§16. Feasibility Study of Helium Concentration Analysis in Material by Laser-induced Plasma Breakdown Spectrometry

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1. Introduction

A first wall and blanket system in the fusion reactor is exposed to 14MeV neutron irradiation and a large amount of radiation damage and nuclear transmutation elements are produced. Helium atoms are not soluble into the metal at all, and stabilize the vacancy by combination. The accumulation of helium can accelerate the growth of the vacancy clusters and induce the void swelling and intergranular embrittlement at high temperature. Therefore, monitoring technology of helium generation in materials under neutron irradiation will require in order to understand the helium accumulation mechanism, the correlation between helium behavior and embrittlement mechanism and the life time estimation of structural element for fusion reactor blanket system application.

A helium monitoring method is usually used by a helium collecting apparatus with melting furnace. However, it requires long term and huge cost for the analysis, and some unexpected radiation exposures are occurred in dismantling and treating the radio-activated specimens. Moreover, only an average data of helium concentration can be analyzed in a few gram of sample for material inspection.

A recent study on hydrogen analysis of nuclear materials using laser-induced plasma breakdown spectrometry (LIBS) has been developed and succeeded. The reason why the hydrogen analysis has been succeeded on the contrary to the ordinary LIBS methods which is conducted under 1 atmospheric pressure, is an alternative technique using low-pressure surrounding gas. To the best knowledge, little has been reported on the analysis of helium as an impurity in solid materials including nuclear applications; a topic which may be beneficial in many field of nuclear material sciences as well as industries.

This study is a feasibility study of helium detection method for nuclear material application using LIBS method.

2. Experimental procedure

Some plates of 15x15x1mm of SUS316 steel were cut out and electro-polished. The helium ion implantation were performed with 200keV He ion with a micro wave ion source implantation device at the Wakasa energy research center. The amounts of the helium implantation were estimated from TRIM-Code calculation. The maximum amount of helium implantation was about 0.5at% at the Bragg peak position.

The LIBS system with a Nd-YAG laser was used for helium detection at Fukui University. The laser irradiation was performed in gas atmosphere (hydrogen, nitrogen, and argon) and at the gas-dependent pressures (10～10000Pa) where an efficient helium excitation occurred. The YAG laser output of 50mJ was corresponded to be the power density of 10^{10}GW/cm^2. As an alternative method for helium detection, the LIBS technique by TEA-CO_2 laser at the Fukui University was used. The carbon dioxide laser irradiation had the material surface melt only and not ablated. The output of TEA CO_2 with 1.5J was less than 10^9GW/cm^2.

3. Results

The specific wave length of helium emission was investigated on LIBS spectrum. The wave length of helium emission at a peak position that 587.5 nm and 667.8 nm, and both peaks were not obtained in both hydrogen, nitrogen, and the argon atmosphere of 10～10000Pa. The depth area of laser irradiation about 3μm was dissociated during the laser ablation in helium monitoring LIBS experiments. The value of helium concentration corresponded to 20wppm of helium in 3μm depth area, and it suggests that the amounts of helium implantation is less than a limit of helium detection for LIBS methods, because the lower limit of hydrogen detection in zircaloy-4 was estimated to be 50wppm in the same LIBS apparatus. In the case of TEA CO_2 laser method, the atmospheric gas was adopted to nitrogen gas. The mismatch of mass weight between helium and nitrogen is large than that between hydrogen and helium in the plasma excitation process in LIBS method. In order to suppress the effect of mass mismatch between helium and atmospheric gas, double pulse laser excitation of LIBS in water will be examined in future.