EROSION BEHAVIOR OF MATERIALS ON BASIS OF TUNGSTEN HOT PRESSED IN VACUUM UNDER MIRROR PENNING DISCHARGE PLASMA IMPACT

G.P. Glazunov, D.I. Baron, M.N. Bondarenko, A.L. Konotopskiy, I.M. Neklyudov, N.P. Odeychuk, S.Yu. Sayenko, A.E. Surkov, I.K. Tarasov, E.D. Volkov

National Science Center "Kharkov Institute of Physics and Technology", Akademicheskaya Str.1, 61108 Kharkov, Ukraine

The erosion behavior of porous W, W-Ni and W-Cu systems produced by hot pressing in vacuum was examined under exposure to plasmas of mirror Penning discharges in argon, nitrogen, helium and hydrogen. The erosion characteristic behavior in dependence on ion energy and mass is analyzed and discussed.

PACS: 52.40.Hf, 79.20.R

1. INTRODUCTION

Tungsten, as one of the most erosion and temperature resistant materials, has good chance to be used in future fusion devices. So, creation of new materials on the basis of tungsten and investigations of their vacuum-plasma properties, in particular, an erosion rate, are the important part of new thermonuclear device creation. In this work the erosion investigations were carried out under steady state Penning discharge plasmas impact on different porosity W, W-Ni and W-Cu systems produced by hot pressing in vacuum (HPV).

2. EXPERIMENTAL AND RESULTS

The experimental setup used in the erosion experiments was the device DSM-1 [1,2] with steady state mirror Penning discharge, which was ignited at magnetic field 0.05 T and at work gas pressure about 0.2 Pa. Plasma characteristics measured by multigrid and single Langmuir probes (central and peripheral discharge regions, accordingly) are presented in the Table, where U is discharge voltage, I is discharge current, T_e and n_e are electron temperature and electron density, φ is plasma potential, E_i – ion energy for maximum of distribution function, ΔE_i – half-width of distribution function.

Nitrogen plasma characteristics in discharges with porous and dense W cathodes

Discharge voltage, current		Edge plasma characteristics for porous/dense cathodes			Plasma characteristics near axis	
U, (keV)	I, (mA)	n_e*10^{10}, (part/cm^3)	T_e*10^4, (K)	φ, (V)	E_i (eV)	ΔE_i (eV)
0.8	0.8	0.03/0.1	0.62/0.9	9/7	0.62	50
1	2.2	0.05/0.15	0.48/0.71	12/9	0.85	60
1.2	5	0.13/0.17	0.37/0.67	12/13	0.93	75
1.5	8	0.15/0.32	0.32/0.52	15/13	1.15	93
1.7	10	0.22/0.65	0.30/0.35	14/15	1.32	110
2	16	0.31/0.93	0.30/0.28	16/16	1.57	132

The comparison of plasma parameters for discharges with high porous and dense cathodes shows the total electron temperature and density decrease for high porosity samples. It should be noted that with the discharge voltage (and accordingly discharge current) increase, the electron temperature decreases and electron density increases. The possible reason could be the sufficiently large number of neutral particles in discharge volume and this fact is confirmed by great sample mass loss. The total electron temperature and density decrease could be explained by electron-neutral particle collisions. The increase of neutral particle number strongly dependences on range of cathode material porosity. This reason can also explain the electron density and temperature dynamics. With discharge current increase the neutral particle number increases. This leads to plasma cooling and to the electron concentration increase in discharges.

Experimental specimens (20-25 mm diameter, Fig. 1) were prepared by the sintering under pressure (hot pressing in vacuum) of tungsten powder and of the (W - 5% Cu) or (W - 1% Ni) powder mixtures. The mixtures were made by powders mixing (with admixture of spirit) in polyurethane mill with VK-8 hard balls during 12 hours up to full mixture homogenization. The work regimes to experimental samples produce were the next: temperature was over the range from 1673 to 2173 K; pressure was of ~ 30 MPa; exposure time was up to 15 minutes; work vacuum was ~ 1.3 Pa. Porosity level was measured by bottle method and was about 50 % for sintered W and 10-12% for (W - 5% Cu) and (W - 1% Ni) samples.

Fig.1. The HPV W on Ni substrate, (W-1% Ni), HPV (W-5% Cu), HPV (W-5% Cu) after Cu evaporated (all above). All samples at the foot are after exposure to plasma

The samples before measurements were mechanically cleaned and vacuum annealed at the temperature of

873 K. Note that this procedure leaded to HPV W-samples cracking. At the same time (W - 5% Cu) and (W - 1% Ni) samples had no damages even after long time repeated thermal cycles. Erosion coefficient values were measured by weight loss method reviewed in details in [1, 2]. The main results on erosion are presented in Figs. 2-6.

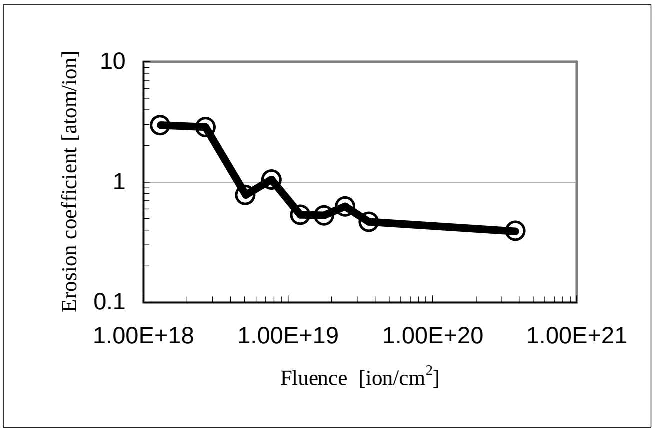

Fig. 2. Erosion coefficient dependence on nitrogen ion fluencies for HPV W on Ni substrate

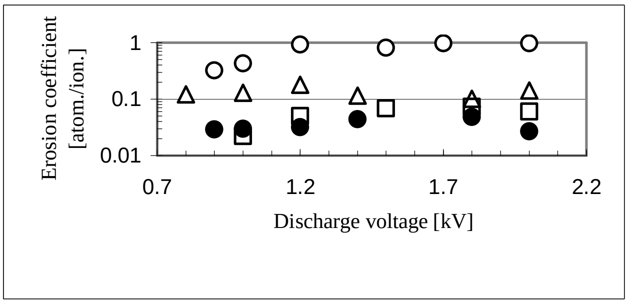

Fig. 3. HPV (W-1% Ni) erosion coefficient dependence on ion energy for: H^+ (●), He^+ (o), N^+(r), Ar^+ (š)

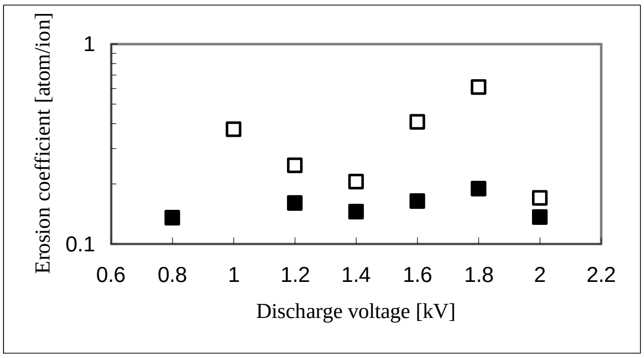

Fig. 4. Erosion coefficient dependence on nitrogen ion energy for: ■ - HPV (W-5% Cu); o - (W-5% Cu) after Cu evaporation

3. DISCUSSION

For all systems erosion coefficient values weakly depends on ion energy in the investigated energy range for all kinds of working gas, that is in a good agreement with numerous literature data. It is seen in Fig.2 that high porous (45% porosity) samples made of W powder hot pressing with Ni substrate show rather high erosion coefficient (in compare with the one for bulk tungsten (about 0.17 at./ion at 1.2 keV ion energy) and very instable erosion characteristics with fluence increase. It caused by two reasons: (i) high level of gas impurities in high porous HPV samples and (ii) loss of mass due to cracking and micro-particles husking. For both systems with nickel and copper as bonding medium, erosion coefficient absolute values are in a good agreement with the data on bulk tungsten sputtering [3, 4] excluding the results on erosion in hydrogen discharges. The visible deviation for pure hydrogen is explained by impurity flow from cathodes during initial stage of discharges as it is earlier shown in [5].

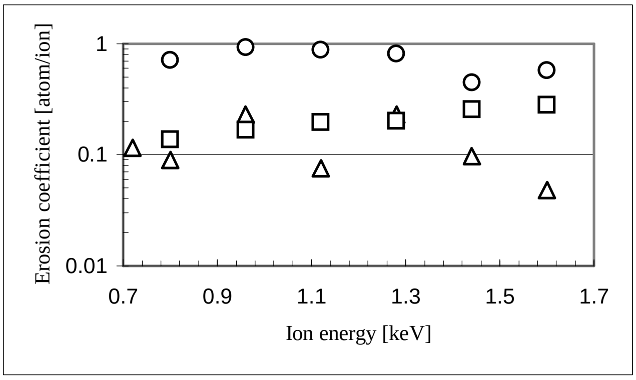

Fig. 5. HPV (W-5% Cu) erosion coefficient dependence on ion energy for: He^+ (r), N^+ (o), Ar^+ (š)

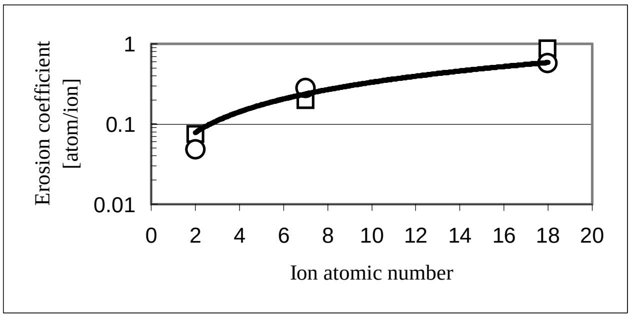

Fig.6. HPV (W-5% Cu) erosion coefficient dependence on atomic number of bombarding ions of 1.4 keV (o) and 1.6 keV (š) energy; curve is the calculated data according to equation for mass dependence of ion sputtering [4]

Note, that for (W-5% Cu) system after Cu evaporation at high temperatures, the erosion coefficient is very instable and erosion rate much more than for this sample before Cu evaporation (Fig.4). The reason can be the similar to that for high porous sintered W (Fig.2) – the loss of material mass due to micro- and macro-particles husking. As to the erosion dependencies on ion mass (Fig. 3), one can say that sputtering in our case is in a good agreement with the reported in [4] equation:

$$a\cdot(Z_1Z_2)\cdot m_1/(Z_1^{2/3}+Z_2^{2/3})^{0.5}\cdot(m_1+m_2),$$

where a is constant, Z_1 and Z_2 are atomic numbers of bombarding ion and Pd-target, respectively, m_1 and m_2 are ion and W atom masses.

4. CONCLUSIONS

Erosion rate of hot pressed high porous tungsten (porosity was up to 50 %, Ni-substrate) after long time ion bombardment is essentially higher than that for dense tungsten films prepared by sputtering in a vacuum, by chemical vapor deposition or for rolled W (about 0.17 at./ion at 1.2 keV ion energy). The erosion rates for (W-1% Ni) and (W-5% Cu) samples before Cu evaporation are near to above mentioned hot pressed or dense W samples in spite of presence of easily sputtered nickel/copper. And such materials could have good perspective to be used as plasma facing materials. But the erosion coefficient for HPV tungsten after copper evaporation is essentially higher and to understand the nature of this the additional investigations are needed.

ACKNOWLEDGEMENTS

This work was supported by the Science and Technology Center in Ukraine (STCU), project # 3134.

REFERENCES

1. G.P. Glazunov et al. // *Problems of Atomic Science and Technology. Series "Plasma Physics" (11).* 2005, N2 , p. 107-109.
2. G. P. Glazunov et al. //*Physica Scripta*. 2003, v. T103, p. 89-92.
3. W. Eckstein et al. // *Sputtering data*. Garching bei Munchen: IPP, 1993, 9/82, p. 342.
4. Y. Yamamura and H. Tawara. *Energy dependence of ion-induced sputtering yields from monoatomic solids at normal incidence.* NIFS-DATA-23, Nagoya, Japan, 1995, p. 114.
5. G.P.Glazunov et al.// *J. Nucl. Mater.* 2001, v. 290-293, p. 266-270.

ЭРОЗИОННОЕ ПОВЕДЕНИЕ ГОРЯЧЕПРЕССОВАННЫХ В ВАКУУМЕ МАТЕРИАЛОВ НА ОСНОВЕ ВОЛЬФРАМА ПРИ ВОЗДЕЙСТВИИ ПЛАЗМЫ ОТРАЖАТЕЛЬНЫХ РАЗРЯДОВ ПЕННИНГА

Г.П. Глазунов, Д.И. Барон, М.Н. Бондаренко, А.Л. Конотопский, И.М. Неклюдов, Н.П. Одейчук, С.Ю. Саенко, А.Е. Сурков, И.К. Тарасов, Е.Д. Волков

Исследовалось эрозионное поведение пористых W, и W-Ni, W-Cu систем, изготовленных горячим прессованием в вакууме при воздействии стационарной плазмы отражательных разрядов Пеннинга в аргоне, азоте, гелии и водороде. Анализируется и обсуждается поведение эрозионных характеристик в зависимости от энергии ионов и их массы.

ЕРОЗІЙНА ПОВЕДІНКА ГАРЯЧЕ ПРЕСОВАНИХ У ВАКУУМІ МАТЕРІАЛІВ НА ОСНОВІ ВОЛЬФРАМУ ПРИ ДІЇ ПЛАЗМИ ВІДБИВНИХ РОЗРЯДІВ ПЕННІНГА

Г.П. Глазунов, Д.І. Барон, М.М. Бондаренко, О.Л. Конотопський, І.М. Неклюдов, М.П. Одейчук, С.Ю. Саєнко, О.Є. Сурков, І.К. Тарасов, Є.Д. Волков

Досліджувалася ерозійна поведінка пористих W, і W-Ni, W-Cu систем, виготовлених гарячим пресуванням у вакуумі при дії стаціонарної плазми відбивних розрядів Пеннінга в аргоні, азоті, гелії і водні. Аналізується і обговорюється поведінка ерозійних характеристик залежно від енергії іонів та їх маси.