EROSION BEHAVIOR OF TUNGSTEN COATINGS IN MAGNETRON TYPE DISCHARGES WITH HOT CATHODE

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The investigations of erosion behavior of vacuum-arc deposited and chemical vapor deposited W-coatings were carried out under steady state plasma impact in magnetron type discharges of cylindrical configuration. For comparison the erosion characteristics were measured for dense bulk tungsten, too. It was shown that erosion rate values both for vacuum-arc deposited and chemical vapor deposited W-coatings are near to that for dense bulk tungsten. The measured erosion rate dependence on atomic number is in good agreement with the data calculated from the equation for mass dependence of physical ion sputtering.

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1. INTRODUCTION

Development of tungsten based materials and studies of their properties, in particular, erosion behavior, are very actual for ITER construction and for future fusion and fission reactors. Earlier [1, 2] the investigations of the erosion behavior of vacuum-arc deposited (PVD) and chemical vapor deposited (CVD) W-coatings on Pd/Ni substrates were carried out under impact of plasma in mirror Penning discharges. It was shown that the erosion rates for both PVD (dense and porous) and CVD W-films are near to that for literature data for bulk tungsten. But those measurements were made at low sample temperatures (room temperature) and for rather high ion energies (0.8-1.8 keV). In this work the erosion behavior of tungsten films is studied under steady state plasma impact in the magnetron type discharges of cylindrical configuration, under conditions when sample temperatures were higher than 1073K and ion energy was lower than 0.7 keV. The data obtained in studies could be useful for W-limiter head plates design during construction of RF-antenna and pump limiter of the Uragan-2M torsatron.

2. EXPERIMENTAL

Experiments were carried out in DSM-1 device (diagnostic stand of materials) with mirror Penning discharge [1, 2]. The device was modernized to work with magnetron type discharges. Two symmetrical cathodes were connected with one cylindrical cathode-sample (Fig.1). The discharges were ignited in magnetic field of 0.05 T under work gas (hydrogen, helium, nitrogen and argon) pressure about 0.2 Pa. The discharge voltage was 0.4 – 1 keV, discharge current changed in the range of 60 – 200 mA. For the research of tungsten coatings erosion of the measurements of voltage-current characteristics were carried out for different used cathodes: bulk hot-pressed W-rod, vacuum-arc and chemical vapor deposited tungsten on Pd-tube of 20 cm length. These characteristics have stabilitron type (Fig.2). The plasma characteristics (peripheral discharge region) were also measured with single Langmuir probe (Tables 1-3, where U is the discharge voltage, I is the discharge current, T_e and n_e are electron temperature and electron density, respectively, φ is plasma potential). Electron temperature and density were calculated from the equations [3]: $T_e=(e/k)\cdot(1/tg\psi)$; $n_0=4I_{e0}/eS(8k\cdot T_e/\pi m_e)^{1/2}$, where e – electron charge, k – Boltzmann's constant, ψ- angle of slope (Fig. 3), I_{e0} – probe electron current when probe potential equals with plasma potential, S – probe area, m_e – electron mass.

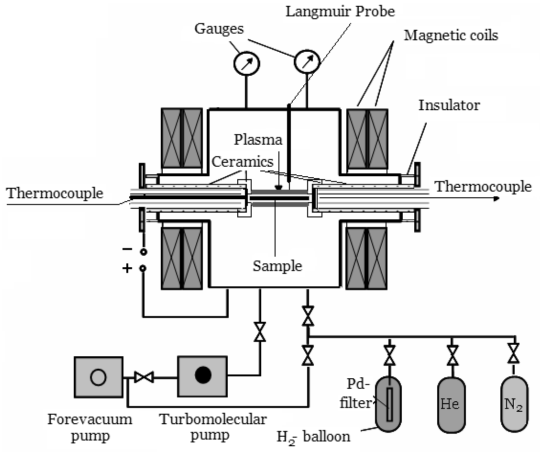

Fig.1. Scheme of DSM-1 experimental device in magnetron type regime

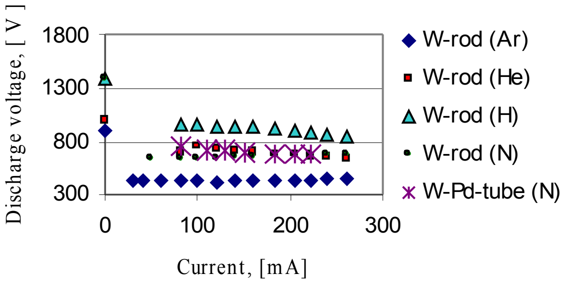

Fig.2. Current-voltage characteristics for magnetron type glow discharges with axial symmetrical configuration

Erosion coefficients were measured by weight loss method with the weighing of samples before and after plasma irradiation [1]. The method accuracy was about 30% and it was determined, mainly, by the discharge current instability, especially, during initial stage of discharge.

3. RESULTS AND DISCUSSION

Tables 1-3 show that electron density n_e increases with discharge current for all used cathodes. At the same time electron temperature decreases. Erosion experiments have shown that W erosion essentially increases with discharge current increase. So, higher flow of neutral particles (W atoms) to plasma is observed. These particles strongly cool the plasma (electron temperature T_e decreases). At the same time, with growth of discharge current the number of electron-neutral particle collisions also increases causing electron density increase. The behavior of plasma potential φ can be explained by the presence of plasma instabilities and charge inhomogeneity along radius, that is often appears in this discharge configuration [4].

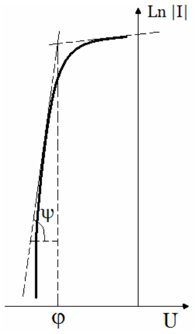

Fig.3. Current-voltage characteristic for single Langmuir probe

Table 1. Plasma characteristics for discharges in nitrogen. Cathodes were made of two-layer W-Pd tube with porous/dense PVD W-films

Discharge voltage and current		Plasma parameters		
U,kV	I,mA	$n_e \cdot 10^9$, cm^{-3}	$T_e 10^4$,K	φ, V
0.7	60	1.22/0.95	0.56/0.23	-25/32
0.7	90	2.11/1.51	0.26/0.26	-25/40
0.7	110	4.45/2.58	0.29/0.15	10/30
0.7	130	4.69/-	0.50/-	30/50
0.7	150	4.97/2.84	0.59/0.23	55/40

Table 2. Plasma characteristics for discharges in Ar, H_2, He, N_2 with tungsten rod cathode

Discharge voltage and current		Plasma parameters Ar/H/He/N		
U, kV Ar/H/He/N	I, mA	$n_e \cdot 10^9$, cm^{-3}	$T_e \cdot 10^4$, K	φ, V
0.45/0.9/ 0.67/0.65	70	2.9/3.8/- /1.1	0.58/0.3 2/-/0.32	12/-220/- /-40
0.45/0.9/ 0.67/0.65	90	1.7/2.7/ 1.6/1.3	0.51/0.3/ 0.56/0.3	14/-190/ -160/-40
0.45/0.9/ 0.67/0.65	110	3.4/3.3/ 4.6/1.5	0.51/0.5/ 0.17/0.4	22/-190/ -195/-30
0.45/0.9/ 0.67/0.65	130	9.1/3.1/ 1.2/2.3	0.32/0.5/ 0.28/0.3	25/-160/ -155/-40
0.45/0.9/ 0.67/0.65	150	8.1/4.4/ 1.5/2.2	0.30/0.5/ 0.53/0.3	24/-165/ -50/-40

Table 3. Plasma characteristics for discharges in N_2 with Pd tube cathode with CVD W- film

Discharge voltage and current		Plasma parameters		
U,kV	I, mA	$n_e \cdot 10^9$, cm^{-3}	$T_e \cdot 10^4$,K	φ, V
0.7	65	0.24	0.69	30
0.7	90	0.83	0.56	25
0.7	115	1.09	0.21	-12
0.7	133	1.74	0.17	-10
0.7	160	1.66	0.32	-1

The main results on erosion are presented in Figs. 4-8. It is seen, that erosion rates of PVD and CVD tungsten films are close to that one for bulk tungsten rod prepared by sintering and hot pressing. There is not essential influence of W porosity on its erosion behavior. This is very encouraging result for development of plasma facing components. Erosion coefficients calculated in $g/cm^2 \cdot s$ units (Fig.4, 5) linearly depend on discharge current but, if to interpret the erosion results as number of sputtered atoms per bombarding ion (Fig.6, 7), erosion coefficient slightly depends on sample temperature in the investigated temperature range.

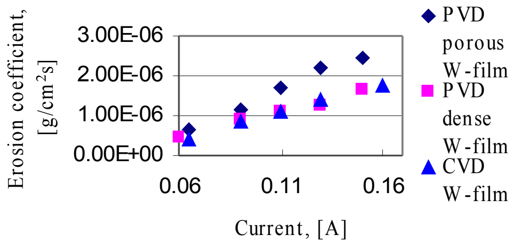

Fig.4. Erosion coefficients (g/cm²s) for W-films under nitrogen plasma irradiation

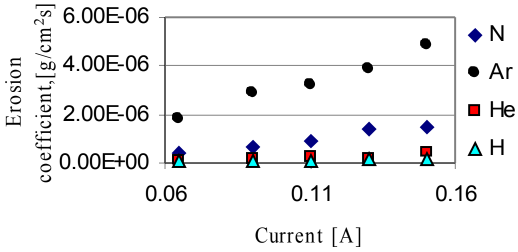

Fig.5. Erosion coefficients (g/cm²s) for W-rod

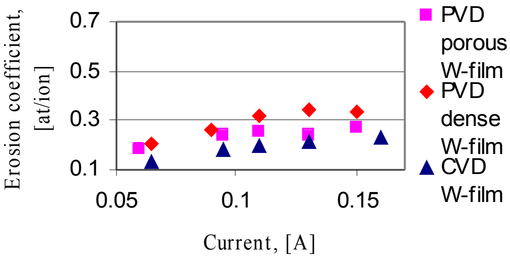

Fig.6. Erosion coefficients (atom/ion) for W-films under nitrogen plasma irradiation

It can be understood if to take into account very high W melting temperature and the known fact of metal sputtering coefficient essential increase only under the temperatures close to melting point. Note, that the sample-cathode temperature, measured with chromel-copel thermocouple is increased from 1073 to 1373 K when discharge current varied from 60 to 150 mA.

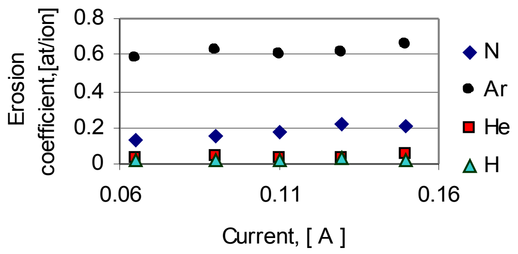

Fig.7. Erosion coefficients (atom/ion) for W-rod

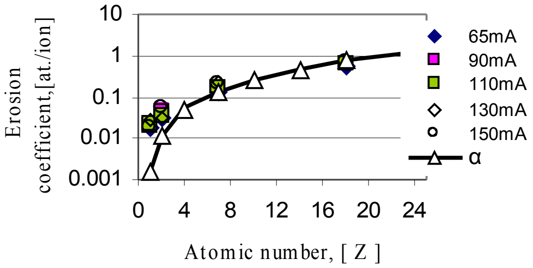

Fig.8. W-rod erosion coefficient for various discharge current versus bombarding ion atomic number Z: curve- calculation with equation [5]
$\alpha=a\cdot(Z_1\cdot Z_2)\cdot m_1/(Z_1{}^{2/3}\cdot Z_2{}^{2/3})^{0.5}(m_1m_2)$, where $a=0,03$, Z_1 and Z_2 – atomic number of ion and W; m_1 u m_2 – the mass of ion and W

The measured erosion rate dependence on atomic number (Fig.8) is in a good agreement with the data which were calculated from the equation of physical ion sputtering mass dependence [5]. Long time repeatable termocycling tests showed high thermal-fatigue life and temperature resistance of the investigated W-coatings in spite of large difference in the thermal expansion coefficients for W and Pd.

4. CONCLUSIONS

The erosion rate values both for PVD (high porous and dense) and CVD W-coatings are near to that for dense bulk tungsten. Erosion coefficients calculated in g/cm^2s units are linearly depend on discharge current. In the terms of sputtered atoms per bombarding ion, erosion coefficient slightly depends on sample temperature in the investigated thermal range. It can be understood taking into account very high W melting temperature and known fact of essential increase of metal sputtering coefficient when temperatures are near to melting point.

The measured erosion rate dependence on atomic number is in a good agreement with the data calculated from the equation of physical ion sputtering mass dependence. Temperature cycle tests showed high thermal-cycling stability and temperature resistance of investigated W-coatings.

All these properties, i.e., low erosion, high thermal-fatigue life, allow to propose PVD and CVD W-coatings as protection for head plate of pump limiter and RF antenna limiter of Uragan-2M torsatron.

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ЭРОЗИОННОЕ ПОВЕДЕНИЕ ВОЛЬФРАМОВЫХ ПОКРЫТИЙ В РАЗРЯДАХ МАГНЕТРОННОГО ТИПА С ГОРЯЧИМ КАТОДОМ

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Проведены исследования эрозионного поведения покрытий вольфрама, осажденных вакуумно-дуговым и газофазным способом, при воздействии стационарной плазмы разрядов магнетронного типа цилиндрической конфигурации. Для сравнения измерены также эрозионные характеристики массивного вольфрама. Показано, что величины скорости эрозии для вакуумно-дуговых и газофазных покрытий близки к таковым для плотного массивного вольфрама. Измеренная зависимость скорости эрозии от атомного номера ионов находится в хорошем согласии с рассчитанной по уравнению для зависимости физического распыления металла от массы ионов.

ЕРОЗІЙНА ПОВЕДІНКА ВОЛЬФРАМОВИХ ПОКРИТТІВ У РОЗРЯДАХ МАГНЕТРОННОГО ТИПУ З ГАРЯЧИМ КАТОДОМ

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Проведені дослідження ерозійної поведінки покриттів вольфраму, осаджених вакуумно-дуговим і газофазним способом, при дії стаціонарної плазми розрядів магнетронного типу циліндрової конфігурації. Для порівняння зміряні також ерозійні характеристики масивного вольфраму. Показано, що величини швидкості ерозії для вакуумно-дугових і газофазних покриттів близькі до таких для щільного масивного вольфраму. Зміряна залежність швидкості ерозії від атомного номера іонів знаходиться в хорошій згоді з розрахунковою по рівнянню для залежності фізичного розпилювання металу від маси іонів.