EROSION BEHAVIOR OF W-Ta COATINGS IN PLASMAS OF STATIONARY MIRROR PENNING DISCHARGES

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Investigations had been carried out of the influence of Ta alloying (2…16 wt.%) in W-coatings on their erosion behavior in steady state plasmas of Penning discharges in different gases: argon, nitrogen, and hydrogen. The coatings were deposited on stainless steel substrates by argon ion sputtering of targets made from appropriate metals. For comparison the erosion behavior had been examined of pure W and Ta coatings obtained by the same method. It was shown the essential decrease of an erosion rate after Ta addition in W coatings. The possible physical mechanism is suggested to explain such erosion behavior.

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INTRODUCTION

The creation of new functionally graded materials on the basis of tungsten and investigations of their properties, in particular erosion behavior, are very important now in view of ITER construction. The admixture of various materials, e.g., of Cu, Ta in W is used to improve its mechanical properties [1-5]. What about erosion of such two components systems it was shown in [2] that the erosion rates for (W-5%Cu) samples are near to that for dense W samples in spite of presence of easily sputtered copper. When Ta is added in the W coatings this leads to increasing of film mechanical properties as it is observed in [4]. So it was the certain interest to examine an erosion behavior of W-Ta coatings under plasmas impact.

1. EXPERIMENTAL AND RESULTS

The experiments were carried out at the DCM-1 device (IPP NSC KIPT, bench for diagnostics of materials under plasmas irradiation, Fig. 1) under operating conditions of mirror Penning discharge [3], which was ignited at magnetic field 0.05T, at work gas pressure about 0.2 Pa. The discharge voltage values were 1 keV, irradiation doses were $10^{18}…10^{19}$ ions/cm^2. The samples for studies were stainless steel disks of 25 mm diameter, coated by W, Ta or W-Ta films of different thickness and composition. The scheme of the erosion experiments is clear in Fig. 1.

The method of argon ion-plasma sputtering of tungsten and tantalum targets using the gas-plasma source (ISSPMT NSC KIPT) was applied to obtain pure W, Ta and W-Ta coating with tantalum concentration from 2 to 16 %. The design and principle of operation of the gas-plasma source (GPS) used for production of multicomponent coatings is described in detail in [6]. In the present paper a vacuum chamber comprises a GPS in the form of a tubular anode of 200 mm in diameter and 380 mm long with a tungsten hot cathode. Outside the anode there is a focusing coil, which generates a magnetic field of about 50 Oe. Experiments were carried using a filament current of a tungsten spiral of 100 A at a positive anode potential in the range of +50 V and under argon pressure of ~ 0.8 Pa. The discharge current was 35 A. Sputtering targets were polycrystalline W and Ta plates onto which a negative potential of -700 V has been applied. The concentration of elements in the coatings was given by the ratio between the areas of tungsten and tantalum targets. The anode-target distance was 50 mm. The ion-current density on the target was 10…20 mA/cm^2. Coatings were deposited on substrates at a negative potential of -50 V. The thickness of coatings has been measured by the "shadow knifes" method using the microinterferometer MII-4 and was ~ 3 μm. The element concentration in the coating was measured by the X-ray fluorescence method with the spectrometer "Sprut".

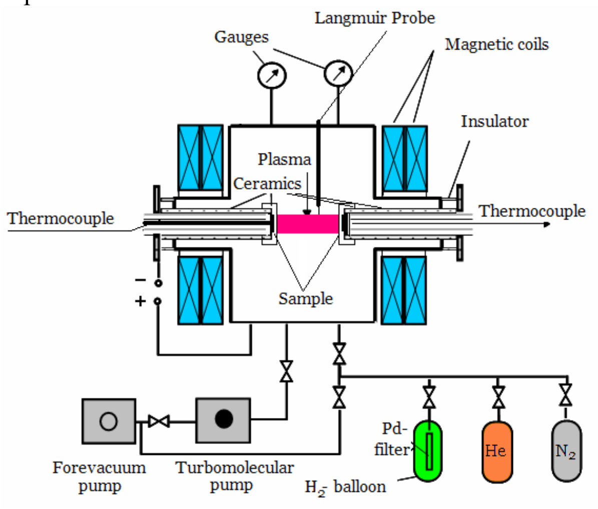

Fig. 1. Scheme of the experimental device DSM-1

Experimental technique for erosion rate measurement by weight-loss method had been described in detail in the previous works [7, 8]. The main error of erosion coefficient measurements was ≈ 30 % and was mainly caused by some current instability on the initial stage of discharges due to impurity flow from cathodes. This was the reason of large difference in erosion coefficients in hydrogen plasma in compare with literature data.

The erosion coefficient values measured after argon, nitrogen and hydrogen plasmas impact for W, Ta and W-Ta coatings in dependence on atomic number of bombarding ions and alloy addition Ta concentration in W are shown in Figs. 2, 3.

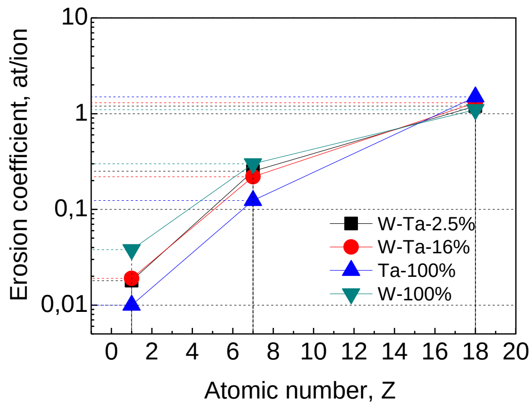

Fig. 2. W-Ta coatings erosion coefficient versus atomic number of bombarding ions

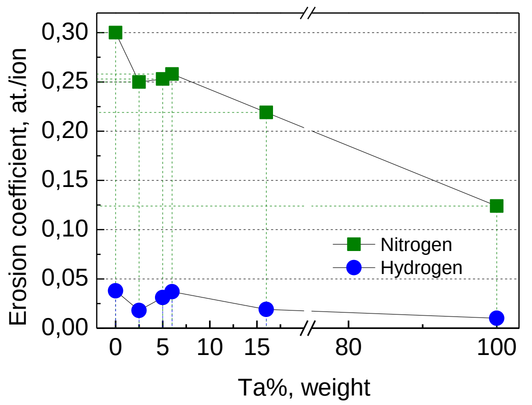

Fig. 3. W films erosion rate dependence on the Ta concentration

2. DISCUSSION

It is seen in Fig.3 the addition of Ta leads to essential decrease of erosion rate (sputtering coefficient/yield), especially for light (hydrogen) ions. For hydrogen plasma erosion coefficient W-16%Ta coatings is about 0.018 at/ion H^+ instead of ~0.038 at/ion for pure W coatings. In the case of N^+ bombarding ions it is only 0.22 and 0.3 at/ion, consequently. In both cases a decrease in the erosion rate of W-Ta coatings is near linear dependence on the concentration of the doping material (Ta). The experiments in argon plasma had shown negligible influence of Ta alloy addition.

Note, the measured erosion rate in hydrogen plasma for pure Ta film is 0.01 at/ion and 0.038 at/ion for W coatings. I.e., sputtering of Ta under light ion bombardment is essentially lower than that for W. This difference is less for W and Ta erosion rates under nitrogen plasma impact. And in the case of heavy ions bombardment (Ar^+) the erosion of W is a little lower than for Ta. Really, it is clear from Fig. 4 that the dependence of ion induced sputtering yield on metal properties (melting temperature, density, boiling point etc,) is much lower for heavy ions than for light ones. So, the observed erosion rate decrease after Ta addition in W coatings could be caused by more erosion resistant Ta on the surface and in the nearing surface layer of the coating. Of course, this is the preliminary results and to know more exactly the nature of erosion decreasing the additional investigations are needed.

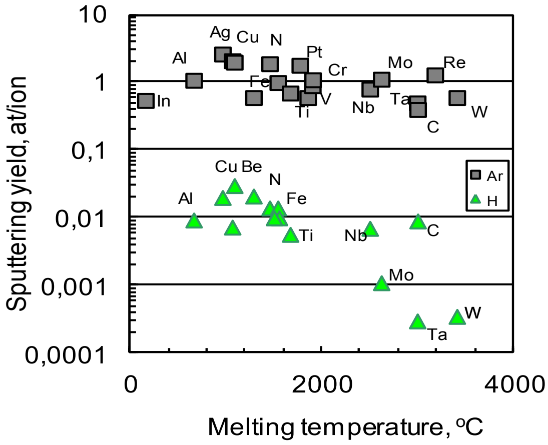

Fig. 4. Ar^+ and H^+ ions induced sputtering yields at normal incidence [9, 10] versus melting temperature of various metals

CONCLUSIONS

The W, Ta, and W-Ta coatings erosion coefficients had been measured after steady state mirror Penning plasma discharges impact. It had been shown that addition of Ta (2.5…16 wt.%) in W coating leads to essential decrease of W erosion rate, especially for light ions. For hydrogen plasma erosion coefficient of W-16 %Ta coatings is about 0.018 at/ion H^+ instead of 0.038 at/ion for pure W coatings. In the case of N^+ bombarding ionsit is only 0.22 and 0.3 at/ion, consequently. In both cases a decrease in the erosion rate of W-Ta coatings is near linear dependence on the concentration of the doping material (Ta). The experiments in argon plasma had shown negligible influence of Ta alloy addition. Taking into account the obtained results and literature data on ion induced sputtering of metals, such erosion behavior could be caused by more erosion resistant Ta on the surface and in the nearing surface layer of the coatings.

REFERENCES

1. Zhang-Jian Zhou, Shu-Xiang Song, Juan Du, et al. Perfomance of W/Cu FGM based plasma facing components under high heat load test // *Journal of nuclear science and materials.* 2007, v. 363-365, p. 1309-1314.

2. G.P. Glazunov, M.N. Bondarenko, A.L. Konotopskiy, A.E. Surkov, E.D. Volkov. Erosion behavior of hot pressed in vacuum tungsten-copper material under steady state plasma impact // *The 18th International Conference on Plasma Surface Interaction (Toledo, Spain),* Book of abstracts. 2008, p. 2-57.

3. G.P. Glazunov, D.I. Baron, M.N. Bondarenko, A.L. Konotopskiy, I.M. Neklyudov, N.P. Odeychuk, S.Yu. Saenko, A.E. Surkov, I.K. Tarasov, E.D. Volkov. Erosion Behavior of Materials on Basis of Tungsten Hot

Pressed in Vacuum under Mirror Penning Discharge Plasma Impact // *Problems of Atomic Science and Technology. Series "Plasma Physics*". 2007, № 1, v. 13, p. 93-95.

4. V.M. Lunyov, A.S. Kuprin, V.D. Ovcharenko, V.A. Belous, A.N. Morozov, A.V. Ilchenko, G.N. Tolmachova, E.N. Reshetnyak, R.L. Vasilenko. Structure and properties of W, Ta and W-Ta coatings deposited with the use of a gas-plasma source // *Problems of Atomic Science and Technology*. 2016. № 1, v. 101, p. 140-144.

5. G.P. Glazunov, M.N. Bondarenko, E.D. Volkov, A.L. Konotopskiy. Characteristics of low temperature plasma discharges with combined cathode in crossed electrical and magnetic fields // *Proceedings of the International scientific conference "Physical and chemical principles of formation and modification of micro- and nanostructures".* 2008, v. 2, p. 431-434.

6. V.A. Belous, V.M. Lunyov, G.I. Nosov, A.S. Kuprin, G.N. Tolmachova, I.V. Kolodij. Investigation on the processes of TiSiN coating formation by sputtering Ti and Si targets with ions generated by the gas-plasma source // *Physical surface engineering.* 2013, v. 11, № 4, p. 412-419.

7. G.P. Glazunov, A.A. Andreev, D.I. Baron, R.A. Causey, A.M. Hassanein, K.M. Kitayevskiy, A.L. Konotopskiy, V.I. Lapshin, I.M. Neklyudov, A.P. Patokin, A.E. Surkov, E.D. Volkov. Hydrogen permeability and erosion behavior of the W-Pd bimetallic systems // *Fusion Engineering and Design*. 2006, issues 1-7, p. 375-380.

8. G.P. Glazunov, E.D. Volkov, D.I. Baron, A.P. Dolgiy, A.L. Konotopskiy, A. Hassanein. Effect of Low/High Hydrogen Recycling Operation on Palladium Sputtering under Steady State Plasma Impact // *Physica Scripta.* 2003, v. T103, p. 89-92.

9. W. Eckstein, C. Garsia-Rosales, J. Roth, W. Offenberger. Sputtering Data. (9182). *IPP, Garching, Munchen.* 1993, p. 342.

10. Y. Yamamura and H. Taware. Energy Dependence of Ion-induced sputtering yields from monoatomic solids at normal incidence // *Research Report NIFS. Data Series, NIFS-DATA-23.* 1995, p. 114.

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ЭРОЗИОННОЕ ПОВЕДЕНИЕ W-Ta-ПЛЁНОК В ПЛАЗМЕ СТАЦИОНАРНОГО ОТРАЖАТЕЛЬНОГО РАЗРЯДА ПЕННИНГА

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Исследуется влияние легирующей добавки Ta (2…16 вес.%) в W-пленке, на эрозионное поведение в плазме разряда Пеннинга различных газов (аргона, азота и водорода). Покрытия наносились путём распыления ионами аргона мишеней из соответствующих металлов на подложку из нержавеющей стали. Для сравнения исследовано эрозионное поведение в различных газах однокомпонентных W- и Ta-пленок, полученных тем же методом. Обнаружено существенное уменьшение скорости эрозии после добавления Ta в W-покрытия. Предлагается физический механизм для объяснения такого поведения эрозии.

ЕРОЗІЙНА ПОВЕДІНКА W-Ta-ПЛІВОК У ПЛАЗМІ СТАЦІОНАРНОГО ВІДБИВНОГО РОЗРЯДУ ПЕННІНГА

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Досліджується вплив легуючої добавки Ta (2…16 ваг.%) в W-плівці на ерозійну поведінку в плазмі розряду Пеннінга різних газів (аргону, азоту і воденю). Покриття наносилися шляхом розпилювання іонами аргону мішеней з відповідних металів на підкладку з нержавіючої сталі. Для порівняння досліджена ерозійна поведінка в різних газах однокомпонентних W- і Ta-покриттів, отриманих тим же методом. Виявлено істотне зменшення швидкості ерозії після додавання Ta в W-покриття. Пропонується фізичний механізм для пояснення такої поведінки ерозії.