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# Absorption experiments on the CASTOR tokamak

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*Introduction*. The present work is undertaken to investigate extra-equilibrium absorption of low energy hydrogen particles in the tokamak environment with a purpose both to better understand the role of nonmetallic coatings on plasma facing materials in the D/T inventory and recycling, and to develop a method of neutral flux diagnostics.

The probability of absorption, $\alpha$, of suprathermal hydrogen atoms (~1 to tens of eV) in metals through the nonmetallic films typically covering a metal surface radically depends on film thickness. In the case of a monolayer film, this probability is comparable/close to that for a clean metallic surface. However, it may decrease dramatically, if the film thickness exceeds one monolayer. In reality, the thickness of nonmetallic coating depends on temperature: at high enough temperatures, typically only one nonmetallic monolayer exists at the surface under vacuum conditions, and the probability of absorption of suprathermal hydrogen is very high. At lower temperatures, both monolayer and polyatomic coatings are possible, and, correspondingly, $\alpha$ may vary over a wide range.

A plasma facing absorption probe (AP) made of the investigated material is installed in the CASTOR tokamak [1] to study the dependence of the probability of absorption of suprathermal hydrogen particles on the nonmetallic coating type and thickness, and on metal temperature. The CASTOR tokamak provides a good opportunity to perform such experiments due to a relatively high, up to $10^{20}$ H/($m^2\times s$), flux of suprathermal hydrogen particles (~7 eV Franck-Condon atoms), the easiness to change samples, and the vacuum system being free of carbon containing impurities.

The main goal of the current experiments was to investigate a possibility of the reliable registration of suprathermal hydrogen atoms coming from the plasma under operational conditions of the CASTOR tokamak, by using a probe surface coating obtained as a result of 1600 K heating in vacuum.

*Experimental.* A movable resistively heated absorption probe of 0.02 mm Nb foil (surface area, $S_{probe}$, ~50 $cm^2$) is placed in a bakeable vacuum chamber connected to a CASTOR tokamak port through a gate valve. The chamber is pumped with a 200 l/s TMP. The pressure is measured by a mass-spectrometer and a set of vacuum gauges. The state of the AP surface (coating type and thickness) can be varied *in situ* by controlled reactions with specially introduced chemically active gases. One can obtain the clean Nb surface by heating the AP up to 2400 K. At the first step of the study presented here, the Nb probe was only treated by heating in vacuum at 1600 K. Such a heating results in dissolution of the multilayer oxide films, with only oxygen monolayer remaining at the surface [2].

Measurement of hydrogen absorption from the plasma was performed in two steps. First, the probe was moved from the chamber into the tokamak. Its position in the diagnostic port was fixed to be just aligned with the torus wall. Then, an operational hydrogen pressure was established, and a plasma discharge was executed. After the exposure to the plasma, the AP was moved back into the chamber. The amount of absorbed hydrogen was measured by $H_2$ thermal desorption from the probe at its heating up to 1300 K. A typical example of the thermodesorption curve is presented in fig. 1, curve 1. The surface area under this curve is proportional to the number of hydrogen particles absorbed both from the plasma and from the background hydrogen molecules.

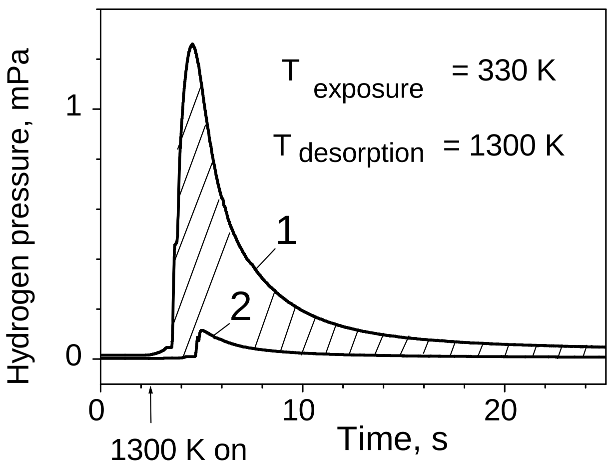


Fig. 1. Hydrogen thermodesorption at permanent pumping with a 200 l/s speed

Second, the above procedure was repeated, but without plasma discharge. The corresponding thermodesorption curve is presented in fig. 1, curve 2, which then refers to the effect of background hydrogen molecules. The number of suprathermal hydrogen particles absorbed during the discharge is proportional to the difference of the areas under the curves 1 and 2, respectively (hatched area in fig. 1).

*Experimental results and discussion*. Temperature dependence of the probability of $H_2$ molecule absorption through the probe surface, $\alpha_{H2}$, is presented in fig. 2, curve 1. As it follows from these data, $\alpha_{H2} = 1.5\ 10^{-3}\exp-(13.6\ \mathrm{kJ}/kT)$, which is typical for the $H_2$ absorption by Nb through a surface covered by a nonmetallic (e.g. by O [2]) impurity monolayer (note that $\alpha_{H2} = 0.1$–$0.3$ for clean Nb surface [3]).

The number of suprathermal particles absorbed during the tokamak discharge, $N_H$, was measured as a function of the AP temperature (fig. 2, curve 2) and of the plasma pulse length

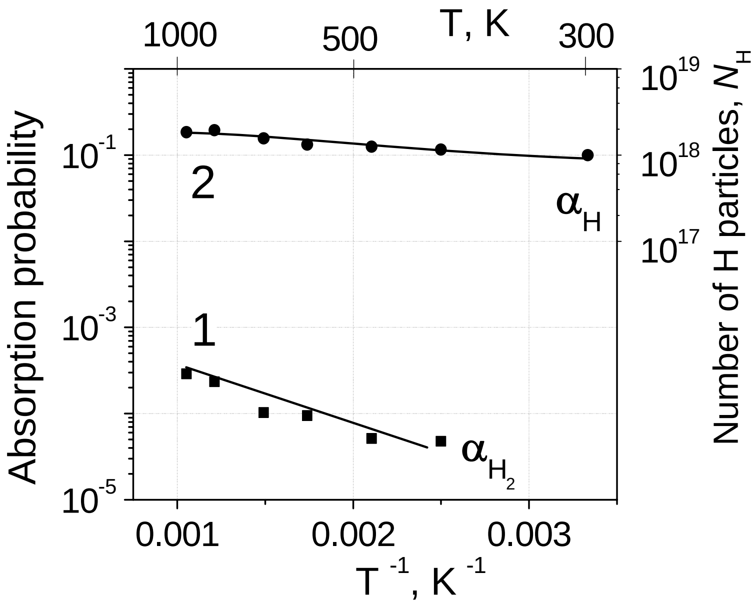


Fig. 2. Temperature dependence of the probability of hydrogen absorption by the probe surface: (1) hydrogen molecules, (2) suprathermal particles (Franck-Condon atoms)

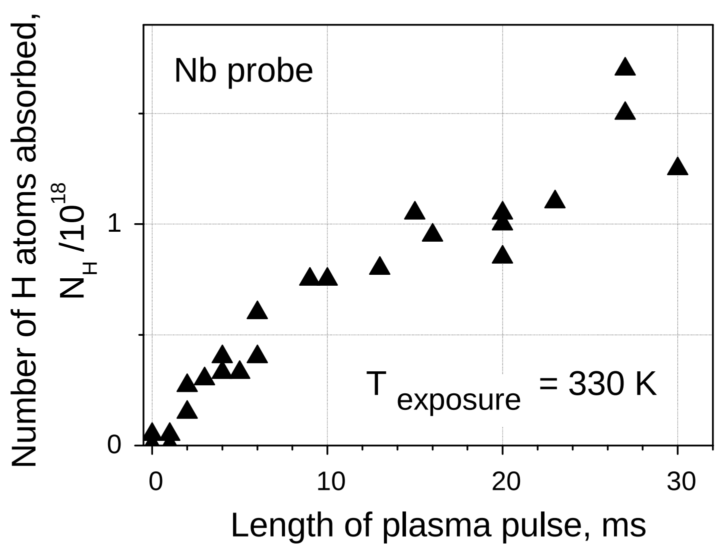


Fig. 3. Dependence of hydrogen absorption on pulse length

(fig. 3). As one can see, the amount of the absorbed suprathermal particles weakly depends on the probe temperature and is nearly proportional to the pulse length. These data permit us to estimate the fluence of suprathermal hydrogen particles falling onto the AP surface during plasma pulse. Actually, at high enough temperatures, when oxygen coating for sure does not exceed one monolayer, the probability of absorption of the suprathermal hydrogen particles should be in an agreement with the known data on the implantation coefficient $\alpha_H$. For instance, one can take $\alpha_H \approx 0.2$ as a typical value for the energy range around ten eV ($\alpha_H \approx 0.2$ is ascribed to our experimental data for the suprathermal hydrogen: fig. 2 curve 2, left axis). Correspondingly, the fluence of suprathermal hydrogen particles is $N_H / \alpha_H \times S_{probe} \approx 10^{17}$ H/cm$^2$.

One also can estimate this value from another side, proceeding from plasma parameters. The plasma density, $n_H$, reaches a maximum of ~$10^{19}$ m$^{-3}$ during the discharge start–up phase [4], and the flux onto the probe surface is ¼ $n_H$ $v_H$, where the mean velocity of hydrogen atoms, $\nu_H$, is ~3.7 $10^4$ m/s. As the absorption of suprathermal H particles is almost proportional to the plasma pulse length (fig. 3), one can suppose that this value is not noticeably changing during the whole discharge. Finally, the fluence of H atoms during a standard 25 ms discharge equals ~ 2 $10^{17}$ $H/cm^2$, which is in a reasonable agreement with the experimental data.

*Measurement sensitivity.* The sensitivity of measurement is one of the key points both for the present investigation and, in particular for possible diagnostic of hydrogen neutral fluxes in tokamaks. Measurement sensitivity is the higher, the larger the ratio $N_H / N_{H2}$ , where $N_H$ is the number of suprathermal particles absorbed from the plasma, and $N_{H2}$ is the number of particles absorbed from the molecular background. The value of $N_H / N_{H2}$ was in the range 2–10, depending on the probe temperature. But this ratio was found to increase when the probe is exposed to several successive plasma discharges before thermodesorption (e.g. a "triple" plasma pulse results in a more than two-fold increase of $N_H / N_{H2}$).

*Resume.* The possibility of a reliable registration of H atoms in the tokamak environment was demonstrated in spite of a short plasma pulse and of a relatively high $H_2$ pressure background. The probability of absorption of 7 eV Franck-Condon atoms was found to depend weakly on the metal temperature. The measured number of the absorbed H atoms is virtually proportional to the length of the plasma discharge, and it is in a reasonable agreement with that estimated from the plasma parameters.

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*References*

1. Stockel J, Badalec J, Duran I, Hron M, Horacek J, Jakubka K, Kryska L, Petrzilka J, Zacek F, Heller MVP, Brazilio ZA, Caldas IL, *Plasma Phys. Contr. Fusion* 41 A577-A585, Suppl. 3A 1999.
2. A.I. Livshits, V.N. Alimov, M.E. Notkin and M. Bacal, *Appl.Phys. A* 80 (2005) 1661.
3. E. From and E. Gebhard, edt., Gase und Kophlenstoff in Metallen (1976) Springer, Berlin. M.Pick, *Phys. Rev. B* 24 (1981) 42-87.
4. Raicu A, Ionescu-Bujor T, Pantea A, Valeanu V, Badalec J, Jakubka K, Kopecky V, Stockel J, Valovic M, Zacek F., *Czech. J. Phys*, 37 (7) 850-861 1987.