

Advanced Atomic Energy Research Section

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1. Introduction

Main objective of our research division 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 CO₂ 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. The following are the main research achievements in the fiscal year of 2025.

- Analysis of permeation wall structure for Li-Pb breeding blanket
- Development of water-cooled hollow cathode for IEC fusion neutron source
- Development of protecting layer on F82H against supercritical CO₂ and liquid Li
- Quantification of N diffusivity in Fe-Ti alloy as nitrogen impurity trap for liquid Li

2. Fusion fuel (hydrogen isotope) recovery system development from liquid lead lithium droplets

Lead lithium eutectic alloy (Pb-17at%Li, LiPb) is a promising liquid material for the fuel (hydrogen isotope) breeding on a fusion reactor. Efficient recovery of the bred fuel is a key viable issue of liquid blanket.

We are studying the recovery method from liquid Pb-Li droplets in a vacuum, named as vacuum sieve tray (VST). This fiscal year, on a collaboration work with National Institute for Fusion Science (NIFS), we challenged the tritium permeation reduction. It is the one of key issues which must be cleared for the fusion viability. As a first step, we investigated the inside thin layer which was deposited while LiPb flowing for two thousands hours. This layer has caused adverse effects, the diffusion coefficient degrades, on the deuterium dissolving of experimental setup. It is a downside factor for experiments, however, it is a good tips for the permeation reduction point of view. The GD-OES (glow discharge optical emission spectroscopy) analysis was performed. As shown in Fig. 1, the deposited

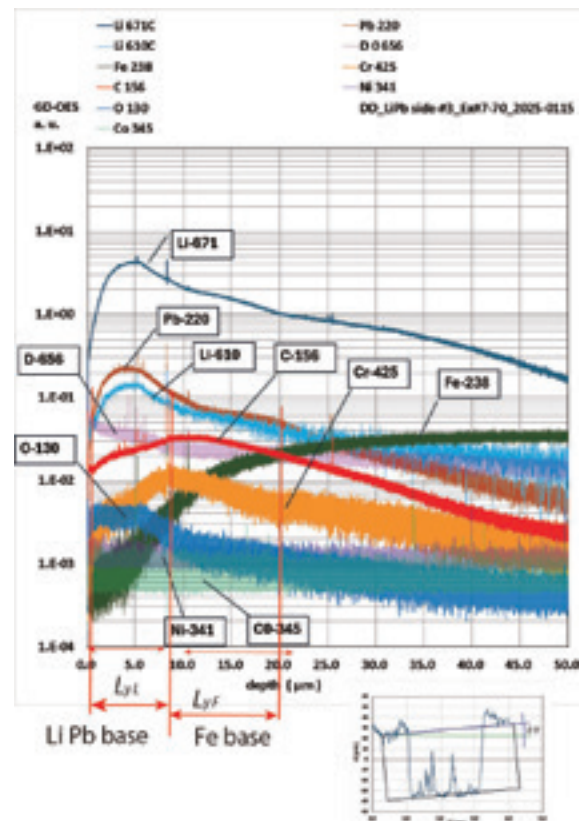


Fig.1 An ODS analysis result of the obtained surface thin layer deposited on a LiPb flowing side of the deuterium dissolving tube. The layer was consisted of the front side LiPb based one and secondary Fe based one.

layer was consisted of two parts. The front one is LiPb based one, and the inner side was Fe based chromium one. The obtained layer diffusion coefficient was approximately $1 \times 10^{-13} \text{ m}^2 \text{ s}^{-1}$, which is close value with that of the lithium-deuterium hydride. This layer is generated automatically while LiPb flowing without any artificial treatment. So far, forming the reduction layers inside of the piping devices, valves, flow control, etc., were issues for permeation reduction. This obtained result has a guiding light. We continue to investigate this subject for the next years.

3. Cr Coating as an anti-corrosion layer for F82H in Fusion Blanket Environments

RAFM steel F82H is a key candidate for fusion blankets, but its compatibility with supercritical carbon dioxide sCO₂ and liquid lithium (Li) is a major

concern. This study evaluates electrodeposited Cr coatings (20 μm) as a multifunctional barrier to suppress oxidation and selective leaching.

In $s\text{CO}_2$ (550°C, 17 MPa, 1000 h), Cr-plated F82H (wet electrochemical plating in Sargent's bath) showed significantly lower mass gain (0.44 mg/cm^2) than bare F82H (5.09 mg/cm^2) as Fig.2. SEM-EDX revealed a protective Cr_2O_3 -equivalent layer that inhibited oxygen inward diffusion.

In liquid Li (550°C, 500 h), GD-OES profiles demonstrated that the Cr layer effectively mitigated Li penetration into the matrix, whereas bare F82H showed clear Li and N signals. The effective diffusion coefficient (D_{eff}) for oxygen (10^{-19} to 10^{-20} m^2/s) quantitatively supports the coating's role as a robust diffusion barrier. Cr coatings provide simultaneous protection against $s\text{CO}_2$ oxidation and liquid Li corrosion, offering a viable strategy for high-efficiency fusion blankets.

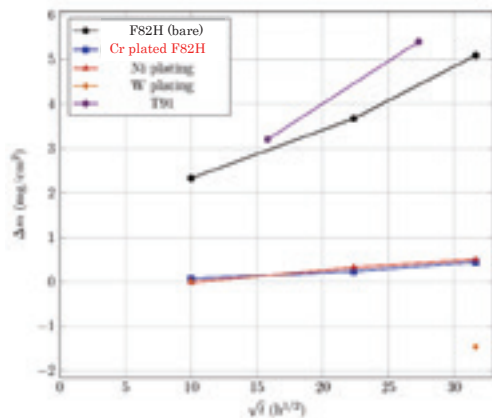


Fig.2 Mass gain of various specimens in $s\text{CO}_2$ environment (550°C, 17 MPa).

3. Development of water-cooled hollow cathode for IEC-type fusion neutron source

In glow discharge-type deuterium–deuterium IEC fusion neutron sources, fusion reactions occurring on the cathode surface contribute significantly to the neutron production rate (NPR); therefore, cathode design plays a crucial role in enhancing NPR. Although the NPR generally increases with discharge current, it tends to stagnate in the high-current regime due to deuterium desorption caused by cathode heating. Water cooling has been shown to mitigate this stagnation for nontransparent cathodes, but its effectiveness for transparent cathodes has not been clarified experimentally. In this study, a transparent cathode with active water cooling and a spherical geometry was designed and fabricated using stainless steel tubing. Neutron production experiments were conducted with and without water cooling. With water cooling, applied voltages of 20–40 kV were investigated. Without water cooling, the applied voltage was limited to 25 kV. The results showed that the NPR increased linearly with discharge current without stagnation when water

cooling was applied. A maximum NPR of $(1.8 \pm 0.02) \times 10^6$ n/s was achieved at 40 kV and 50 mA. Compared with our previously reported disk cathode and non-transparent water-cooled cathode of the same diameter, the transparent water-cooled cathode exhibited a significantly enhanced NPR. These findings indicate that combining cathode transparency with active cooling is an effective strategy for improving neutron production in glow discharge-type fusion neutron sources.



Fig.3 Outlook of the water-cooling hollow cathode made of 3.2 mm-O.D. SUS316L tube

4. Nitrogen diffusion behavior in nitrogen getter materials for liquid lithium

Nitrogen impurities in liquid lithium must be controlled because they accelerate corrosion of structural materials in fusion neutron source systems. However, nitrogen diffusion behavior in candidate getter materials such as Fe–Ti alloys remains unclear. In this study, Fe–Ti alloy thin films were prepared by resistance heating evaporation and pulsed laser deposition (PLD). The films were exposed to nitrogen containing liquid lithium to investigate nitrogen diffusion behavior in the alloy. Nitrogen depth profiles were measured using GD–OES. The nitrogen diffusion coefficients in Fe–Ti films were estimated by fitting a diffusion equation to the measured nitrogen depth profiles. The diffusion coefficients were on the order of 10^{-16} m^2/s at 550 °C for films containing 8.7 at% Ti and 10.5 at% Ti. These results provide basic data for nitrogen removal system design in liquid lithium loops.

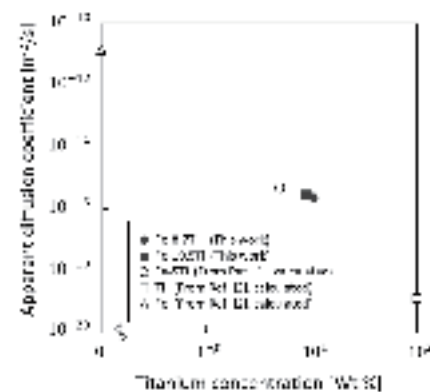


Fig.4 Nitrogen diffusion coefficient in Fe–Ti alloys as a function of Ti concentration at 550 °C.

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Collaboration Works

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Financial Support

1. Grant-in-Aid for Scientific Research

八木重郎, 基盤研究(B), 機能性被覆の劣化診断手法と修復技術の開発 (分担金)

八木重郎, 基盤研究(B), 高強度中性子環境における電気絶縁被覆機能材料の反跳原子による特性変化 (分担金)

2. Others

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八木重郎, 中部電力株式会社, 耐食性付与被覆/母材界面の中性子照射影響評価

八木重郎, 国立研究開発法人量子科学技術研究開発機構, 固体増殖材による低放射化フェライト鋼の腐食と機械的強度への影響評価

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八木重郎, J K A 補助金 研究補助 (国際交流), 海外で開催される国際会議等で研究発表を行う大学院生の研究交流活動補助事業

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