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Сборник содержит материалы, представленные в виде устных докладов на международной школе по физике взаимодействия плазмы с поверхностью.

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July, 28 (Chair: S.Krasheninnikov, N.Ohno)

9:00-9:30	V.Kurnaev. Opening
9:30-10:30	V.Kurnaev. Fusion and energy
10:30-10:45	**Coffee break**
10:45-11:45	R.Pitts. ITER Status and Challenges
11:45-12:45	R.Pitts. ITER Status and Challenges (cont.)
12:45-14:00	**Lunch**
14:00-15:00	S.Krasheninnikov. From plasma to wall and back.
15:00-16:00	D.Ruzic. Overview of plasma technology
17:00-19:00	**Reception**

July, 29 (Chair: D.Ruzic, M.Mayer)

9:30-10:30	A.Kreter. Diagnostics for plasma-material interaction studies
10:30-11:30	N.Ohno. Plasma-wall related experiments on NAGDISS and LHD
11:30-11:45	**Coffee break**
11:45-12:45	D.Ruzic. Li as a first wall material
12:45-14:00	**Lunch**
14.00 – 15:00	S.Mirnov. Li experiments on tokamaks
15:00 - 16:30	**Student’s talks**

July, 30 (Chair: R.Pitts, T.Tanabe)

9:30-10:30	T.Tanabe. Carbon as a material for the first wall
10:30-11:30	M.Mayer. Erosion and deposition studies in fusion devices
11:30-11:45	**Coffee break**
11:45-12:45	R.Pitts. Dust in ITER: generation, diagnosis and clean-up
12:45-14:00	**Lunch**
14:00-15:00	T.Tanabe. Fusion reactor to be safe and economic energy source
15:00-16:30	**Student talks**

July, 31 (Chair: K.Nordlund)

9:30-10:30	K.Nordlund. The molecular dynamics method for simulation of plasma-wall interactions
10:30-11:30	F.Djurabekova. The Monte Carlo method for simulation of plasma-wall interactions
11:30-11:45	**Coffee break**
11:45-12:45	D.Borodin. Modelling of Plasma-Surface experiments using the 3D local impurity transport Monte-Carlo code ERO and extrapolation of the results for ITER
12:45-14:00	**Lunch**
14.00 –15:30	**Student's talks**
15:30-17:00	**Laboratory tour**

August, 1 (Chair: G.Van Oost, L.Begrambekov)

9:30-10:30	L.Begrambekov. Inelastic collisions as the driving force of gas exchange processes on the surface.
10:30-11:30	A. Pisarev. H in metals.
11:30-11:45	Coffee break
11:45-12:45	G.Van Oost. Experiments radial E field in edge plasmas
12:45-14:00	**Lunch**
14.00 – 15:00	A.Pisarev. Technological applications of plasma surface interaction
15:00 - 16:30	Student's talks

August, 2 (Saturday)

Excursions

August, 3 (Sunday)

Outing

August, 4 (Chair: V.Kurnaev)

9:30-10:30	G.Van Oost. Erasmus Mundus Fusion Education Networks.
10:30-11:30	S.Jin. Nanotechnology
11:30-11:45	Closing

STUDENTS TALKS

July, 29

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ON THE DETERMINATION OF THE BINDING ENERGIES FOR DEUTERIUM IN TUNGSTEN FROM THERMAL DESORPTION MEASUREMENTS WITH DIFFERENT HEATING RATES

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INVESTIGATION OF CO-DEPOSITION OF Li-D MIXED FILMS IN MAGNETRON DISCHARGE

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MEASUREMENT CONCENTRATION OF WATER MOLECULES BY THE ABSOLUTE INTENSITY SPECTRUM HYDROXYL IN GLOW DISCHARGE WITH HOLLOW CATHODE

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EMISSION PROPERTIES OF THE PLASMA FACED MODEL-MATERIAL COVERED WITH THIN INSULATOR FILMS

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LASER CLEANING OF DIAGNOSTIC FIRST MIRRORS FROM TOKAMK LIKE CONTAMINANTS

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LEIS ANALYSIS OF THE SURFACE DURING WATER VAPOR ADSORPTION

July, 30

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CALCULATION OF MECHANICAL STRESSES CAUSED BY PULSE HEAT LOAD

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ELECTROMAGNETIC EFFECTS ON FINITE BETA PLASMA

BLOB DYNAMICS

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ABLATION OF HIGH-Z MATERIAL DUST GRAINS IN EDGE PLASMAS

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GAS EXCHANGE BETWEEN OXYGEN CONTAMINATED HYDROGEN PLASMA AND STAINLESS STEEL VESSEL

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EXPERIMENTAL STUDIES OF DIVERTOR RELEVANT PLASMA-SURFACE INTERACTIONS IN MAGNUM-PSI AND PILOT-PSI LINEAR PLASMA GENERATORS

July, 31

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LUNAR SURFACE COMPOSITION ANALYSIS USING SOLAR WIND

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SURFACE MODIFICATION OF TUNGSTEN AFTER IRRADIATION BY ELECTRON BEAM AND PLASMA STREAM

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The crystal structure of ZnO films doped with Cu, obtained by electrochemical method

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** See the Appendix of F. Romanelli et al., Proceedings of the 24th IAEA Fusion Energy Conference 2012, San Diego, USA*
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EROSION AND DEPOSITION IN JET DIVERTOR DURING 2011-2012 CAMPAIGN

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MODELING OF HYDROGEN DESORPTION FROM TUNGSTEN SURFACE

August, 1

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DEUTERIUM PERMEATION THROUGH LOW-ACTIVATION STRUCTURAL MATERIALS

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INVESTIGATION OF HYDROGEN BEHAVIOR IN ZIRCONIUM UNDER PLASMA IRRADIATION AND BARRIER PROPERTIES OF IRRADIATED LAYER

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GAS EXCHANGE BETWEEN OXYGEN CONTAMINATED HYDROGEN PLASMA AND STAINLESS STEEL VESSEL WALL

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HYDROGEN ISOTOPES RETENTION IN LOW-ACTIVATION STEEL RUSFER

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DEUTERIUM RETENTION IN EROSION PRODUCTS OF PLASMA FACING MATERIALS UNDER ITER-LIKE TRANSIENT LOADS

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ON THE DETERMINATION OF THE BINDING ENERGIES FOR DEUTERIUM IN TUNGSTEN FROM THERMAL DESORPTION MEASUREMENTS WITH DIFFERENT HEATING RATES

Understanding of hydrogen isotopes behaviour in metals is of great importance for many areas, including nuclear fusion. Thermal desorption spectroscopy (TDS) is a commonly used method for such purposes. Numerical diffusion-trapping models with surface recombination, which are implemented in various codes such as TMAP7, are often used for simulation of TDS spectra. In these codes parameters of trapping sites (detrapping energy, trap concentration profile, attempt frequencies, etc.) act as variables and adjusted in order to fit the simulated spectra with experimental ones. However, simple analytical models, especially the first-order desorption model, are sometimes still used. In that particular case the detrapping energies can be directly determined from the shift of desorption maximum in the TDS measurements of identical samples performed with different heating rates.

In this work we simulated thermal desorption spectra from tungsten with different heating rates (from 0.1 K/s to 50 K/s) using the TMAP7 code. Various detrapping energies, trap profiles and trap population were used. Besides, two recombination rate coefficients were used: the value for clean W surface from Pick and Sonnenberg's model [1] and the experimental value from Anderl et al. [2].

It was observed that in the case of Pick and Sonnenberg's recombination rate, the relation between the detrapping energy, desorption peak position, and heating rate was consistent with the first-order desorption model in a wide range of parameters. In the case of Anderl's recombination rate, the predictions based on the model were valid only in some particular cases. A numerical criterion of validity of the first-order desorption model for determination of the binding energies for deuterium in tungsten from TDS measurements with different heating rates was suggested.

[1] M.A. Pick, K. Sonnenberg, J. Nucl. Mater. 131 (1985) 208
[2] R.A. Anderl et al., Fus. Technol. 21 (1992) 745

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CALCULATION OF MECHANICAL STRESSES CAUSED BY PULSE HEAT LOAD

Intense transient events in ITER such as bursts of Edge Localised Modes (ELMs) pose a threat to plasma facing components (PFCs). The pulse heat load during the transient events results in local temperature rise and, consequently, mechanical stresses due to thermal extension. The stresses are reason of several dangerous processes (e.g. crack and dust formation). The work is aimed to analytical calculation of the stresses.

Despite the thinness of heated surface layer, the calculation of mechanical stresses requires consideration of volumetric effects of thermal extension. The thermal extension should be taken into account as a summand proportional to temperature change in Hooke's law [1].

At the case of heat load caused by transient events the one-dimensional approach is relevant before crack formation. There is exact solution of one-dimensional problem of elasticity. The solution permits simple interpretation: each layer of material seeks for thermal extension, but cold layers do not admit it expand along the surface. As a result the stresses along the surface appear. The model of plastic deformation for tungsten has to take into account brittle-to-ductile transition. The one-dimensional approach allows deriving of the conditions of crack formation and the crack depth. The results of the calculation agree with experimental data obtained at JUDITH-1, PSI-2 and GOL-3 [2-4].

The derivation of crack width, distance between cracks and conditions of parallel to surface crack formation require at least two-dimensional calculation of stresses around crack.

References

[1] L.D. Landau and E.M. Lifshitz, Theory of Elasticity (Volume 7 of A Course of Theoretical Physics), Pergamon Press 1970
[2] A. Huber, A. Arakcheev et al., Phys. Scr., T159 (2014) 014005.
[3] M. Wirtz, J. Linke et al., J. Nucl. Mater., 330 (2013) S833-S836.
[4] A.V. Arzhannikov, V.A. Bataev et al., J. Nucl. Mater. 438 (2013) S677-S680.

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MEASUREMENT CONCENTRATION OF WATER MOLECULES BY THE ABSOLUTE INTENSITY SPECTRUM HYDROXYL IN GLOW DISCHARGE WITH HOLLOW CATHODE

A method of vacuum leak test complex systems with water-cooling systems is describes.

The idea of the spectroscopic method is based on the known mechanism of dissociative excitation of water molecules with the emergence of the radical OH_{hot}* ($A^2\Sigma$) with rapid rotation [1]. The ensemble of these molecules can be distinguished from the spectrum of the (0,0) band transition $A^2\Sigma$-$X^2\Pi$.

Experiments were carried out at the facility [2] with a discharge in a rectangular hollow cathode, the initial filling gas - a mixture of helium and water vapor. Absolute intensity of the luminescence of individual electronic-vibrational-rotational lines was carried out with the help of the band lamp. Electron concentration in the discharge is determined by the probe method as a saturation of the electronic branch of the VAC and the EDF for the second derivative of the VAC. In the table shows of the measured values for the photon flux Φ line Q_1 (15) on the axis of the hollow cathode, the concentration of $[OH^*_{hot}]$ and $[H_2O]$. Also given the concentration of water in the filling mixture:

$[H_2O]$, cm^{-3} (fill)	Φ, c^{-1}	$[OH^*_{hot}]$, cm^{-3}	$[H_2O]$, cm^{-3} (exp.)
$2 \cdot 10^{15}$	$(6,1\pm0,9)\cdot10^{11}$	$(1,3\pm0,1)\cdot10^{5}$	$(7\pm2)\cdot10^{14}$

The difference between the source and the measured concentrations of water molecules in the discharge can be be explained by: 1) the dissociation of water in the discharge; 2) heating of the gas in the discharge.

The study was performed by a grant from the Russian Science Foundation (project №14-12-00784).

References

[1] V.N. Ochkin. Spectroscopy of Low Temperature Plasma. WILEY-VCH, 2009, 609 p.
[2] A. B. Antipenkov, O. N. Afonin, V. N. Ochkin, S. Yu. Savinov, S. N. Tskhai. Experimental Verification of the Method for Detection of Water Microleakages in Plasma Vacuum Chambers by Using the Hydroxyl Spectrum. Plasma physics, 2012, Vol. 38, № 3, pp. 221-225.

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EXPERIMENTAL STUDIES OF DIVERTOR RELEVANT PLASMA-SURFACE INTERACTIONS IN MAGNUM-PSI AND PILOT-PSI LINEAR PLASMA GENERATORS

Materials in the ITER divertor will be exposed to high plasma and heat fluxes that cannot be reached in present-day tokamaks and are not easily reproduced in laboratories. The Magnum-PSI [1] and Pilot-PSI [2] linear plasma generators at FOM Institute DIFFER are unique in enabling plasma-surface interactions studies under high fluxes of low temperature plasmas ($n_e \sim 10^{19}$–10^{21} m^{-3}, $T_e \sim 1$–3 eV, $\Gamma_{ion} \sim 10^{23} – 10^{25} m^{-2}s^{-1}$, $\varphi_q \geq 10$ MW/m^2 in steady state). In addition to steady state loading, a high repetition rate ELM replication system (f > 100 Hz, $\varphi_q \sim 0.10$–0.15 GW/m^2, $t_{pulse} \sim 0.7$–1.5 ms in Magnum-PSI [1, 4]) is used to investigate the effect of transient loading on the plasma-facing components behavior [3, 4]. This makes it possible to study plasma-surface interactions in the regime relevant for ITER and reactors that will follow ITER in Magnum-PSI and Pilot-PSI.

The present contribution will describe the capabilities of the DIFFER linear devices and will give a short overview of the PSI-related research activities at DIFFER. In particular, the following topics will be touched upon: ELM-induced tungsten surface damage and melting, helium-induced tungsten nanostructure formation, deuterium retention in radiation damaged tungsten, enhanced erosion of liquid tin.

References
[1] H.J.N. van Eck, et al., Fus. Eng. Des. (2014), in press
[2] G. De Temmerman, et al., Nucl. Fusion 51 (2011) 073008
[3] J. J. Zielinski, et al., Appl. Phys. Lett. 104 (2014) 124102
[4] T.W. Morgan, et al., Submitted to Plasma Phys. Control. Fusion

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EMISSION PROPERTIES OF THE PLASMA FACED MODEL-MATERIAL COVERED WITH THIN INSULATOR FILMS

Investigation of the emission properties of the plasma-faced materials covered with thin insulator films is actual problem due to beryllium and tungsten, chosen as first wall materials for international thermonuclear reactor ITER, can be easily covered by oxide layer. Aluminum is usually used as model material for imitation experiments because beryllium is toxic. As it was found in the simulation experiments on the linear simulator [1], formation of a thin (~10 nm) oxide layer on the aluminum target had strongly increased electron emission under plasma impact. However there was no ability in [1] to measure the film thickness without exposure to atmosphere. In this work we present the results of in situ measurements of emission properties of some model material with thin dielectric layer on its surface in correlation with dielectric film thickness.

"Large Mass-Monochromator MEPhI" set up allows to analyze thin surface films in the range of 5-60 Å using the energy analyzer and surface element analysis directly during sputtering process. Miniature anode for electric field-current measurement was situated opposite the sample, so ions scattered from the surface can go through vacuum gap between cathode and anode.

The model sample was made of Si smooth substrate with ~150 Å of tungsten and then 30 Å of aluminum on its surface. Aluminum layer was completely oxidized after exposure to atmosphere forming thin insulator film.

The experimental results have shown that for various values of the insulator film thickness detectable current was measured only after microbreakdown series. Current-voltage characteristic of these samples had strong hysteresis effect and was interpreted by "switch-on" model [2]. After microbreakdowns the film was damaged and became discontinuous. Comparison of the field emission properties with other PFC materials has shown that emission is as high as in the case of tungsten nano "fuzz" sample [3].

References

[1] K. M. Gutorov et al; Bul. of the Rus. Academy of Sciences: Physics, Vol. 74 (Feb. 2010), Iss. 2, pp. 188-191
[2] R.V.Latham High voltage vacuum insulation, Academic press, (1995)
[3] S. Kajita; Fusion Engineering and Design; Vol. 88 (2013) pp. 2842–2847

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DESIGN AND FABRICATION OF NANOSTRUCTURED FUNCTIONAL MATERIALS USING PLASMA PROCESSING

New nanostructured materials such as one-dimensional or two dimensional materials can provide exciting and useful functional properties for modern electronic, magnetic, photonic, thermal, or biological applications. Some example nanomaterials that can be prepared by plasma-material interactions include aligned carbon nanotubes, graphene nanostructures, diamond, metallic or semiconducting nanowires. These nanowire, nanoisland or nano hole array structures can be made in either periodically patterned or random configurations.

Manipulations of plasma density, orientation, positions and the duration of plasma treatment can be utilized to design specific desired structures. Carbon nanotube growth morphology can be altered for formation of abruptly bent or zig-zag nanotube configurations which can be useful for multi probe devices and high surface-area catalytic surfaces. Two-dimensional materials such as thin graphene layer and MoS_2 layer can be modified into nano-ribbon or periodic nano hexagonal array structures for substantially modified bandgaps, improved optical transparency, or large surface area structures for enhanced sensors and electronic devices. Controlled plasma etching can be employed for patterning of extremely fine nano-island arrays with 10 nm regime dimensions for ultra-high-density magnetic recording media. Metallic nanowire array generated by high temperature plasma etching can be useful for medical device and biomedical applications such as coronary stents, enhanced cell growth, and drug delivery applications, as well as catalytic surfaces and mechanical shock absorbing surface nanostructural applications.

In this talk, the principles of how various configurations of nanostuctures can be created via plasma processing will be described, and various potential scientific and technical applications of plasma-produced nanomaterials will be discussed.

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DIAGNOSTICS FOR PLASMA-MATERIAL INTERACTION STUDIES

Plasma-material interaction (PMI) is a critical issue for the availability of the fusion reactor. The first wall materials will be subjected to high power and particle fluxes, which will lead to material erosion of the material, transport through plasma and deposition, which may take place far away from the original location. These processes will affect the lifetime of first wall components and the retention of radioactive tritium.

PMI investigations in both large scale and lab scale devices require sophisticated diagnostic methods to monitor each step of the process, including surface characterization of the material sample exposed to plasma. The PMI diagnostics can be divided in three groups: "in-situ", "in-vacuo" and "ex-situ", the latter one is also often referred to as "post-mortem". The diagnostics are called in-situ, when the measurements are performed during the running experiment. Many of in-situ techniques also deliver real time data. In-situ analyses are challenging but provide a better insight in dynamics of PMI processes. In-vacuo surface analysis methods are applied after the plasma experiment, but before the sample is exposed to the air atmosphere, which may modify its surface condition, e.g. through oxidation. Ex-situ (post-mortem) methods are used after the transport and storage of the sample in air.

In this lecture, a selection of diagnostical methods from each of the groups will be introduced. Examples of in-situ methods are Optical Emission Spectroscopy (OES) and Quartz MicroBalance (QMB). Laser based techniques like Laser Induced Desorption (LID) and Laser Induced Breakdown Spectroscopy (LIBS) can be applied in-vacuo for the analyses of retention and elemental composition, respectively. There is a variety of post-mortem surface analysis techniques available in a network of specialized laboratories. Examples of these techniques are Thermal Desorption Spectrometry (TDS) for the analysis of retained gases, Scanning Electron Microscopy (SEM) and Surface Profilometry (SP) for the investigation of surface morphology, Ion Beam Analysis (IBA) and Secondary Ion Mass Spectrometry (SIMS) for the analyses of surface composition. Erosion, unlike deposition, is difficult for the direct quantification. Examples of refined techniques applied for this purpose, like the use of "smart samples" with reference markers, will also be given in this presentation.

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ELECTROMAGNETIC EFFECTS ON FINITE BETA PLASMA BLOB DYNAMICS

Plasma blobs are coherent turbulent structures usually observed in the scrape-off layer (SOL) of magnetic confinement devices. The intermittent individual blob is characterized by its density, which is higher than the surrounding plasmas and its filamentary shape that is stretched along the magnetic field line. Recent study with an electrostatic blob model shows the coherency of blob structure is substantially limited by resistive drift wave [1]. However, the electrostatic approximation is only valid in low beta filaments ($\beta=8\pi nT/B^2<<m_e/m_i$). Therefore, there has been an increasing interest in the electromagnetic effects on blob dynamics to explain and predict the characteristics of ELM filaments and edge turbulent transport projected to high-β devices such as ITER. In this study, we examine both macroscopic and microscopic impacts of the electromagnetic effects on blob dynamics. It is found that inhomogeneity of magnetic curvature or plasma pressure along the filament length leads to bending of the high-beta blob filaments. This bending of magnetic fields may cause the far SOL region to be connected to the inner region with higher temperature. Linear stability analysis and nonlinear BOUT++ simulations demonstrate that electromagnetic effects in high temperature or high beta plasmas suppress the resistive drift wave turbulence when resistivity drops below some certain value.

References

[1] Justin R. Angus, Sergei I. Krasheninnikov and Maxim V. Umansky, Phys. Plasmas 19 (2012) 082312

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LASER CLEANING OF DIAGNOSTIC FIRST MIRRORS FROM TOKAMK LIKE CONTAMINANTS

First Mirrors (FMs) will be crucial components of plasma diagnostics in ITER and future fusion machines. Since FMs will directly face thermonuclear plasma, they will be prone to both plasma erosion and/or surface redeposition of materials eroded from tokamak first wall. In particular, the dramatic decrease of FM reflectivity due to the deposition of contaminants could lead to a failure of the diagnostic system. Among the possible solutions to tackle this issue, the laser cleaning technique is currently under investigation [1].
This work presents a novel approach in which the same laser system is exploited to experimentally investigate the process of FM production, contamination and laser cleaning. By means of pulsed laser deposition (PLD) it was possible to produce rhodium (Rh) films with realistic properties as FM coating [2,3] suitable also to perform laser cleaning tests. In order to mimic the redeposition phenomenon onto mirror surface, PLD was employed to deposit on Rh films carbon (C) and tungsten (W) based materials with tailored morphology, stoichiometry and nanostructure, resembling those found in currently operating tokamaks [4]. The contaminated Rh films were treated with Nd:YAG nanosecond laser pulses, with different wavelengths (1064 nm, 266 nm). A suitable sample handling procedure allowed to clean mirrors of some cm^2 in a few minutes. In general, we observed that the response to the laser cleaning process is strongly dependent on the contaminant properties. Nevertheless, by properly choosing the laser parameters, a satisfactory recovery of mirror reflectivity was achieved for most of the samples, thus proving the adaptability and the effectiveness of the technique in conditions potentially relevant for tokamak application. The versatility of this approach can also be exploited to investigate laser cleaning of other ITER-relevant materials, like beryllium or beryllium proxies.

[1] E.E. Mukhin et al. Nucl. Fusion 52 013017 (2012)
[2] M. Passoni, D. Dellasega, et al., J. Nucl. Mater. 404, 1 (2010)
[3] A. Uccello, D. Dellasega, et al., J. Nucl. Mater. 432, 261 (2013)
[4] A. Uccello, A. Maffini et al., Fus. Eng. Des., 88, 1347-1351 (2013)

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ABLATION OF HIGH-Z MATERIAL DUST GRAINS IN EDGE PLASMAS

Nowadays it is well recognized that dust particles can play an important role in fusion plasma performance and material transport. Therefore, it is important to have a good physics understanding of the most important processes dust grains encounter in the course of the interactions with fusion grade plasmas. Many fundamentals of grain-plasma interactions were developed by dusty-plasma community. However, grain-plasma interactions in fusion devices have some important distinctions. In particular, in hot and dense fusion plasma environment dust grains ablate rather quickly. The effect of the vapor on grain-plasma interactions can only be neglected for relatively small grains (below ~10 microns). Meanwhile, it is important to know how the vapor "shielding" alters grain-plasma interactions for larger (~100 microns) grains, which may pose significant threat for plasma performance and even result in disruption (especially for the case where these are high-Z material grains).

Here we present the result of the analysis of high-Z material (e.g. tungsten) grain ablation in edge plasma where plasma temperature is below keV. We find that due to large mass of vapor atoms/ions, which slows down energy exchange, vapor remains "cold" within a time range when it shields the grain. For this case, unlike the case of cryogenic hydrogen targets, the main shielding effects is due to radiation energy loss caused by the interactions of plasma electrons with atoms and ions of the vapor.

We present the expression for the grain ablation rate, which scales very differently, with respect to plasma parameters and grain radius, from dependencies obtained in.

Obviously that the comparison with experimental data would help tremendously in further refinement of our theoretical model.

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LEIS ANALYSIS OF THE SURFACE DURING WATER VAPOR ADSORPTION

The interaction of water vapor with boronized tungsten walls (boron carbide thin on tungsten) changes the parameters of the discharge plasma, which increases the radioactive losses 3 times resulting in discharge failure as it was shown on the L-2M stellarator [1].

In this work results of *in-situ* LEIS (low energy ion spectroscopy) analysis of tungsten samples during water vapor adsorption are presented. All experiments were performed at the facility based on MEPhI mass monochromator [2].Thermochemical water vapor source [3] based on $Ca(OH)_2$ thermal decomposition is used for experiments with water adsorption on the cathode. The partial pressure of water vapor in vacuum chamber was regulated from $3 \cdot 10^{-8}$ Torr to $3 \cdot 10^{-6}$ Torr by heating $Ca(OH)_2$. This permits changing of adsorption rate from monolayer per 300 s to one monolayer per 30 s for adsorbat-clean surface.

Experiments show that the H^+ and O^- peaks intensity (in LEIS energy spectra) increase sharply in the first few minutes of water vapor injection, and then go to saturation even further increase in the partial pressure of water vapor. Thus tungsten at room temperature completely covered by monolayer of water during 20 minutes (the partial pressure of water vapor $\approx 2 \cdot 10^{-7}$ Torr). Comparison of energy spectra scattering H^+ with Scatter code simulations shows that maximum thickness of the water deposited on W does not exceed 40 Å. It is interesting to note that simple single scattering model can be also used to evaluate water layer thickness because for grazing angle geometry high atomic number of substrate gives high probability of elastic scattering of hydrogen projectiles with succeeding inelastic stopping in layer of water molecules.

References

[1] Voronov G. S. et al., Plasma Physics Reports, 277–288 (2013), Vol. 39, No. 4.
[2] Mamedov N.V., et al., Bul. of the Rus. Academy of Sciences: Phys, 683–686 (2012), Vol. 76, No. 6
[3] Kurnaev V.A. et. al. Fusion Engineering and Design, 1414-1417 (2013), Vol. 88 Iss. 6-8.

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INVESTIGATION OF CO-DEPOSITION OF Li-D MIXED FILMS IN MAGNETRON DISCHARGE

Lithium is considered as a possible plasma-facing material for future fusion devices due to its many positive effects on plasma operation [1-2]. Co-deposition of lithium films with hydrogen isotopes on plasma facing components during operation can be a problem from the viewpoint of tritium retention.

A set-up for co-deposition of Li-D mixed films and in situ thermal desorption spectroscopy has been constructed. There is a gas-blousing system to investigate interaction of deposited layers with various gases in situ

Experiments for co-deposition of Li-D mixed films and in situ thermal desorption spectroscopy have been conducted. It was found that hydrogen isotopes were accumulated in the films. The deuterium concentration in the films was thus estimated to be in the range of D/Li=5-20% for various films.

Two sharp peaks with maxima at 710 K and 850 K were observed in the D2 and HD typical TDS spectra. Different ratios between amplitudes of these two peaks were observed, but the peak at 710 K was always much higher. There are also peaks at 650 K and 810 K, but they are always very small. Lithium films completely evaporated after being heated to 1100 K in all experiments.

It was found that the amount of deuterium in the Li-D films decreases if the film was kept in air after deposition before TDS measurements. In particular, there was no deuterium detected in the film after the sample was kept in air for three days. The film did not completely evaporate after TDS in this case.

It was found that the number of deuterium atoms in the Li-D films decreases when films come in contact with water vapor.

References

[1] S.V. Mirnov. Fusion Engineering Design. №6 v85 (2010) 919-923
[2] S.V. Mirnov. Journal of Nuclear Materials. V390-391 (2009) 876-885

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SURFACE MODIFICATION OF TUNGSTEN AFTER IRRADIATION BY ELECTRON BEAM AND PLASMA STREAM

Experimental research of tungsten erosion after irradiation with electron beam and plasma flux was carried out. Tungsten targets were exposed in exit unit of the multimirror trap GOL-3 with wide spectrum electrons (energy up to 1 MeV and duration about 8 μs) and plasma stream (with temperature about 1 keV and duration 1 ms). Total heat load was 1 MJ/m^2 per shot with set of 10 pulses. Some of the targets were preheated to 500℃ to simulate temperature of divertor material of the thermonuclear reactor.

Targets after irradiation were studied by SEM. Previously observed crack net on tungsten after irradiation at room temperature were absent at 500℃. However bubble formation was more extensive in 3-4 folds on preheated targets. Also experiments of multipulse tungsten irradiation at test facility with multiapertural electron injector were carried out. Targets were exposed 10, 100 and 1000 shots with heat load 0,75 MJ/m^2 at maximum per shot. Observed cracks at target after 100 and 1000 shots thicker 2-3 times than cracks on 10-pulses target surface. Crack propagation on target after 1000 pulses leaded to melting of thin surface layer near crack edges.

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THE CRYSTAL STRUCTURE OF ZnO FILMS DOPED WITH Cu, OBTAINED BY ELECTROCHEMICAL METHOD.

This article is devoted to the influence of the electrochemical doping of copper on the crystal structure and substructure of zinc oxide films.

Glass with a conductive transparent layer of indium oxide doped with tin oxide ITO (Asahi *U*, 10 ohm/□), thickness ITO 250-300 nm was used as the substrates. The substrates were prewashed in aqueous solution Na_2CO_3, double-distilled water and isopropyl alcohol. The structures of zinc oxide were obtained by potentiostatic electrochemical deposition[1] at a potential -0.95 V from the aqueous solution of $ZnCl_2$ (5 M) using different concentrations of CuCl2 (2.9; 5.7; 8.6; 11.4; 14.3; 28.5; 56. 9 mkM), within 30 minutes. Solution KCl (0, 1 M) was used as the supporting electrolyte. Investigation crystal structure ZnO was carried out using X-ray diffraction meter DRON-4-07 in copper radiation Cu-K <α> with wavelength of 1.5432 Å and shooting speed 2 and 0.2 degrees per minute.

The resulting diffraction patterns of doped zinc oxide films at different concentrations of CuCl2 showed that the phase composition of the films does not change, but the intensity of the zinc oxide lines considerably varies due to changes in the degree of perfection of texture. The calculation and comparison of the experimental diffractograms of data from the reference data database JCPDS № 36-1451 has shown that the diffraction peaks belong to the ITO substrate of hexagonal wurtzite zinc oxide, and the diffraction peaks typical of copper and its oxides were not detected.

The lattice parameters of undoped zinc oxide totaled a = (0,3245 ± 0,0005) nm, c = (0,5218 ± 0,0005) nm, which correspond with the reference data in E-JCPDS. It was also reported a decrease of the parameter c for the films of copper-doped zinc oxide, which may be associated with the substitution of copper (ions Cu2 +) in the zinc oxide lattice. It was ascertained the influence of the moment you enter the ligature in the electrolyte from which deposited zinc oxide films formed on the structure.

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EROSION AND DEPOSITION IN JET DIVERTOR DURING 2011-2012 CAMPAIGN

Erosion of plasma-facing materials is an important problem affecting lifetime of fusion installations. Redeposition of materials can lead to accumulation of hydrogen isotopes, including tritium. Before experimental campaign of 2011-2012, first wall of JET (Britain) was changed from carbon one to ITER-like Be and W one. In this work, analysis of erosion and deposition in the inner and outer divertors of JET during 2011-2012 campaign is shown.

Samples taken from divertor tiles 1, 3, 4, 6, 7 and 8 were analyzed with Rutherford backscattering (RBS) with protons, nuclear reaction analysis (NRA) with $^{3}He^{+}$ ions and with scanning electron microscopy (SEM).

In the outer divertor, no detectable erosion takes place. On tiles 7 and 8, very little Be, C and D were detected on the surface. On tile 7, amount of deposits increased steadily towards the bottom of the tile. For D, besides a clear surface peak, a long low tail was observed in the NRA spectra for all the samples, indicating that D is also accumulated in the W layer.

Tiles 4 and 6 showed relatively similar distribution of deposits on their surfaces. There were maxima at the central sloped areas of those tiles, with lower amounts of material deposited at the flat surfaces near the corners of the tiles.

On tile 3 there was no W layer on Mo – this was done to study W redeposition. This was the only tile where strong erosion was detected, with more than 50% of Mo eroded in the upper areas of the tile. At the same time, W redeposition was observed, also intensifying at the upper areas of the tile.

Tile 1 showed complicated erosion-deposition pattern. At the bottom of the tile there was both deposition of Be, C and D, and erosion of W, detectable both by means of RBS and by means of SEM. This is likely the area from where W migrated to tile 3. In the middle area of the tile and on the upper, flat area ("apron") very thick flaky deposits were observed, with complicated multilayered structure. This is the only area where thick deposits were observed.

Total amount of C accumulated in the divertor was 9 g; Be 28 g; D 0.6 g.

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LUNAR SURFACE COMPOSITION ANALYSIS USING SOLAR WIND

Moon surface composition and structure analysis comprises an essential part of Moon origin and evolution research, which also concerns solar system. Lunar regolith surface layer analysis may be conducted by means of analyzing the atoms dislodged from the surface by solar wind, which primarily consists of H^+ (~96%) и He^{++} (~4%) ions with characteristic energies of 1 keV and 4 keV respectively, and with flow rate of $3*10^8$ ions/sm^{2}sec.

For analyzing the neutral atoms dislodged and reflected from the Moon surface by solar wind it is convenient to use high-aperture electrostatic analyzers. To do so it is necessary to convert the neutral atoms into charged ions beforehand. Currently, solid-state convertors are being used for this purpose due to the ease of operation, small size and weight.

The particles that are being registered pass several stages, each of which influences their final number and energy: scattering of lunar regolith driven by solar wind flow, reflection of scattered atoms from convertor surface and conversion to ions, motion of resulting charged particles in the fields of registering apparatus.

Total motion computation may be conducted with the help of computer modeling using, for instance, the SIMION ion optics modeling program and the SCATTER code for calculation of interaction between atomic particles and condensed medium.

When solar wind interacts with the Moon surface the atoms with characteristic energies up to 100 eV are dislodged from it.

Scattered atoms reflect from the convertor surface and part of them is ejected as ions. At the energies of scattered particles up to 100 eV angular distribution of reflected particles is close to the cosine one (angles of incidence up to ≈60°) and energy loss is dispensable for high atom number convertors.

The obtained results may serve as SIMION code modeling input parameters of charged particles motion in analyzer. Among all the particles reflected in a certain point of a convertor it is necessary to mark those that get to the analyzer entrance slit.

Thus, the number of regolith particles of certain kind getting to the registering apparatus and their energies may be calculated while solar wind serves as a test harness.

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DEUTERIUM RETENTION IN EROSION PRODUCTS OF PLASMA FACING MATERIALS UNDER ITER-LIKE TRANSIENT LOADS

Erosion of the plasma facing materials (PFMs), in particular evaporation of the materials, in a fusion reactor under intense transient events is one of the ITER problems. The current experimental data is insufficient to predict the properties of the erosion products, significant part of which will be formed during transient events (Edge-Localized-Modes (ELMs) and disruptions).

The paper concerns the experimental investigation of the graphite and tungsten erosion products deposited under pulse plasma load at the QSPA-T: heat load on the target was 2.4 - 2.6 MJ/m^2 with 0.5 ms pulse duration. Designed diagnostics for measuring the deposition rate allowed to determine that the deposition of eroded material occurs during discharge, and the deposition rate is in the range (0.1 - 100) · 10^{19} at./s·cm^2, which is much higher than that for stationary processes.

It was found that the relative atomic concentration D/C and D/(W + C) in the erosion products deposited during pulse process are on the same level as for the stationary process. It means that amount of the trapped deuterium during transient events is expected to be comparable or even higher than that for stationary process between transients: D/C and D/(W + C) ratios are approximately the same both for stationary process and transient events, but the amount of deposited material is much higher during transient events.

An exposure of erosion products to photonic energy densities relevant to those expected mitigated disruptions on ITER (pulse of 0.5 ms duration, energy density 0.1 – 0.5 MJ/m^2) significantly decreases the concentration of trapped deuterium.

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GAS EXCHANGE BETWEEN OXYGEN CONTAMINATED HYDROGEN PLASMA AND STAINLESS STEEL VESSEL WALL

The certain parts of stainless steel (SS) vessel wall of fusion devices are subjected to plasma irradiation. Oxygen is the most common impurity of plasma of today fusion devices and oxygen contamination is sure to be present in ITER plasma.

This paper investigates the processes taking part during interaction of gas discharge deuterium plasma with oxygen addition with SS wall of the plasma chamber made from austenitic stainless steel containing 18% Cr, 10% Ni, 1% Ti. The range of oxygen concentration varied from 0.5 to 30%.

Irradiation of the vessel surface with ions or/and neutrals of (D_2+O_2) plasma in all investigated conditions led to number of effects like: activation of hydrogen diffusion from the vessel wall, practically total disappearance of oxygen concentration from the plasma, D_2O, HDO, H_2O, H_2, and HD formation and emission from the wall surface, deuterium and oxygen trapping. The amount of deuterium trapped in stainless steel was less than the amount of removed hydrogen.

The above mentioned processes are shown to be the result of the chain of the reactions initiated by interaction of deuterium atoms or ions with Cr_2O_3 molecule of the SS surface oxide layer.

The dependence of the processes on oxygen concentration are presented and discussed.

Conclusion is made that (D_2+O_2) plasma irradiation could be used for stainless steel plasma vessel outgasing and for decrease of tritium inventory in vessel walls.

References

[1] A. Airapetov, L. Begrambekov, et al., J. Nucl. Mater. 451(2011) 1042-1045

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INVESTIGATION OF HYDROGEN BEHAVIOR IN ZIRCONIUM UNDER PLASMA IRRADIATION AND BARRIER PROPERTIES OF IRRADIATED LAYER

Zirconium alloys are used as materials for active core components of PWR. While working zirconium details are being saturated by hydrogen and then they undergo hydrogen embrittlement and further degradation. Protective methods connected with zirconium surface modification are actively developed. However the optimal regimes of surface modification are still not found and the mechanisms that regulate hydrogen exchange between the zirconium surface and the ambient are still poorly understood.

In this work hydrogen behavior in zirconium alloy E110 under plasma irradiation as well as the influence of irradiation on hydrogenation kinetics of the alloy in overheated steam tests were investigated. The amount of hydrogen atoms in zirconium was measured by thermal desorption spectrometry (TDS).

Irradiation of the sample $7\times7\times1$ mm^3 was conducted by argon plasma with the following parameters: residual gas (>90%H_2O) pressure $(1.3\div40)\times10^{-3}$ Pa, ion energy 250 eV, flux 7.5×10^{15} cm^{-2}s^{-1}, fluence 9×10^{18} cm^{-2}, samples temperature was ~500-600 K. The results of experiments have shown that with the increase of residual gas pressure in the range of $(1.3\div30)\times10^{-3}$ Pa hydrogen trapping decreases while the irradiation by argon ions at residual gas pressure of $>3\times10^{-2}$ Pa leads to desorption of up to 30% of hydrogen atoms from zirconium. Low-temperature hydrogen desorption from zirconium might be caused by interaction of hydrogen atoms from the bulk of zirconium with the oxygen atoms from the oxydized surface layer as it was proposed in [1,2]

The samples irradiated by the ions of Ar+10%O_2 plasma were exposed to overheated steam of 673 K. The tests results have shown that hydrogenation of irradiated samples occurs essentially slower than of unirradiated ones. For instance, the hydrogen desorption from the plasma treated sample exposed to steam for 2000 h reaches 0.4×10^{19} cm^{-2} whereas the desorption from unirradiated sample - 1.6×10^{19} cm^{-2}.

References
[1] W.J. Peterson, et al., Appl. Surf. Sci. 121-124 (1985) 24
[2] D.A. Asbury, et al., Surf. Sci., 213-226 (1987) 185

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DEUTERIUM PERMEATION THROUGH LOW-ACTIVATION STRUCTURAL MATERIALS

For the next step fusion devices, such as DEMO or fusion neutron sources, in which large neutron fluxes and fluences are expected, reduce activated and heat-resistant construction materials should be used. For these purposes, the most promising materials are ferritic-martensitic steels, vanadium alloys and silicon carbides, which are being developed in several countries.

In Russia V-(4÷10) Ti-(4÷10) Cr alloys, austenitic and ferritic-martensitic steels for the nuclear industry applications is developed and manufactured in "VNIINM" Academician AA Bochvar. Interaction of hydrogen isotopes with structural and plasma facing materials is one of the important factors, determining the possibility of using these materials in fusion reactors. Permeation of hydrogen isotopes through structural materials is one of the key characteristic which must be considered during fusion reactor designing and operating. From this feature essentially depend: handling, radiation safety and economic efficiency of fusion reactor because of the high cost of tritium, its radioactivity and difficulties of it reproduction in fusion reactor without neutron breeder.

In this paper, experimental investigation of deuterium permeation through ferritic-martensitic steel EK-181 (Fe-12Cr-2W-V-Ta-BC), austenitic steel ChS-68 (used in BN-600 for cartridge elements) and V-4Ti-4Cr alloy on PIM facility in the NRC "Kurchatov Institute" by exposing to deuterium gas or during plasma irradiation was performed.

Deuterium permeation was investigated in pressure range from $5\cdot10^{-2}$ to 100 Pa and in temperature range 600-900 K. It was shown that the dependence of the permeating flux through the EK-181 steel was proportional to the inlet pressure $J \sim p^{0.86}$ (permeability is limited by processes on the surface),

In the investigated range of pressures and temperatures deuterium permeation through ChS-68 steel was limited by diffusion processes

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MODELING OF HYDROGEN DESORPTION FROM TUNGSTEN SURFACE

Hydrogen retention and recycling on metallic plasma-facing components are among the key-issues for future fusion devices due to both safety and operational reasons. Understanding of these processes requires proper description of hydrogen desorption from metallic surface, which is usually modeled by the desorption flux . Here the desorption rate constant K is often approximated by . However, for tungsten, which has been chosen as divertor material in ITER, desorption parameters (E,,γ), experimentally measured for fusion-related conditions, show a large discrepancy[1]. Indeed, various complex phenomena may affect recombination of surface hydrogen atoms into molecules (e.g atomic islands, roughness, surface reconstruction, impurities, ect) [2]. Understanding the processes governing hydrogen desorption from tungsten and their dependencies on material conditions is thus required to provide hydrogen desorption models reproducing experimental data.

In this talk, we present investigations on hydrogen desorption from tungsten surface as a function of the hydrogen coverage. Using molecular dynamics simulations, effects of hydrogen diffusion and coalescence on hydrogen recombination into molecules are analyzed, and a kinetic model to describe the competition between the diffusion, the coalescence and the recombination of hydrogen is presented. Different desorption regimes are identified and effects of these regimes on thermodesorption experiments are discussed.

[1] R. Causey, Journal of Nuclear Materials 300 91–117 (2002)
[2] S. Markelj, et al., Applied Surface Science 282 478-486 (2013)

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INVESTIGATION OF HYDROGEN BEHAVIOR IN ZIRCONIUM UNDER PLASMA IRRADIATION AND BARRIER PROPERTIES OF IRRADIATED LAYER

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References
[1] W.J. Peterson, et al., Appl. Surf. Sci. 121-124 (1985) 24
[2] D.A. Asbury, et al., Surf. Sci., 213-226 (1987) 185

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HYDROGEN ISOTOPES RETENTION IN LOW-ACTIVATION STEEL RUSFER

Reduced-activation ferritic-martensitic steels (RAFMS) are possible advanced structural materials for the construction of future fusion reactors with high fluxes of neutrons, such as DEMO or a Fusion Neutron Source (FNS). Neutrons are responsible for displacement damage, while high heat fluxes may create high thermal stresses (and as consequence cracks, fracture), or molten/resolidified areas in the materials. High neutron and/or high heat or plasma fluxes may therefore strongly influence the hydrogen retention properties of the materials. In the present work Russian type of low-activation steel, EK-181 (Rusfer), was investigated.

Irradiation with 20 MeV W^{6+} ions was used as proxy for displacement damage created by neutrons. Rusfer samples were irradiated to a damage level of 1 dpa at the damage peak. The effect produced by a plasma was simulated by irradiation of specimens with hydrogen plasmas in the LENTA linear plasma device up to fluences of 10^{25} D^+/m^2 at ion fluxes up to 10^{22} D/m^2s and ion energy of 100 eV. High heat flux load was simulated by pulse heat loads in the QSPA-T facility with 10 pulses of 0.5 MJ/m^2 with a duration of 0.5 ms.

The hydrogen isotope retention properties of damaged and undamaged Rusfer were investigated by exposure of the samples to deuterium gas at temperatures in the range from 300 to 773 K and pressure 10^4 Pa. Trapping of deuterium in the damage zone was examined by the $D(^3He,p)^4He$ nuclear reaction with ^3He energies between 0.69 and 4.5 MeV allowing determination of the D concentration up to a depth of 8 μm. The amount of deuterium retained in undamaged Rusfer steel increases with increasing temperature and has maximum at 500 K. Generation of ion-induced displacement damage and subsequent exposure to D_2 gas significantly increases the D concentration in the damage zone. Irradiation of Rusfer with high heat fluxes or by high-flux irradiation with a low temperature plasma at elevated temperature leads to a decrease of retention in Rusfer due to a decrease of the amount of hydrogen trapping sites. Trapping of tritium was examined using an imaging plate (IP) and β-ray induced X-ray spectrometry (BIXS).

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DEUTERIUM RETENTION IN EROSION PRODUCTS OF PLASMA FACING MATERIALS UNDER ITER-LIKE TRANSIENT LOADS

Erosion of the plasma facing materials (PFMs), in particular evaporation of the materials, in a fusion reactor under intense transient events is one of the ITER problems. The current experimental data is insufficient to predict the properties of the erosion products, significant part of which will be formed during transient events (Edge-Localized-Modes (ELMs) and disruptions).

The paper concerns the experimental investigation of the graphite and tungsten erosion products deposited under pulse plasma load at the QSPA-T: heat load on the target was 2.4 - 2.6 MJ/m^2 with 0.5 ms pulse duration. Designed diagnostics for measuring the deposition rate allowed to determine that the deposition of eroded material occurs during discharge, and the deposition rate is in the range (0.1 - 100) $\cdot 10^{19}$ at./s$\cdot$cm^2, which is much higher than that for stationary processes.

It was found that the relative atomic concentration D/C and D/(W + C) in the erosion products deposited during pulse process are on the same level as for the stationary process. It means that amount of the trapped deuterium during transient events is expected to be comparable or even higher than that for stationary process between transients: D/C and D/(W + C) ratios are approximately the same both for stationary process and transient events, but the amount of deposited material is much higher during transient events.

An exposure of erosion products to photonic energy densities relevant to those expected mitigated disruptions on ITER (pulse of 0.5 ms duration, energy density 0.1 – 0.5 MJ/m^2) significantly decreases the concentration of trapped deuterium.

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GAS EXCHANGE BETWEEN OXYGEN CONTAMINATED HYDROGEN PLASMA AND STAINLESS STEEL VESSEL WALL

The certain parts of stainless steel (SS) vessel wall of fusion devices are subjected to plasma irradiation. Oxygen is the most common impurity of plasma of today fusion devices and oxygen contamination is sure to be present in ITER plasma.

This paper investigates the processes taking part during interaction of gas discharge deuterium plasma with oxygen addition with SS wall of the plasma chamber made from austenitic stainless steel containing 18% Cr, 10% Ni, 1% Ti. The range of oxygen concentration varied from 0.5 to 30%.

Irradiation of the vessel surface with ions or/and neutrals of (D_2+O_2) plasma in all investigated conditions led to number of effects like: activation of hydrogen diffusion from the vessel wall, practically total disappearance of oxygen concentration from the plasma, D_2O, HDO, H_2O, H_2, and HD formation and emission from the wall surface, deuterium and oxygen trapping. The amount of deuterium trapped in stainless steel was less than the amount of removed hydrogen.

The above mentioned processes are shown to be the result of the chain of the reactions initiated by interaction of deuterium atoms or ions with Cr_2O_3 molecule of the SS surface oxide layer.

The dependence of the processes on oxygen concentration are presented and discussed.

Conclusion is made that (D_2+O_2) plasma irradiation could be used for stainless steel plasma vessel outgasing and for decrease of tritium inventory in vessel walls.

References

[1] A. Airapetov, L. Begrambekov, et al., J. Nucl. Mater. 451(2011) 1042-1045

Magnetic Fusion Devices: from Plasma to Wall and Back

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The physics of edge plasma in fusion devices plays a vital role. It bridges hot fusion core and material walls and crucial for both plasma confinement and the life-time of the first wall. The physics of edge plasma is very complex and multifaceted. The processes involved are ranging from: atomic physics associated with hydrogenic and impurity species; to hydrogen and impurity radiation; neutral gas trnsport; classical plasma transport for both fluid and kinetic regimes; plasma turbulence and anomalous cross-field plasma transport; to the modification of wall structure and surface morphology due to plasma-wall interactions; dust generation, dynamics and transport; and the transport of hydrogenic species in the wall material.
In this talk we review the physics of some of these processes, including: classical cross-field and parallel plasma transport; basic oridin and main features of anomalous cross-field egde plasma transport in a tokamak; transport of hydrogenic species in wall mterial; effects caused by He irradiation of Tungsten (recall that He is the ash of D-T rections in the core plasma of fusion reactors); synergistics effects of the interctions of edge plasma and the first wall.
We also consider recent important accomplishments and discuss remaining issues.

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