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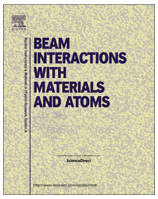

Powder modification under influence of heat, electric field and particle irradiation

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ABSTRACT

Influence of heat, electric field and particle irradiation of powders of boron and tungsten are presented and discussed in the paper. It is shown that the particles of both powders are emitted from their surface when electric field applied normally to the powder surface exceeds some minimal magnitude. Simultaneous influence of electric field and irradiation by hydrogen- and argon plasma ions or by hydrogen atoms activates particle emission at the temperatures <1300 K. Hydrogen- and argon plasma ion irradiation in the temperature range 1300–1800 K stimulates a succession of powder modifications with the increase of powder temperature and power of ion irradiation.

Driving forces and processes of powder modifications were found to be electric field forces, irradiation enhanced diffusion, interatomic forces, surface tension, sputtering by ion irradiation and ion induced stresses in the newly formed uniform layers.

1. Introduction

Dust production and its influence on the plasma remain among still unclarified problems of International Thermonuclear Experimental Reactor (ITER). Dust influences the plasma parameters, leads to retention of hydrogen isotopes inside the plasma chamber, etc.

A number of papers were devoted to investigations of dust production and its behavior in fusion devices. Features and mechanisms of dust production were considered in papers [1–3], dust migration and influence of dust on the performance of fusion devices were analyzed in papers [2,4,5], dust levitation and behavior in plasma were the subject of paper [6].

Evaluation of the peculiarities and mechanisms of plasma interaction with dust layers can help to overcome the negative consequences of dust presence in plasma- and fusion devices and in a number of technological installations. At the same time only very few specific sides of plasma-dust interaction have been studied till now [7–9].

The paper investigates peculiarities and driving forces of the processes initiated in the tungsten and boron dust/powder by various influences including powder outgasing due to heating, powder particle emission under electric field forces and both atom and ion by atom irradiations, powder structure modification due to cumulative action of heat, electric field and ion irradiation.

2. Experimental

The experiments were performed in the Multifunction Complex for Plasma Surface Irradiation and Mass Analysis (MICMA, former TDS-2) [10]. Fig. 1 presents the scheme of the vacuum chamber (1) of MICMA device modified for the experiments with powders.

The plasma chamber is designed as the vertically arranged cylinder (2). Plasma (3) is ignited between the heated tungsten cathode (4) installed on the upper base of the chamber and the anode (5), which is designed as the lower base connected through the insulator (6) with the cylindrical wall of the plasma chamber. The powder layer 2–3 mm thick is placed on the substrate (7) which is a cleaned and annealed plate of high purity tantalum. The substrate is installed below the anode at a distance 15 mm and aligned parallel to it. Separately pumped quadrupole mass-spectrometer (8) is used to measure gas release from the powders. The plane tungsten spiral (9) heated by direct current was placed behind the substrate. Powder could be heated by irradiation from the tungsten spiral and also by impinging ion flux. For the investigation of the powder behavior in electric field the substrate was biased with respect to the anode. Hydrogen atoms used for powder irradiation were generated on the heated cathode and passed to the powder through the circular opening (10) in the anode screened by the microscopic tantalum gauze. The ions of

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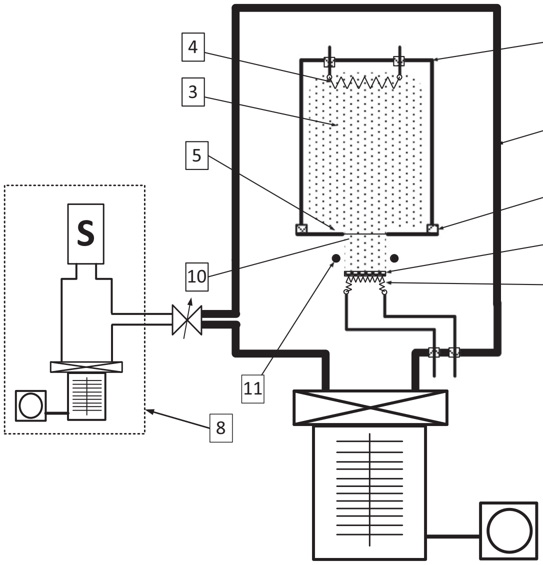


Fig. 1. Scheme of vacuum chamber of MICMA device (The numbers on the scheme are defined in the text).

hydrogen- or argon plasma were drawn off from the plasma through the opening in the anode and accelerated towards the negatively biased substrate. Anti-dynatron ring (11) suppressed ion–electron emission from the irradiated powder.

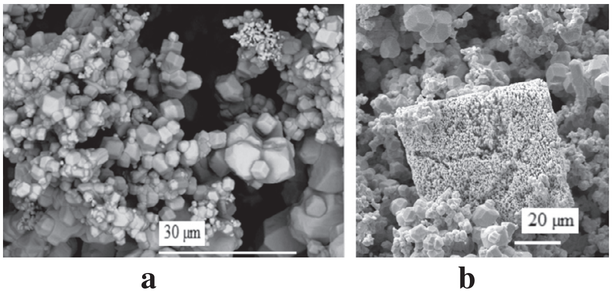
Residual gas pressure in the experimental device did not exceed 1.5×10^{-4} Pa. Pressure of the working gas was $\leqslant 1$ Pa (hydrogen) and $\leqslant 10^{-1}$ Pa (argon).Hydrogen plasma consisted of the H_2^+ ions (82–85%) and of $(H_1^+ + H_3)$ ions (15–18%). Thus, experimental results were analyzed assuming powder irradiation solely with H_2^+ ions. Irradiation parameters – ion energy, ion current density, powder temperature – were varied in the ranges $E = (1–7)$ keV/at, $j = (10–50)$ A/m^{2}s, $T = (300–1800)$ K.

The tungsten powder was comprised of two main fractions of crystalline micro particles with the dimensions: 5 ± 1.5 μm and 1 ± 0.2 μm (“large” and “small” particles). The boron powder also includes two main fractions of micro particles with dimensions 2–5 μm and $\leqslant 1$ μm. The shapes of the large ones point to their crystalline structure. The powder temperature was measured by W–Re thermocouple made from the wires with diameters 0.3 mm and by the pyrometer. Compositions of the powders and tantalum substrate are presented in Table 1.

3. Experimental results

3.1. Agglomerations of “virgin” powder particles

Scanning Electron Microscope (SEM) images showed certain agglomerations in the “virgin” tungsten powder. Large particles formed volumetric chains, and some of the small particles joined the chains (Fig. 2a). The small particles somehow united in geometrically shaped clusters with dimensions 40–60 μm (Fig. 2b).



a b

Fig. 2. The particle agglomerations in the “virgin” tungsten powder. (a) Volumetric chains, (b) Geometrically shaped clusters.

3.2. Powder outgasing

During the low rate heating (≈1–5 K/s) the powders were outgased in the temperature range 500–830 K, and outgasing was not accompanied by any powder modifications. The TDS measurements revealed that the gas emitted from the tungsten powder consisted predominantly of water molecules. Comparison of TDS spectra with that of bulk tungsten showed that the released water molecules ($\approx 5, 3 \times 10^{18}$ mol/g) were sorbed on the powder particle surfaces. Their concentration in the sorbed layer was estimated as being $\approx 5 \times 10^{19}$ mol/m^2.

Boron powder during slow heating desorbs H_2 (5×10^{21} mol/g), OH (1×10^{21} mol/g), H_2O (3×1021 mol/g). Analysis of the TDS spectra (Fig. 3) allows conclusion that the water molecules were emitted from the sorbed layer of the powder particles, and the majority of hydrogen was released from their bulk.

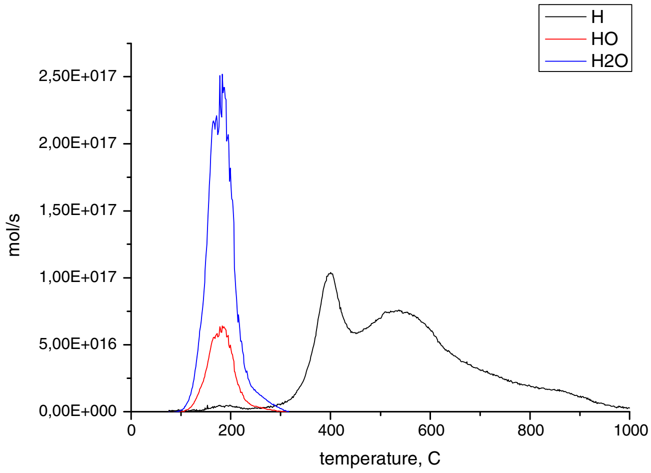


Fig. 3. TDS spectra of boron powder.

Table 1
Compositions of powders and tantalum substrate.

Tungsten powder									
Component	W	Mo	Fe	As	K	Na	Al + C + Ca + Ni + S + Si		$(O + H_2O)$
Content (at.%)	$\geqslant 99.5$	0.2	0.02	0.03	0.02	0.02	0.027		0.12
Boron powder									
Component		B		Cl		C		Fe + Al + Cu + Mg + Si + Pb	
Content (at.%)		$\geqslant 99.1$		$\leqslant 0.3$		$\leqslant 0.1$		$\leqslant 0.5$	
Tantalum substrate									
Component	Ta	W	Fe	C	Mo	Nb	Si	Ni	O
Content (at.%)	99.95	0.002	0.0017	0.0011	0.001	0.001	0.001	0.0005	0.0081

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