§18. Hydrogen Transport in Liquid Metals under Steady State Plasma Bombardment

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1. Introduction

The application of liquid metals as plasma facing materials(PFM) draws increasing interest as a potential means to resolve the technical issues associated with exhaust power and particle handing in magnetic fusion devices [1, 2]. Molten Li is one of the candidates for this application because of its low atomic number and high absorptivity of impinging species. It has been used in fusion devices including NSTX and EAST. In these confinement devices, it is considered that the interaction of hydrogen plasma with liquid Li plays an important role in determining edge plasma characteristics and hence core confinement performance.

GaInSn is a kind of liquid metal at room temperature, and safe for handling. So it is a good modeling material for studying pure Ga and Sn, both of which have also been proposed as liquid metal PFM. In JxB-force convected liquid metal experiments, flowing GaInSn has shown ability of reducing hydrogen recycling when facing to plasma bombardment[3], although the details of hydrogen adsorption and desorption characteristics are still unknown.

Hydrogen diffusivity in the bulk of materials and surface recombination coefficients are essential parameters for studying particles control in the edge plasma, the tritium inventory issue, and the recovery of D, T from liquid metals. However, hydrogen diffusivities in liquid Li show several orders difference in literature. For GaInSn, no information related to hydrogen transport is available in literature as we know.

In the present work, to get hydrogen diffusivity and surface recombination coefficients for liquid Li and GaInSn, hydrogen plasma-driven permeation (PDP) through liquid Li and GaInSn been conducted respectively.

2. Experimental results

For the plasma-driven permeation (PDP) experiments in the present work, a technique holding liquid GaInSn on a mesh sheet by surface tension is proposed and an experimental setup is prepared, as shown in Fig. 1, to be mounted in a laboratory-scale linear plasma device, VEHICLE-1. In the PDP experiments, the ion bombardment flux is set of the order of 10^{16} $cm^{-2}s^{-1}$, and the bombarding energy is set at 50 eV by applying a negative DC bias between the sample tray and the VEHICLE-1 vacuum chamber. A liquid metal sample is fixed in such a way that the upstream surface is exposed to hydrogen plasma, while the downstream side is pumped to ultrahigh vacuum (10^{-6}-10^{-5} Pa). The thickness of the liquid metal is about 2-4mm. The time evolution behavior of hydrogen permeation due to PDP is followed by the partial pressure of H_2 measured by a quadrupole mass spectrometer (QMS). The temperature dependence on the steady state hydrogen permeation flux has been obtained in the range from 313 to 402ºC for liquid Li and from 380 to 508ºC for GaInSn.

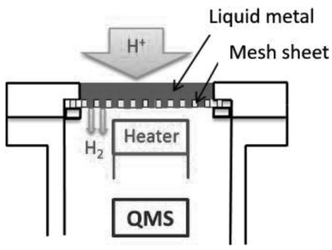

Fig.1 Schematic diagram of the experimental setup for PDP through liquid metals

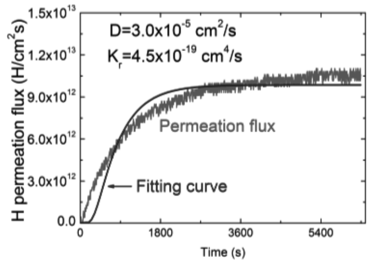

Fig.2 Hydrogen diffusivity and surface recombination coefficients for GaInSn are obtained by fitting the permeation breakthrough curve.

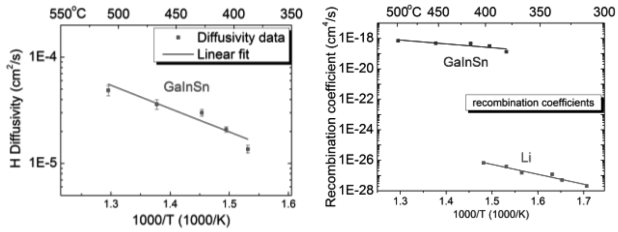

Fig.3 Hydrogen diffusivity and surface recombination coefficients.

In the experiments, it is found that hydrogen PDP is surface recombination-limited for liquid Li and diffusion-limited for GaInSn under present experimental conditions. For liquid Li, the dissolved hydrogen is uniformly distributed in the bulk at quasi-steady state, while the concentration is fixed to be solubility limit in α_{liquid} phase [4]. Then hydrogen surface recombination coefficients for liquid Li are obtained. As diffusivity plays a minor role in a recombination-limited PDP, to get precise diffusivities from PDP is infeasible. However, the recombination limited PDP in this work suggests that diffusivity of hydrogen in liquid Li is sufficiently rapid, in the order of 10^{-5}-10^{-3} cm^2/s. For GaInSn, hydrogen diffusivity and surface recombination coefficients are obtained by curve fitting method, as shown in Fig.2. As a result, temperature dependence of hydrogen diffusivity and surface recombination coefficients for liquid Li and GaInSn are shown in Fig.3.

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[2] Y. Hirooka, Fusion Engineering and Design 85 (2010) 838–846
[3] Y. Hirooka et al, paper submitted to Fusion Eng, Des. 2015
[4] Hans Ulrich Borgstedt et al. J. Phys. Chem. Ref. Data, Vol.30, No. 4, 2001