Studies of hydrogen interaction with solid by real-time ERDA

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Abstract
In fusion reactors plasma near the wall of reactor (edge plasma) interacts with it. Processes on surface have to be well understood for stable behavior of fusion plasma and control of power load to the wall. Special cell has been constructed for studying these surface processes. It enables one to expose samples to neutral hydrogen atmosphere and depth profiling the concentration of H and D. At different conditions in the cell different processes occur on a surface and in bulk. Concentration of hydrogen was measured with ion beam analytical method ERDA. Measurements were preformed on Ti and W. Time evolution of processes on the surface and in the bulk was studied with consecutive recording of spectra. It is shown that by H and D concentration depth profiling qualitative data of phenomena on surface and in bulk can be obtained. For specific conditions in the cell a model describing adsorption and recombination of D on W surface was proposed. By fitting analytical time evolution of concentration to measured one quantitative data important for plasma edge modeling were obtained.
1 Introduction

In the year 2005 the broad international (EU, USA, Japan, Rusia, Korea, China) agreement for building the biggest fusion reactor ITER has been signed and construction will start next year in Chadarache, France. There is still a lot of questions, which need to be answered, before it will be finished. One of the major questions to be answered is the choice material to be used for the inner wall and divertor. Divertor is a part of vacuum vessel, where plasma is intentionally directed to the wall. In that part the impurities and ash (He) will be pumped out of the reactor. Targets of the divertor have to sustain high power (20 MW/m$^2$), momentum and particle flux. Materials proposed for divertor target and for the main chamber are C and W and Be, W and C, respectively.

Close to the wall, between the hot plasma and the wall is so-called edge plasma, which is much cooler and less dense than the core plasma. Interaction between the edge plasma and the wall is important for plasma behavior and for lowering power load to the material. Processes in edge plasma determine energy flux to divertor, erosion of material, transport of impurities and their redeposition on the wall. Hydrogen wall interaction processes (adsorption, absorption, recombination and ion neutralization) and volume recombination processes are important for hydrogen recycling on the wall and in edge plasma. Through these processes ionized particles coming from plasma to the wall of reactor neutralize and new neutral particles are created (atoms, molecules). Hydrogen and hydrogen ions that are absorbed in the wall are partially retained there, what presents fuel loss and contamination of the wall. Fuel in fusion reactors is D and radioactive T, so material, which retains small amount of hydrogen (T) is needed.

A special chamber for studying interaction between hydrogen and fusion relevant material was constructed on Jožef Stefan Institute, MicroAnalytic Center (MIC). Sample in the cell can be exposed to hydrogen atmosphere. At this point the interest is only for processes with neutral particles (atoms and molecules). They are studied by depth profiling the absolute concentration of H and D in material in real-time with ion beam analytical method ERDA (Elastic Recoil Detection Analysis) [1]. Measurements with W and Ti were already performed and desorption of hydrogen from the surface, adsorption of
D on the surface and recombination of hydrogen at the surface could be clearly observed. Constructed set-up and measurement procedure will be presented here.

Experimentally studied phenomena will be described with appropriate models and by fitting model functions to measured spectra, quantitative data for processes will be obtained. Parameters, which can be determined with such measurements, are important for modeling of fusion edge plasma. The main reaction in fusion reactor is fusion of $\text{D} + \text{T} \rightarrow \text{He (3.5 MeV)} + \text{n (4.1 MeV)}$. $\text{T}$ is radioactive whose lifetime is approximately 12 years. In our case samples are exposed to $\text{H}_2$ and $\text{D}_2$ and isotope effects can be studied and findings can be further extrapolated to $\text{T}$.

2 Chamber for sample exposure to hydrogen

Special cell (Lunca) was constructed for sample exposure to controlled neutral hydrogen atmosphere and real time in-situ depth profiling of hydrogen in a sample. We control the atmosphere by controlling the rate of dissociation and vibrational distribution of hydrogen molecules. Molecules in neutral gas are not only in ground state, but also in vibrationally exited state.

Cell is schematically shown in figure 1. Its position in the ERDA chamber is shown in figures 2 and 3. The cell itself is a half of cylinder, with inner radius 35 mm and height 50 mm. Sample is mounted on the flat side of Lunca. It is heated from the backside, by a special heater. Temperature of the sample is monitored by a thermocouple on the sample holder plate.

![Figure 1: Schematic drawing of Lunca for exposure to controlled neutral hydrogen atmosphere and in-situ hydrogen depth profiling.](image)

Temperature of the round part of the half cylinder is controlled by water cooling and it is also monitored by thermocouple. There are two rectangular windows on the cylindrical envelope, one is the entrance window for incoming probing high energy beam and another window is for allowing recoiled particles to reach detector. They are on the half height of the cylindrical envelope on $15^\circ$ with respect to the sample surface. In order to reduce gas leak out of the cell, both windows are closed with Al foil, beam foil is $0.8 \mu\text{m}$ thick and recoil detector foil is $6 \mu\text{m}$. The second foil is thicker, in order to stop scattered particle. Another $6 \mu\text{m}$ Al foil is placed in front of detector, so together $12 \mu\text{m}$ thick foil stops the incident scattered particles. Gas inlet and pressure measurement ports are on the bottom of the cell. Gas pressure is measured with Baratron, a capacitive pressure gauge. A 6 cm long tungsten filament (0.2 mm diameter) is mounted on the top of the cell. When
heated, this filament is used for dissociation of hydrogen molecules.

\[ H_2 + W(T > 1200K) \rightarrow H + H + W(T) \]

Temperature of the filament was determined by optical pyrometer as a function of heating current.

Described special cell has been used for our first experiments of sample exposure to neutral hydrogen atmosphere with simultaneous depth profiling of hydrogen concentration in the sample.

### 2.1 Processes on the surface

Our main interest is to study interaction of neutral particles (H\(_2\), H, D\(_2\), D) with different materials. We wish to observe the time evolution of processes on a surface and also underneath it and so to get information about their mutual influences. Processes which we want to study are shown in figure 4. Process in first figure is dissociative adsorption of hydrogen molecule on the surface (chemisorption). It is typical for hydrogen molecules to dissociate on a metal surface. The second process is recombination of atoms on a surface, where atoms interact on the surface and then they desorb from it as a molecule. If both atoms are adsorbed on a surface then mechanism is called Langimur-Hinshelwood (second figure). Eley-Rideal mechanism is when one atom is in gas state and the other is adsorbed.
on a surface where they then recombine (third figure). A process, which is somehow in the middle of both recombination processes, is shown in fourth figure. Diffusion of atoms in the bulk is shown in last figure. Kinematics of these processes was presented in my first seminar. With our in-situ, real time measurements of hydrogen content in a sample we want to quantify coefficients describing above processes.

Metals concerning interaction with hydrogen can be separated into two groups [2]. In the first group are metals with exothermal type of solution (V, Nb, Ta, Ti, Pd etc.). Barrier for recombination and desorption on a metal surface for hydrogen is higher than barrier for hydrogen surface to bulk diffusion. Hydrogen coming from a surface can easily diffuse into bulk, on the other hand there is a large probability that hydrogen coming from the bulk to the subsurface, returns back into the bulk. Second group are metals with endothermal type of solution (Fe, Ni, Co, Mo, W etc.). On contrary to the first group the barrier for surface to bulk diffusion exceeds the barrier of desorption. In this case the recombination process is faster than diffusion in bulk, so concentration in bulk is much lower than concentration of hydrogen on a surface.

Processes which were presented in figure 4 are happening also on plasma facing surfaces of fusion reactor. They are, due to very high particle flux, even more abrupt in reactor and are also the main processes of hydrogen recycling on a surface. In order to understand what is happening on the walls, small experiments like ours are needed. One of interesting issue is the role of neutral molecules which come of a surface. Molecules that are produced trough recombination are in general vibrationally excited. It was shown [3] that even highly exited molecules come of a surface. Collision cross sections for neutralization of hydrogen ions coming from plasma are very dependant on vibrational distribution of hydrogen molecules [4]. If ions are neutralized before they hit the wall then their energy is distributed more uniformly on the wall and particle flux to the wall is strongly reduced. Further research in interaction of hydrogen with solids is needed to control and enhance this neutralization mechanism.

3 ERDA method - Kinematic background

ERDA is ion beam analytical method where depth profile of light elements by bombarding a target with heavy projectiles can be measured. When a projectile travels trough a target it loses energy and only slightly changes direction of motion. The process of energy loss of a projectile in a dense medium is characterized by stopping power (S) of this medium for a particular projectile. The projectile mostly interacts with electrons in a medium trough inelastic scattering, so it transfers energy to electrons by ionization and excitation of atoms. Stopping power is well presented by Bethe-Bloch equation:

\[
S = -\frac{dE}{dx} = \frac{4\pi e^4 z^2}{m_0 v^2} N Z \ln\left(\frac{2m_0 v^2 I}{I}\right).
\]

The relativistic part of the equation was neglected, due to low beam energy (MeV range) of present interest. Z and N are atomic number and atomic density of a target, respectively. Atomic number of incoming particle is z, v is its velocity and \(m_0\) is mass of electron. I is the average ionization potential. The stopping power is proportional to \(z^2\) and Z, so the projectile losses more energy if the target and projectile have higher atomic numbers. On the other hand the projectile loses less energy if its energy is higher. We get stopping
power and its dependence on energy for different materials and projectiles from program SRIM [5].

Projectile can also scatter elastically on nuclei. The cross section (CS) for such scattering is of the order $10^{-26}$ cm$^2$, what is in comparison to inelastic scattering with electrons bounded in atoms almost 10 orders of magnitude smaller. The projectile loses some of its energy and is significantly scattered from its initial direction of motion when it collides with a target nucleus. Energy is transferred to target nucleus, which is recoiled out of its initial position. Recoiled nucleus will be called the recoiled particle. On the other hand scattered projectile is called the scattered particle after the collision. Ratio between final energy ($E_1$) and initial ($E_0$) of the projectile is:

$$K = \frac{E_1}{E_0} = \left(\frac{\sqrt{1 - \mu^2 \sin^2 \theta + \mu \cos \theta}}{1 + \mu}\right)^2. \quad (1)$$

$\theta$ is the scattering angle and $\mu = \frac{m_1}{m_2}$, where $m_1$ and $m_2$ are masses of a projectile and a target, respectively. The ratio between gained energy of the recoiled particle ($E_r$) and initial energy ($E_0$) of the projectile is:

$$K' = \frac{E_r}{E_0} = \frac{4m_1m_2 \cos^2 \phi}{(m_1 + m_2)^2}. \quad (2)$$

$\phi$ is the recoil angle. Both expressions are obtained from calculating the kinematics of the collision, where conservation of momentum and energy are taken into account and target was assumed to be initially at rest. This two-body elastic scattering is the basis for ERDA and RBS method. Concentration depth profile of elements can be determined by detecting the energy of scattered particles (RBS) or recoiled particles (ERDA), if target nucleus is heavier or lighter from the projectile, respectively.

In the MIcroanalytical Center (MIC) at JSI probing ion beams are created with 2 MV tandemtron accelerator. For ERDA described here we have been using 4.2 MeV Li$^{2+}$ ion beam. Ion beam is directed into the line, where cell Lunca is positioned. Experimental set-up of ERDA is shown in figure 5. Detector for recoiled particles (H and D in present case) is ERDA detector, where angle of detection is $\phi = 30^{\circ}$, with respect to the direction of incident particles. Angle of RBS detector is $\theta = 165^{\circ}$. The angle of incoming beam with respect to sample surface is $\alpha = 15^{\circ}$. 12 $\mu$m Al foil is placed in front of the ERDA detector. Its purpose is to stop scattered incident ions and possibly some other heavier particles. On the other hand it is thin enough to let through H and D ions.

If we know the geometry of experiment, initial energy of incoming particles, the stopping powers of projectile and recoiled particle and the final energy of recoiled particle, we can determine depth where collision happened and mass of recoiled particle.

### 3.1 ERDA spectrum and depth profile determination of H and D

We want to connect energy of the recoiled particle and position of collision site. The only thing we know is initial energy and mass of incoming particles and geometry parameters. By following the paths of particles we will determine unknown quantities.

Paths of particles trough a target is shown in figure 6. A projectile that impinges on
a target will penetrate into it and slow down. Energy of the incoming particles at depth \( x \) is \([6]\):

\[
  E(x) = E_0 - \int_0^x S^T(E) dL_1 = E_0 - \frac{x}{\cos \theta_1} S^T_{in}.
\]

(3)

\( S^T \) is stopping power for a projectile in a target and \( S^T_{in} \) is its stopping power at mean energy \( \bar{E} = \frac{E_0 + E(x)}{2} \). At \( x \) projectile collides with a lighter nucleus. Energy of recoiled nucleus right after the collision is:

\[
  E_{20} = K' E(x).
\]

Now we follow recoiled particle that is directed out of the target and has enough energy to come out:

\[
  E_2 = E_{20} - \int_0^{\cos \theta_2 / \cos \phi} S^T_r(E) dL_2 = E_{20} - \frac{x}{\cos \theta_2} S^T_{r(out)}.
\]

(4)

\( S^T_r \) is stopping power for recoiled particle and \( S^T_{r(out)} \) is its stopping power at mean energy \( \bar{E} = \frac{E_{20} + E_2}{2} \). Difference between detected energy of a particle, which comes from surface and from depth \( x \) is:

\[
  \Delta E = K'E_0 - E_2 = \left[ \frac{K'}{\cos \theta_1} S^T_{in} + \frac{1}{\cos \theta_2} S^T_{r(out)} \right] x
\]
Energy loss factor $[S]$ is defined:

$$\Delta E = [S] x$$

If the collision happens on a surface, than the recoiled particle has maximum energy $E_2 = K'E_0$. If collision happens deeper in bulk, the projectile on the way in and recoiled particle on the way out lose energy. Energy of the recoiled particle is consequently lower. Depth of the collision can be obtained from the energy difference $\Delta E$ (figure 7). If we have different light particles in a sample (H, D), different particles can be distinguish due to different $K'$. $K'$ at $\phi = 30^\circ (2)$ is 0.33 and 0.52 for H and D, respectively. Energies of H and D when colliding with 4.2 MeV $^7$Li$^{2+}$ on a surface are 1.4 MeV and 2.1 MeV, respectively. Contribution of surface concentration of H and D in the spectrum can be well resolved, while if D is also in the bulk then it can come to some discrepancy at determination of concentration of D and H.

Spectrum of ERDA or RBS is collected in pulse height analysis mode (PHA). Each detected particle contributes one pulse in the spectrum and its energy determines pulse amplitude. Particle contributes a pulse to a channel $i$ where energy of particle ($E_p$) is $E_i \leq E_p \leq E_i + \Delta E$.

Spectrum intensity at a certain channel is proportional to density of a target element at certain depth and to collision cross section. Conservation laws and proper interaction between particles have to be considered, when calculating the cross section for elastic two-body collision. CS for recoiled particle in a laboratory system, where Couloumb repulsion of nuclei is taken into account, is [6]:

$$\frac{d\sigma}{d\Omega} = \left( \frac{zZe^2}{2E_0} \right)^2 \frac{1}{(\mu + 1)^2 \cos^3 \phi}.$$  

CS in a laboratory sistem for scattered particles, with Coulomb interaction force, is [1]:

$$\frac{d\sigma}{d\Omega} = \left( \frac{zZe^2}{2E_0} \right)^2 \frac{1}{\left( \sqrt{1 - (\mu \sin \theta)^2} + \cos \theta \right)^2 \sin^4 \theta}.$$  

These cross sections are called Rutherford’s. An approximation that cross-section (CS) is Rutherford’s, is in most cases rather good, especially for RBS. For ERDA this approximation is not always good. At collisions of lighter particles (Li $\rightarrow$ H) nuclear reactions can occur, so CS are usually different from Rutherford CS. For ERDA accurate experimental
CS are needed. For Li$^{2+}$ on H accurate CS do exist, on the other hand there is not any CS for Li$^{2+}$ on D. At the moment we use Rutherford’s CS, what gives us only approximate absolute concentration for D in sample.

For determination of concentration depth profile of H and D we use program SIMNRA [7]. In this program all known CS and also stopping powers for different particles in different targets are included. When fitting experimental spectrum the geometry of the set-up and angles have to be known and with some iteration of the target composition proper agreement between measured and simulated spectra is obtained. Program enables one also to include a foil in front of ERDA detector, what mainly shifts the spectrum of detected particles to lower energies.

Depth resolution of the method is proportional to energy resolution. Relation between each other is [1]:

$$\delta x = \frac{\delta E_d}{[S]}.$$  

Energy resolution is dependent on initial uncertainty of beam energy, energy straggling of incoming and outgoing particle when traveling through a target and Al foil, uncertainty of the geometry and energy resolution of detector. Energy straggling is the spread of an ion beam energy due to stopping in dense medium. Losing energy in a dense medium is a statistical process, so fluctuations of energy loss broadens the energy distribution of a particle and consequently contribute to energy resolution. Energy resolution for H in W is 87 keV on the surface. At x= 100 nm the uncertainty of energy is 102 keV. Consequently depth resolution is 43 nm and 50 nm, respectively.

### 4 Measurement of real time ERDA

Lunca has been used for experiments with sample exposure to neutral hydrogen atmosphere and simultaneous hydrogen depth profiling. In experiment following parameters can be varied:

- Composition of input gas (H$_2$ or D$_2$).
- Gas pressure in the cell.
- Sample temperature.
- Degree of dissociation (variation of filament temperature).
- Presence of vibrationally exited molecules, by cooling the envelope.

We have done first measurements on Ti and W. Measurement procedure consists of consecutive spectra recording. In order to achieve sufficient statistics each spectrum was recorded as long as total irradiation dose was equal 13 $\mu$ C. Consequently typical accumulation time was 10-15 minutes. Series of consecutive spectra were then analyzed in order to get time evolution of H and D in a sample. Each spectrum is labeled by a letter following alphabetic order. In each set of measurements few spectra were recorded without changing conditions in the cell. In a single set of measurements consecutive spectra give real time evolution of processes occurring on the surface and in bulk.
At first we let in the H$_2$ gas but we could not distinguish between hydrogen which was already in the sample and H that was freshly adsorbed on the sample. For clean experiments hydrogen in a sample should be reduced by heating or by any other effective method (ion sputtering). Some consecutive ERDA spectra for H in Ti are shown in figure 8, yield of recoiled particles versus energy channels. Peak at channel around 250 is due to recoiled H from the surface while the signal at lower channels (lower energy) is due to H from bulk. One can see that hydrogen concentration decreases due to heating the sample. Atoms diffuse from the bulk to the surface, recombine and desorbe as molecules. Temperature was gradually increased from room temperature to 130°C. There is still some hydrogen on the surface, so to reduce it sample should be heated to higher temperatures.

![Figure 8: Erda spectra for Ti, while heating the sample. Concentration of H is reduced by heating. Black line is at room temperature, red is at approximately 70°C, green is at ≈ 100°C and blue is at ≈ 130°C. Incident projectile ions are 4.2 MeVLi$^{2+}$.](image)

Initial ERDA spectrum of hydrogen in W is shown in figure 9. One can see, that there

![Figure 9: First ERDA spectrum for W.](image)

is a difference between Ti and W. Hydrogen is distributed rather uniformly in the bulk of Ti and a bit higher concentration is on its surface. On the other hand for W hydrogen is only on the surface and there is almost no hydrogen in the bulk. These observations
are in accordance with division of metals in two groups, where Ti is in the first group (exothermal type) and W is in the second (endothermal type).

Processes for W will be mainly presented in this report. As it was already mentioned, hydrogen was mainly on the surface. This observation coincides with our predicted energy resolution. We have calculated that energy uncertainty of hydrogen particles recoiled from the surface is 87 keV, while from the experiment we get 65 keV (figure 10).

Analysis of one series of consecutive spectra collected for tungsten sample are shown in figure 11. Conditions in the cell were changed in sections. During these sections spectra were recorded, so time evolution of processes on the surface and in the bulk was followed. Surface concentration of H and D obtained from spectra labeled with letters are shown in figure 11. Concentration was obtained by fitting experimental spectrum with simulated spectrum from SIMNRA.

Figure 11: Temporal development of concentration of hydrogen on the surface versus index of spectrum.

First we gradually heated the sample from room temperature to 100°C. As one can see concentration is almost constant. Sample should be heated to higher temperatures to reduce surface hydrogen. After that sample was exposed to D2 gas (spectra g-n).
Concentration of deuterium gradually rises, but concentration of hydrogen stays almost the same. Deuterium molecules have adsorbed on the surface. During measuring spectra sample temperature was still slightly rising. Pressure inside the cell was $2.7 \times 10^{-3}$ mbar. After exposing sample to $\text{D}_2$ for about three hours it was additionally exposed to D (spectra d2-d10). D was obtained by turning on the dissociation filament. Its temperature was 1350°C. Concentration of D on the surface increased almost instantaneously. Atoms from the atmosphere adsorbed on the surface with high probability. On the contrary surface concentration of hydrogen decreased. Presumably deuterium atoms interacted with hydrogen atoms, they recombined and desorbed as molecule HD from the surface. After a while concentration of D started to decrease, presumably due to the sample temperature increase. Namely, sample was heated by radiation from the dissociation filament, which was placed in front of it. Surface coverage is dependent on temperature and it is lower at higher temperatures. Two characteristic ERDA spectra are shown in figure 12. Spectrum denoted as "Exposure to $\text{D}_2$" was obtained after about two hour exposure of the surface to $\text{D}_2$ atmosphere at pressure 2.8 µbar ("n" in figure 11). Spectrum denoted as "Exposure to $\text{D}_2+\text{D}$" is the first spectrum after turning on the dissociation filament ("d2" in figure 11). Low energy peak at 800 keV is from recoiled H particles on the surface. The peak at about 1.5 MeV is due to ejected D from the surface.

5 Determination of parameters of analytical model

For any analytical describing of processes, presented above, a model is needed. It must take into account processes at surface, hydrogen transport from surface to bulk and diffusion in a bulk. Diffusion equation is valid in bulk, while conditions on the edge are determined by surface processes. As could be seen from described observations for W sample after adsorption D remains on surface. There has been no noticeable diffusion of deuterium in the bulk during the experiment that lasted about nine hours.

To describe spectra representing the time evolution of hydrogen concentration recorded while exposing W to $\text{D}_2$ (spectra labeled from g-n), a model for dissociative adsorption of molecules was proposed. We took into account only surface reactions: dissociative
adsorption of deuterium molecules and recombination of atoms on the surface.

\[
\frac{d\theta}{dt} = 2S\gamma - 2k^\theta \theta^2
\]  

(5)

\(\theta\) is surface concentration of deuterium and \(S\) is sticking coefficient, which tells us the probability for molecule to adsorb on a surface. \(\gamma = \phi \cdot p\) is so-called impinging rate, the number of particles that hit a surface from surrounding atmosphere in one second, where \(p\) is pressure, \(\phi = \frac{1}{\sqrt{2\pi m k T}}\) and \(k^\theta\) is recombination coefficient. The first term on the right hand side of (5) is representing dissociative adsorption of hydrogen molecules to metal surface and the second term is representing recombination of two atoms at the surface. In the equation we have not included recombination with \(H\) atoms, because no reduction of hydrogen was observed from measurements. Probability for deuterium to diffuse into bulk is very small, so we have neglected its influence on \(\theta\). We have also neglected the part where it is taken into account that particle comes from bulk on the surface, because concentration of deuterium in bulk is negligible. If we solve equation (5), we get:

\[
\theta(t) = \sqrt{\frac{S\gamma}{k^\theta}} \tanh(2\sqrt{S\gamma k^\theta} t + C_1).
\]  

(6)

\(C_1\) is a constant, which is determined from initial conditions:

\[
C_1 = \text{arctanh}(\sqrt{\frac{k^\theta}{S\gamma}}\theta_0).
\]

In our case initial concentration was 0, so \(C_1\) is also 0. The unknown parameters \((k^\theta\) in

![Figure 13: Measured concentration of deuterium versus time (dots) and the fitted function (line).](image)

S) are determined so that analytical function (6) is in good agreement with the measured time evolution of concentration of D on the surface. Parameters were determined with least squares fitting method. Measured and calculated model concentration of deuterium are shown in figure 13. Agreement between measured and calculated function is rather good. Values of the parameters are:

\[
S = 1.7 \times 10^{-5} \pm 0.4 \times 10^{-5}
\]

\[
k^\theta = 2.2 \times 10^{-20} \text{ cm}^2/\text{s} \pm 0.4 \times 10^{-20} \text{ cm}^2/\text{s}
\]
Comparison of parameters to any other measurements was not made yet due to unknown exact CS for scattering Li ions on deuterium and consequently absolute concentrations can not be accurately determined. Even though it was shown that the model reproduces measurements rather good.

Only one part of measurements where we have exposed sample to deuterium molecules was evaluated with a method. Different models will be developed and applied to measurements for other conditions in the chamber. From those measurements additional information about the processes will be gained.

6 Conclusion

A special cell for exposure of samples to neutral hydrogen atmosphere was constructed. It was mounted in ERDA chamber on the PIXE/RBS/ERDA line at 2MV tandemron accelerator at MIC, Jožef Stefan Institute in Ljubljana. Detectors for recoiled and scattered particles are part of ERDA chamber, where they can be rotated around the chamber axis. By combining possibility to exposing samples to controlled hydrogen atmosphere and to measuring the depth profile of H and D in a sample with analytical method ERDA, we have a powerful tool for studying relevant surface processes.

First measurements were made on W and Ti. Conditions in the cell such as temperature of the sample and composition of the hydrogen atmosphere can be varied. At different conditions different phenomena are taking place on a surface. It was shown that these phenomena could be observed in real-time by in-situ concentration measurements.

In the neutral hydrogen atmosphere molecules can be vibrationally exited. Population of exited molecules can be determined with special system for vibrational spectroscopy of hydrogen gas that we have also developed. With spectroscopy of molecules in the atmosphere above the sample one would get complete information about the conditions in the cell.

We have shown that by measuring the depth profile of hydrogen in time it is possible to determine parameters, for the processes of hydrogen interaction with solid. These parameters are important for edge plasma modeling of fusion reactors and also for surface science in general as hydrogen is one of the most important constituent in many natural phenomena. Furthermore studies of isotope effect H versus D allow deep insight in these phenomena. Findings can be further extrapolated to tritium, which is radioactive and requires special laboratory procedures.

References


