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Deuterium transport in a J×B-force convected liquid metal GaInSn under steady state plasma bombardment

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It has been widely recognized that the erosion and cracking are critical problems for plasma-facing components (PFCs) made of solid materials when submitted to the high power loads in fusion devices. As a possible solution, liquid metals have been proposed as plasma-facing materials because of their self-cooling and self-healing properties. At present, lithium, tin, and gallium are the primary liquid metal candidates for plasma-facing materials. Liquid lithium covered divertor was tested on NSTX, and continuously flowing liquid lithium limiter with a loop was performed in EAST, both of which yielded improved plasma performance. Free-falling liquid gallium drops were tested on the T-3M and ISTTOK tokomaks, where no severe effects on the main plasma parameters have been found.

$Ga^{67}In^{20.5}Sn^{12.5}$ is a low chemical reactivity alloy with the melting point of 10.5°C. In the present work, it is chosen as a modeling material for studying pure Ga and Sn, as well as liquid Li for their application with the concept of ACLMD (Actively Convected Liquid Metal Divertor) [1]. A mini-ACLMD setup employed GaInSn is installed in a linear plasma device Vehicle-1, to investigate the J×B-force convection effects on particle recycling behavior over liquid metals under plasma bombardment. The magnetic field at the liquid target position in Vehicle-1 has been measured to be about 350 Gauss, and DC steady currents are applied in the liquid between the central electrode and side wall, as shown in Fig. 1. The liquid metal is bombarded with deuterium plasma with a bias of -100V. It has been found that deuterium recycling from the liquid is reduced, when forced convection is applied to the liquid. And the recycling is reduced more as the current increases, as shown in Fig. 2.

A finite element analysis method has been applied to simulate the deuterium transport in the liquid, based on the mass balance equation (1):

$$\frac{\partial C}{\partial t} = \underbrace{\nabla \cdot (D\nabla C)}_{\textbf{Diffusion}} \; \underbrace{- \boldsymbol{u} \cdot \nabla C}_{\textbf{Convection}} + \underbrace{G}_{\textbf{Source}} \qquad (1)$$

where the second term describes the diffusive transport, while the third term accounts for the convective transport due to a velocity field **u**. And the time dependent velocity vector **u** are taken from the CFD module, by solving the Navier-Stokes equations. As a result, a comparison of the deuterium concentration profile along direction of depth at time t=10s with different currents are shown in Fig. 3. It is found that the amount of deuterium retained in the liquid with convection (J=50A/ 70A/ 90A) is more than the amount in the case of without convection (J = 0A). And more deuterium is retained in the liquid as the current increases.

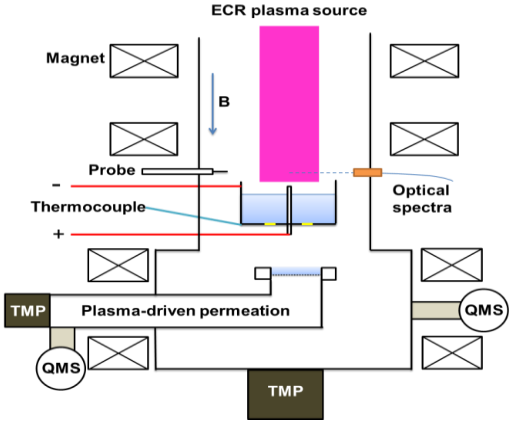

Fig. 1. Schematic diagram of the mini-ACLMD setup in Vehicle-1.

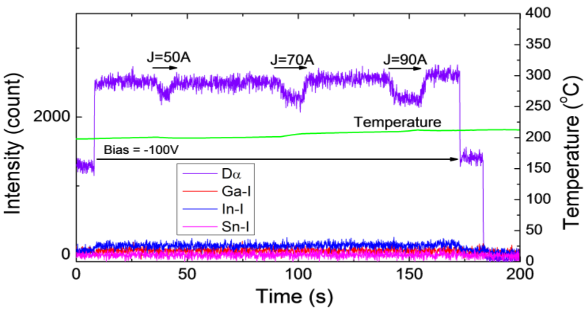

Fig. 2. Current effects on deuterium recycling from J×B-force convected GaInSn.

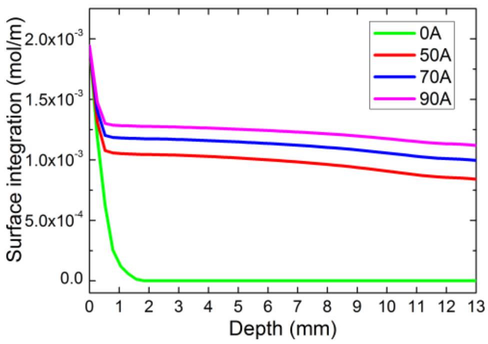

Fig. 3. Deuterium concentration profile along direction of depth at time t=10s with different currents.

[1] M. Shimada, Y. Hirooka, Actively convected liquid metal divertor, Nuclear Fusion 54 (2014) 122002(7pp).