Journal of Nuclear Materials 505 (2018) 174–182

Contents lists available at ScienceDirect

Journal of Nuclear Materials

journal homepage: www.elsevier.com/locate/jnucmat

Deuterium permeation behaviors in tungsten implanted with nitrogen

Chuan-hui Liang [a, *, 1], Dongping Wang [a, 1], Wei Jin [a], Yuanfu Lou [a], Wei Wang [b], Xiaoqiu Ye [b, **], Chang-an Chen [b], Kezhao Liu [b], Haiyan Xu [b], Xiaoying Wang [b], Aart W. Kleyn [a]

[a] Center of Interface Dynamics for Sustainability, Institute of Materials, China Academy of Engineering Physics, Chengdu 610200, China
[b] Science and Technology on Surface Physics and Chemistry Laboratory, P.O. Box 718-35, Mianyang 621907, China

ARTICLE INFO

Article history:
Received 19 October 2017
Received in revised form
28 March 2018
Accepted 17 April 2018
Available online 18 April 2018

ABSTRACT

Surface modification of tungsten due to the cooling species nitrogen seeded in the divertor region, i.e., by nitrogen ion implantation or re-deposition, is considered to affect the permeation behavior of H isotopes. This work focuses on the effect of nitrogen ion implantation into tungsten (W-N) on the deuterium gas-driven permeation behavior. For comparison, both permeation in tungsten implanted with W ion (W-W) and without implantation (pristine W) are studied. These three samples were characterized by scanning electron microscopy (SEM), X-ray diffraction (XRD), and X-ray photo-electron spectroscopy (XPS). The SEM results revealed that the W-W sample has various voids on the surface, and the W-N sample has a rough surface with pretty fine microstructures. These are different from the pristine W sample with a smooth and compact surface. The XRD patterns show the disappearance of crystallinity on both W-W and W-N sample surfaces. It indicates that the ion implantation process results in an almost complete conversion from crystalline to amorphous in the sample surfaces. The sputter-depth profiling XPS spectra show that the implanted nitrogen prefers to form a 140 nm thick tungsten nitride layer. In permeation experiments, it was found that the D permeability is temperature dependent. Interestingly, the W-N sample presented a lower D permeability than the W-W sample, but higher than the pristine W sample. Such behavior implies that tungsten nitride acts as a permeation barrier, while defects created by ions implantation can promote permeability. The possible permeation mechanism correlated with sample surface composition and microstructure is consequently discussed in this work.

1. Introduction

Tungsten (W) attracts much attention as a primary candidate material for the divertor in future fusion devices [1]. This material will undergo extremely serious erosion by heating, plasma particle bombardment, and neutron irradiation. Thus, impurity seeding as an approach to reduce the power load on the divertor is currently being actively pursued [2–4]. The experiments have shown that nitrogen has favorable properties in cooling the edge plasma [5]. However, the presence of nitrogen as a new plasma species will lead to additional plasma-surface interactions such as implantation into tungsten. Such interactions influence the behavior of hydrogen isotope (H) permeation, which effects H recycling and has an impact on inventory and safety issues in future Tokamak devices. For a reliable assessment of the hydrogen isotopes inventory, it is therefore of fundamental interest to study the deuterium permeation behavior in tungsten materials damaged by nitrogen implantation.

During nitrogen implantation, the tungsten near surface region to a depth of several hundred nanometers was modified in two ways: (i) void and/or vacancy cluster defects were generated and showed microstructure change, (ii) nitrogen doping resulted in a change of chemical composition. The individual effects of these two ways on deuterium permeation are, to the best of our knowledge, seldom reported. H.T. Lee et al. show that nitrogen can enhance the deuterium permeation flux by exposing tungsten to a mixed deuterium and nitrogen plasma [6]. This exposure process is expected to form a nitrogen-tungsten material, but the influence of resulting modification on permeation behavior wasn't discussed. In

* Corresponding author.
** Corresponding author.
E-mail addresses: liangchh03@163.com (C.-h. Liang), yexiaoqiu@caep.cn (X. Ye).
[1] These authors equally contributed to this work.

https://doi.org/10.1016/j.jnucmat.2018.04.021
0022-3115/

their group, another work mentioned that a deuterium-carbon plasma enhances the deuterium permeation flux by a factor of more than 20 with respect to a pure deuterium plasma [7]. However, Y. Oya et al. observed that carbon-doped tungsten has lower deuterium permeability than the un-damaged tungsten [8]. In case of helium presence in tungsten, the deuterium diffusion was also limited [9,10]. The explanations to these different results are still under debate. The main factor, generated defects or external species and a change of the chemical composition, to determine the permeation behaviors isn't unsolved.

Permeation behavior is closely related to uptake and retention properties. In the latter case, the retention is measured by a depth sensitive analytical tool, such as Nuclear reaction analysis (NRA) [11]. In a permeation experiment, the amount of gas appearing from the sample at its back surface is measured [12]. It is experimentally less complex, but often harder to interpret the permeation mechanisms. There are roughly speaking three steps in a permeation process. For the first step, the loading phase such as H atom is

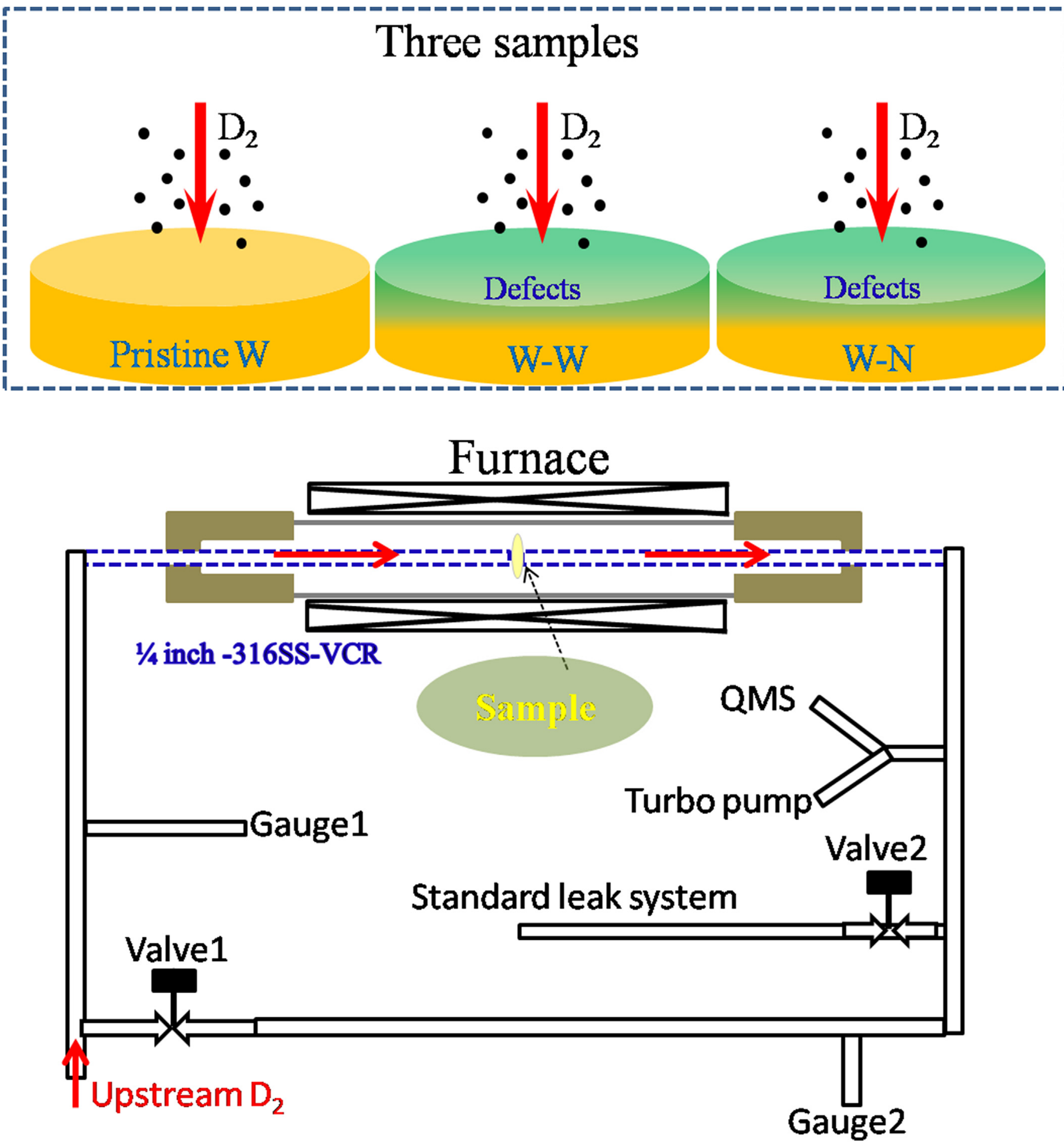

Fig. 1. Schematic flow chart for the permeation experiments and an overview of the experimental device.