Advanced Atomic Energy Research Section

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1. Introduction

Main objective of our research section is to realize advanced energy systems for the sustainable development under global environmental constraints. We have shown a Zero-emission energy scenario based on fusion energy with biomass-based recycling system where biomass waste is converted into liquid fuel or hydrogen. And further we now propose an innovative Negative emission scenario. to isolate CO_2 in the atmosphere by a carbonization process. Our research section focuses on development of hydrogen isotopes fuel circulation system, breeding blankets, fusion material R&D, feasibility study for fusion-biomass hybrid power system, conversion of biomass waste, and fusion neutron generation/measurement. Followings are main research achievements in the fiscal year of 2021.

- Hydrogen permeation quantification through a structure material and the effect of the existence of ceramic breeding material.
- Development and successful operation of liquid lithium lead droplet system for efficient recovery of hydrogen isotope using a heat and mass-transfer loop.
- Development of hydrogen isotope pumping system using proton conducting ceramics for the divertor exhaust in a fusion system.
- Upgrade of a compact fusion neutron source for radiography

2. Hydrogen permeation through structural material

Understanding the permeation behavior of tritium from a pebble bed breeding blanket is essential for establishing a self-sufficient fuel cycle in a nuclear fusion reactor. It is known that double corrosion layers forms on reduced activation ferritic-martensitic (RAFM) steel surface by gas release from a ceramic breeder material, however, its effect on hydrogen permeation behavior has not been elucidated. In-situ measurement of hydrogen permeation through an F82H RAFM wall of a ceramic breeder pebble bed was performed using a new experimental set-up (Fig. 1). The corrosion layer formed on the F82H sample had a dense microstructure, which reduced hydrogen permeation flux at least by one order of magnitude. The permeation reduction factors were 20–50 at the water-coolant temperature of a blanket. A self-repairing ability is expected for the surface oxide layer as the corrosion occurs spontaneously inside a breeding blanket.

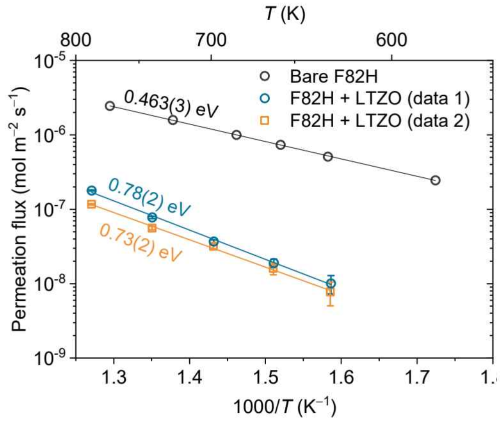

Fig. 1 Hydrogen permeation fluxes through the bare and corroded F82H samples.

3. Development of liquid lithium lead droplet system

Lead lithium eutectic alloy (Pb-17at%Li, Pb-Li) is a candidate liquid breeding material with low chemical reactivity and good tritium breeding ratio. Effective tritium recovery method from the liquid must be developed for the blanket system with minimal tritium

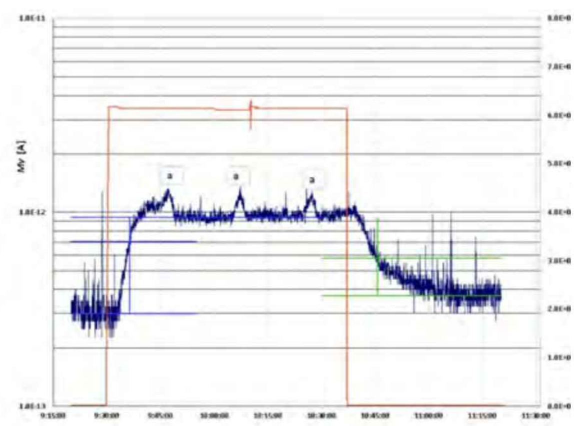

Fig.2: The hydrogen isotope recovery by VST.

loss. The vacuum sieve tray (VST) method, tritium recovery from the liquid droplet surface falling in vacuum, is a candidate developed in this section. This fiscal year, on a collaboration work with National Institute for Fusion Science (NIFS) a VST test device (multiple nozzles system) was integrated to Oroshhi-2 (Pb-Li test loop) at NIFS and the continuous operation campaign was performed in the next fiscal year. One of the recovery result for deuterium is shown in Figure 2. The deuterium fed to the loop system was successfully recovered at the VST test section.

4. Electrochemical transport of hydrogen isotopes for the diverter exhaust development

Hydrogen isotopes pumping system using a proton conducting electrolyte (ceramic) is a candidate diverter exhaust pump for a nuclear fusion system, which can selectively exhaust hydrogen isotopes (D and T) without He, reducing the tritium inventory in the tritium fuel cycle system.

BYCO ($BaCe_{0.8}Y_{0.2}O_{3-\alpha}$) plate with Pt electrodes were fabricated and the hydrogen isotopes transport behavior through the plate was investigated. The experimental setup is shown in Fig.3. H_2 and D_2 containing Ar gas was fed to the outer surface of the BYCO plate, and the inner surface was wept by pure Ar gas, whose H and D concentration was monitored afterward.

The mass flux result obtained at 500℃, changing the feeding gas concentration applying 1 V, is shown in the Figure 4. The current efficiency is assumed to be around 70%, and transport of D was found to be less than that of H.

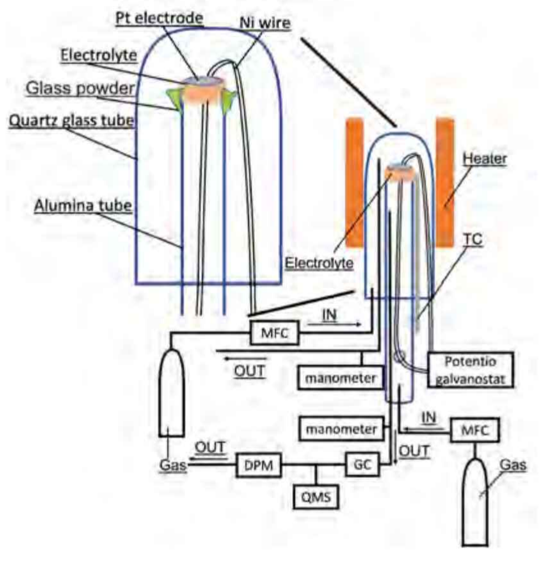

Fig.4: The experimental setup of the hydrogen isotopes pumping system using BYCO plate.

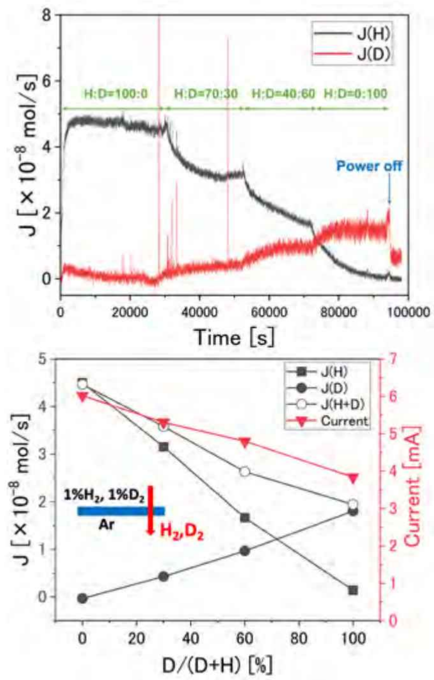

Fig.4: The H and D transport behavior at 500 ℃ trend (upper) and the quasi-steady state analysis (lower)

5. Compact fusion neutron source for radiography

Development of a compact neutron source with a higher neutron production rate is of importance for a wide range of its application, including radiography and boron neutron capture therapy (BNCT). A three-stage feedthrough system is employed in the developed compact IEC to address this contradiction. A feedback control system was developed and applied to the input and output parameters. Characterization of the developed system was performed by scanning the neutron yield as a function of applied voltage and cathode current. To date, a maximum neutron yield of 9.2×10^7 $n{\cdot}s^{-1}$ at 6.4 kW (80 kV and 80 mA) has been obtained. Neutron images (Fig. 5) showed there was good a contrast between the sample and the background. The results suggest that optimization of the experimental parameters is needed to perform higher accuracy neutron radiography.

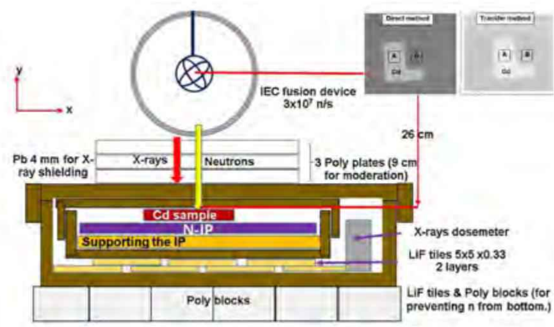

Fig.5 Experimental layout and neutron images by direct method and transfer method.

Collaboration Works

小西哲之，八木重郎，核融合科学研究所・LHD 計画共同研究，ヘリカル炉液体ブランケットトリチウム回収プロセスの基礎工学研究

八木重郎，University of California San Diego（アメリカ），SiC/SiC 複合材料で製作した配管試験体を流動液体金属（PbLi）に曝露し、その腐食特性を調べる

八木重郎，向井啓祐，小西哲之，核融合科学研究所・一般共同研究，高融点鉛リチウム金属間化合物を用いた水素移行に関する基礎研究

八木重郎，量子科学技術研究開発機構・原型炉開発共同研究，液体リチウム流動ループにおける窒素回収

向井啓祐，小西哲之，八木重郎，核融合科学研究所・一般共同研究，LHD 本体室における中性子線量の制御による核融合炉ブランケットの高性能化

Financial Support

1. Grant-in-Aid for Scientific Research

八木重郎，基盤研究(B)，核融合炉ブランケットにおける水素・腐食・照射相乗効果の解明と機能性材料設計（分担金）

向井啓祐，若手研究，核融合ブランケットの中性子輸送と燃料生産性の実験評価

向井啓祐，基盤研究(B)，特殊な電圧プロファイル下の電気透析による６リチウム同位体濃縮技術の研究（分担金）

向井啓祐，基盤研究(B)，核融合炉ブランケットにおける水素・腐食・照射相乗効果の解明と機能性材料設計（分担金）

荻野靖之，特別研究員奨励費，核融合炉ブランケットの中性子輸送とトリチウム増殖現象の実験解析の研究

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小西哲之，京都フュージョニアリング（株），マイクロ波を用いたバイオマスガス化技術開発

八木重郎，量子科学技術研究開発機構，液体リチウム流動ループ中での窒素トラップの健全性評価

向井啓祐，科学技術振興機構，精製・リサイクルの循環型サプライチェーンの導入により想定される国際経済波及効果、並びに資源・環境影響評価に関する国立大学法人京都大学による研究開発

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