

Evaluation of hydrogen recycling from a long duration plasma-exposed tungsten specimen using Fast Ejecting System of Targeted sAmple (FESTA) on QUEST

岳, 其霖

<https://hdl.handle.net/2324/7157375>

出版情報 : Kyushu University, 2023, 博士 (工学), 課程博士
バージョン :
権利関係 :

氏 名 : 岳 其霖

Name

論文名 : Evaluation of hydrogen recycling from a long duration plasma-exposed tungsten specimen using Fast Ejecting System of Targeted sAmple (FESTA) on QUEST

(QUESTにおける高速試料搬送装置FESTAを用いた長時間プラズマ放電曝露タングステン試料からの水素リサイクリングの評価)

Title

区 分 : 甲

Category

論 文 内 容 の 要 旨

Thesis Summary

To achieve stable nuclear fusion power generation in the future, steady state operation (SSO) is required. Fuel particles for the deuterium-tritium fusion reaction will constantly interact with the plasma-facing walls (PFWs), and some may be recycled back into the plasma, playing a vital role in establishing SSO through controllability of plasma performance and density. The recycling feature is significantly influenced by the material, temperature, and surface condition of the PFWs. Fundamental researches have been performed by linear machines that can produce steady plasma, and these results are useful to understand the effect of material properties and temperature on fuel recycling. However, the plasma is completely different from fusion relevant plasma in the view of temperature, density, impurity bombardment etc. Hence, the surface conditions are expected to be different. This indicates that the true understanding of fuel recycling is still under requirement to study using a fusion experimental device that can produce long-duration plasma. In the view of this, a new diagnostic method to estimate fuel recycling on fusion relevant plasmas should be considered and Fast Ejecting System of Targeted sAmple (FESTA) is developed.

In the past fusion experimental devices, carbon, as a refractory material, was widely adopted in PFWs. However, owing to the chemical feature to hydrogen isotopes, a large amount of radioactive tritium retention in PFWs will occur. This causes an excess radioactivation of the machine and is not acceptable. In order to reduce this, all metal PFWs are strongly recommended. QUEST (Q-shu University Experiment with steady-state Spherical Tokamak) equips all-metal PFWs and has a capability to produce long-duration plasma up to 6 hours. The developed FESTA was installed on it and QUEST plasma exposure using FESTA has been conducted. In this paper, basic concept of FESTA and modelling to analyze the data are introduced. The modelling demonstrates that the fuel recycling of tungsten, a promising material in the future fusion devices, is significantly affected by surface recombination coefficient K_r . According to the combination between the FESTA measurement and the modelling, the K_r value during QUEST plasma exposure can be obtained. This indicates that FESTA is available to investigate that fuel recycling during exposure on fusion relevant plasmas. The paper is composed of seven chapters as described below.

In chapter 1, the significance and an overview of nuclear fusion reaction are introduced. The issues in the development of plasma facing materials for future fusion power plants and the way of the choice on PFWs are described.

In chapter 2, the development of hydrogen behavior model in metal materials is introduced. In these models, surface recombination played an essential role in hydrogen desorption from metal surface, because hydrogen is released as a diatomic molecule under surface recombination process. Recently, two kinds of modellings are proposed, in which the surface barrier potential E_C on the metal surface and the subsurface barrier potential ΔE_{Surf} in the metal subsurface are pointed to be significant to hydrogen release through surface recombination, respectively.

In chapter 3, the concept and fundamental specification of newly developed FESTA is introduced. Controlled by LabVIEW, a prepared specimen, can be extracted from QUEST plasma exposure into an isolated test chamber during plasma discharges. The hydrogen desorption from the plasma-exposed specimen was measured by a quadruple mass analyzer (QMA). To obtain an accurate particle amount value, calibration of QMA is required using a flow meter on QUEST at room temperature. When performing FESTA operation without exposing specimen during plasma discharges, some hydrogen particles coming from QUEST plasma became admixed into the measured hydrogen partial pressure in FESTA test chamber. As the impact of this hydrogen amount is significant, a background model has been made to remove the impact on FESTA measurement. The accuracy of the background model is demonstrated.

In chapter 4, the spherical plasma experimental device QUEST and typical long-duration plasma discharge conditions operated in FESTA experiments are introduced. A tungsten sample was exposed to QUEST plasma for 910 s three times at room temperature ~ 308 K using FESTA. Hydrogen desorption flux released from it was evaluated to be increased shot by shot. By applying a hydrogen diffusion model, with the trapping/de-trapping of hydrogen atoms, the FESTA experimental data have been reproduced, and consequently, surface recombination coefficient K_r of the sample during QUEST plasma exposure could be obtained.

In chapter 5, several further works are described. To distinguish the influence of surface barrier potential E_C from subsurface barrier potential ΔE_{Surf} , evaluation of temperature dependence of surface recombination coefficient K_r is required. This is the most important future work for FESTA.

In chapter 6, a thermal desorption spectrum (TDS) experiment was conducted to verify the model calculation using a same tungsten sample that is not exposed to QUEST plasma. The surface recombination coefficient K_r evaluated from TDS modelling analysis is different to that determined in FESTA experiments, implying that an impact from QUEST plasma exposure existed.

In chapter 7, conclusions are given as follows. The hydrogen desorption from a tungsten sample at room temperature has been successfully measured using FESTA. With the help of modelling, the experimental results were reproduced and the surface recombination coefficient K_r of the plasma-exposed sample was also evaluated at room temperature. The reproduction of TDS results using a same tungsten sample before QUEST plasma exposure indicates the impact from QUEST plasma exposure by modelling analysis. An in-situ measurement of hydrogen desorption is necessary, and FESTA has been designed as a valuable tool to evaluate fuel particle balance accurately. Hydrogen desorption from different samples at different temperature is required in the future.