surfaces by desorbed hydrogen. This leads to essential decrease of both plasma energy density delivered to the surface and material erosion. Thus we can conclude that hydrogen buildup promotes a considerable increase in the shielding coefficient

4. References

[1] Klochko Ye.V. et al. International Journal of Hydrogen Energy. 31 (1999) 169

[2] J. Langner et al. Surface and Coatings Technology 128-129 (2000) 105

[3] Yartys V.A. et al. Co-Ordinatory Chemistry. V.18 4 (1992) 409