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Absorption of suprathermal hydrogen particles at the CASTOR tokamak

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Introduction. The interactions of neutral and charged hydrogen particles with plasma facing materials is of prime importance in the present-day fusion devices and their models, as they define D/T fuel recycling and inventory [1, 2]. For that reason, measurements of the hydrogen flux from plasma, of the hydrogen particle energy distribution, and of the molecular composition and ion charge is of a great interest.

Hydrogen–wall interaction is governed to a great degree by the state of the wall surface, which determines the processes of hydrogen absorption/desorption/accumulation. The probability, α, of the absorption of low-energy hydrogen particles (~1 to hundreds eV) in metals through a nonmetallic film typically covering the metal surface radically depends on the film thickness. In the case of a monolayer film, this probability is 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 hence the probability of absorption of suprathermal hydrogen is very high. At lower temperatures, both monolayer and polyatomic coatings are possible, and, correspondingly, α may vary over a wide range.

The present work is a continuation of the study [3] undertaken to: (1) investigate the role played by the nonmetallic coatings on plasma facing materials in hydrogen inventory and in the recycling of low energy hydrogen particles in the tokamak environment; and (2) develop a method of suprathermal particle diagnostics.

A movable plasma-facing resistively heated absorption probe of a Group V metal (0.025 mm vanadium foil) is used to capture the flux of hydrogen particles. The amount of the absorbed particles is measured at a post-exposure thermal desorption of the absorbed hydrogen in a high-vacuum diagnostic chamber connected to a CASTOR tokamak port through a gate valve. Details of the experimental arrangement are published elsewhere [3].

Experimental results and discussion. One should note that the flux of suprathermal particles consists of neutral atoms and charged ions, both of them contribute to the hydrogen particle absorption. For this reason, special attempts were undertaken to perform their separate measurements.

Dependence of the hydrogen absorption on the location of the absorption probe (AP). The dependence of the amount of hydrogen accumulated from the suprathermal hydrogen flux on probe location is presented in fig. 1; it demonstrates a strong dependence of hydrogen accumulation on the distance between AP and plasma. The AP position just in line with the tokamak wall is indicated in fig. 1 as "0" location, which corresponds to the distance 94 mm from the tokamak vessel centre. The "minus" sign refers to AP shift toward plasma. As the concentration of neutral hydrogen atoms is presumed to be uniformly distributed over the whole range of possible AP location, the observed dependence must be most probably due to ions, whose flux to the AP depends on its radial position. The hydrogen accumulation is independent on the probe location in the range of radii +5 – +15 mm (the right branch of the curve in fig. 1) which indicates the absence of ion flux to the AP. Therefore, the experiments with neutral particles were performed over this range of probe location.

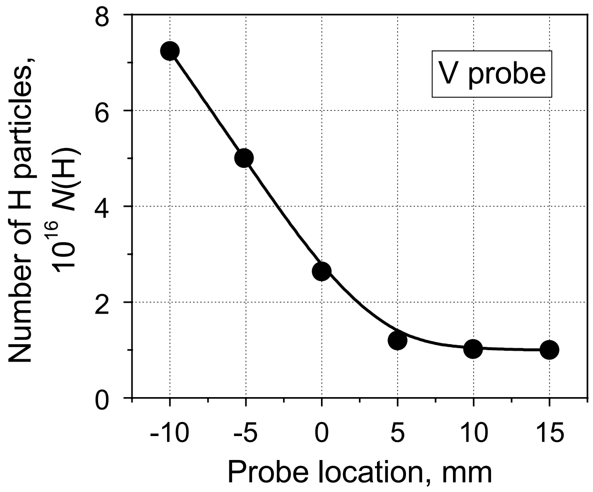

Fig. 1. Dependence of hydrogen accumulation on probe location.
T(exp) = 373 K, floating potential

Absorption of hydrogen molecules. To define the state of AP surface with regard to the hydrogen absorption, the dependence of the kinetics of hydrogen molecule absorption on probe temperature, T, was measured. The absorption probability equals $\alpha_{H_2} = 2.1\ 10^{-2} \exp{-(E / kT)}$, where E = 28200 J and k is Boltzmann constant. That is typical for H_2 absorption by vanadium through a surface covered by nonmetallic (e.g. O) impurity monolayer resulting from the specimen annealing under vacuum conditions [4] (note that α_{H2} = 0.1–0.3 for a clean Nb surface).

Absorption of hydrogen atoms. Temperature dependence of hydrogen atom absorption probability was investigated over temperature range 300 – 1000 K. As one would have expected, the measured probability of absorption for vanadium and niobium [3] probes are very close one to the other, only weakly depending on the probe temperature.

Bias experiment. To study the absorption of hydrogen ions, the vanadium probe was electrically biased with respect to the CASTOR walls and it was placed at a position where there is a measurable ion flux (see above). A typical dependence of ion current on the probe bias voltage is presented in fig. 2.

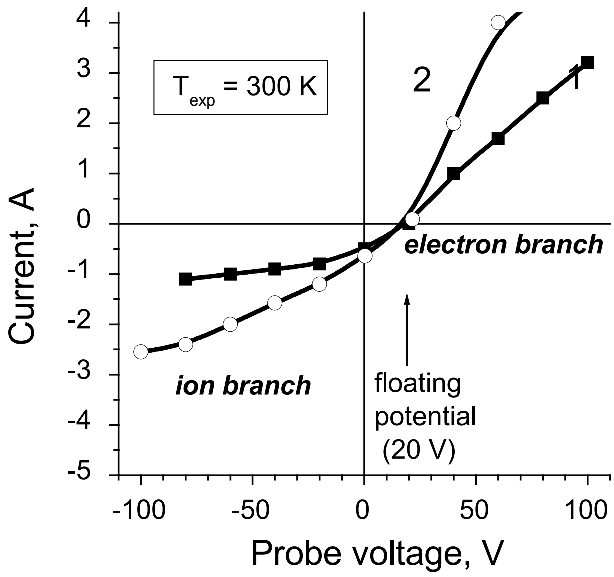

Fig. 2. Dependence of the ion current onto the absorption probe bias voltage for two radial positions of the probe (see also fig. 1).
1 – r_p = 94 mm, 2 – r_p = 84 mm

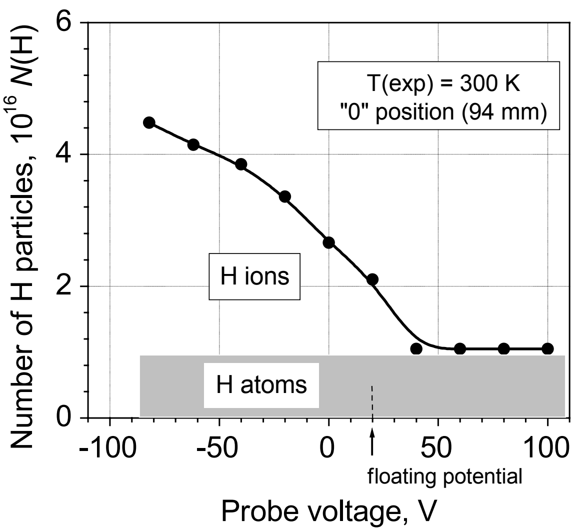

Fig. 3. Dependence of hydrogen accumulation on ion energy

The results of corresponding thermodesorption experiments (fig. 3) demonstrate that the hydrogen absorption does not depend on the probe bias over the range +(40 – 100) V. As the flux of suprathermal particles consists of both neutral atoms and charged ions, one can suggest that such an independence means that the input of ions into the hydrogen absorption is negligible over this energy range, and the hydrogen accumulation in the probe is only due to the input of neutrals. The absorption of neutral hydrogen atoms does not depend on probe bias voltage, and thus it was possible to measure it separately. The results of these measurements are presented in fig. 3 as a gray bar. The difference between the total desorption from the probe and the desorption corresponding to the input of neutral atoms represents the input of hydrogen ions.

It follows from these data that the probability of hydrogen ion absorption depends weakly on the ion energy over the whole investigated energy range and equals to α_H = 0.75 ± 0.05. These numeric estimates are made on the presumption that the ion flux consists of H^+ ions [5].

Conclusion. The possibility of a reliable registration of suprathermal hydrogen particles (atoms and ions) from a tokamak plasma with the absorption probe made of superpermeable vanadium was demonstrated in the CASTOR tokamak conditions, even with its short plasma pulse and a relatively high background H_2 pressure. Dependencies of the absorption of supra-thermal hydrogen particles on probe distance from the plasma, probe bias voltage, and plasma discharge duration, were investigated. These results demonstrate the possibility to study the composition of the hydrogen flux (molecules, atoms, ions) impinging upon the CASTOR liner and to evaluate the fluxes of each component, as well as the energy distribution of the hydrogen ions. The absorption probability of seven eV Franck-Condon hydrogen atoms was found to depend weakly on the metal temperature over the temperature range 300 – 1000 K. The absorption probability of hydrogen ions does not depend on ion energy over the range 20 – 100 eV.

The measured number of H atoms absorbed during a standard 25 ms discharge is in a reasonable agreement with that estimated from the plasma parameters.

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