XPS analysis on chemical states of Li$_4$SiO$_4$ irradiated by 3 keV D$_2^+$

Tianyong Luo*

Fusion Reactor and Nuclear Material Division, Center for Fusion Science of Southwestern Institute of Physics, P.O. Box 432, Chengdu, Sichuan 610041, China

ARTICLE INFO

Article history:
Received 16 December 2009
Accepted 20 October 2010

ABSTRACT

Li$_4$SiO$_4$ will be applied as tritium breeding materials in future fusion reactor. The release behavior of tritium from neutron-irradiated Li$_4$SiO$_4$ should be sensitive to the chemical states of lithium, oxygen and silicon on the surface of Li$_4$SiO$_4$ with irradiated defects. The present study is focused on the influence of hydrogen isotopes and irradiation defects on surface chemical state of Li$_4$SiO$_4$. The X-ray Photoelectron Spectroscopy (XPS) was compared between non-irradiated Li$_4$SiO$_4$ and D$_2^+$-irradiated one. It was observed that the binding energy (BE) of electron for Li-1s, O-1s and Si-2p of non-irradiated Li$_4$SiO$_4$ were 60.9 eV, 536.1 eV and 107.1 eV respectively. However new XPS peak for Li-1s at 57.2 eV, three XPS peaks for O-1s at 536.1 eV, 533.2 eV and 531.3 eV, respectively and three XPS peaks for Si-2p at 104.2 eV and 99.7 eV, respectively were observed in D$_2^+$-irradiated Li$_4$SiO$_4$. It is considered that the XPS peaks of 531.3 eV and 104.2 eV should be corresponding to O-1s and Si-2p in –Si–O–D while the XPS peak of 533.2 eV should be corresponding to O-1s in D–O–D. The formation of –Si–O–D and D–O–D is considered to be due to typical irradiated defects (lithium vacancy, silicon vacancy and implanted deuterium) induced by D$_2^+$-irradiation.

© 2010 Elsevier B.V. All rights reserved.

1. Introduction

In ITER test blanket module design, the elucidation of tritium recovery from solid tritium breeding material is one of critical issues for TBM design. The study of hydrogen isotopes behavior in solid breeding materials is one of the most important subjects in the design of test blanket module. There are a variety of ternary lithium oxides such as Li$_4$SiO$_4$ and Li$_2$TiO$_3$ that could be employed as a candidate solid breeding materials for D–T fusion reactor. Okuno et al. [1–4], Oya et al. [5–7] and Tanaka et al. [8–13] have carried out some studies on behaviors of hydrogen isotopes in these ternary lithium oxides. Li$_4$SiO$_4$ will be applied as tritium breeding materials in EU helium cooled pebble blanket (HCPB) and CN helium cooled solid blanket (HCSB). Tritium should be released as HTO or HT from surface of Li$_4$SiO$_4$ after neutron irradiation. And the ratio of tritium released as HTO to HT is one of key parameters for establishment of tritium extraction system in fusion reactor. The release chemical form of tritium should be determined by surface chemical environment of Li$_4$SiO$_4$ affected by various radiation defects.

The typical irradiation defects induced by neutron irradiation in Li$_4$SiO$_4$ are considered to consist of Li vacancy, Si vacancy and F-centers (oxygen vacancy with one or two electrons). The formation of Li vacancies is considered to be mainly due to the breeding reaction between neutron and lithium. And the displacements induced by neutrons irradiation or/and products of breeding reaction such as helium and tritium ions with high energy of about 2 MeV can provide Li vacancies, F-centers and some Li vacancies. Tritium produced by breeding reactions in Li$_4$SiO$_4$ can be located at Li vacancy to turn to the substitutional T$^+$ for Li$^+$ (sub. T$^+$) and at Si vacancy to the substitutional T$^+$ for Si (sub. T$^+$). Tritium can also be located at an interstitial site to turn into the interstitial T$^+$ (int. T$^+$). Therefore there are three possible states of T$^+$ in Li$_4$SiO$_4$ after neutron irradiation, namely sub. T$^+$, int. T$^+$ and int. T$. All of T$^+$ (whether sub. T$^+$ or int. T$^+$) will be attracted by neighboring oxygen ions to form the –OT– of sub. T$^+$ or int. T$^+$. However the experiments of neutron irradiation or tritium ions irradiation are difficult to be performed. Hence the D$_2^+$-irradiation has been applied as a technique of hydrogen isotopes implantation. It is considered that the displacements or sputtering by D$_2^+$-irradiation can provide Li vacancies, Si vacancies and F-centers. D$_2^+$-irradiation can also induce the deuterium as sub. D$_0$, sub. D$_6$ and int. D$^+$ which is similar to the case of tritium in neutron irradiation. All of D$^+$ (whether sub. D$^+$ or int. D$^+$) will be attracted by neighboring oxygen ions to form the –OD– of sub. D$^+$ or int. D$^+$. Some surface analysis methods combined with deuterium implantation technique have contributed to the study on release behavior of hydrogen isotopes from various ternary lithium oxides affected by irradiation defects [1–13]. It has been observed that deuterium implanted into Li$_4$SiO$_4$ can be desorbed as hydrogen molecular forms (D$_2$/HD) and water forms (D$_2$O/HDO), which is corresponding to that tritium produced in neutron-irradiated Li$_4$SiO$_4$ can be released as HT and HTO. From the viewpoint of tritium extraction system, desorption of tritium as hydrogen molecular forms means higher safety and efficiency than that as water forms.

* Tel.: +86 28 82850389; fax: +86 28 82850956.
E-mail address: luoty@swip.ac.cn

0022-3115/$ - see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.jnucmat.2010.10.019