Status of Neutron Irradiation of Non-Nuclear Materials at HANARO

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1. Introduction

The High Flux Advanced Neutron Application Reactor (HANARO) has been operating as a platform for basic nuclear research in Korea, and the functions of its systems have been improved continuously since its first criticality in February 1995. To support the national research and development programs on nuclear reactors and nuclear fuel cycle technology in Korea, rabbit and capsule irradiation facilities have been developed and actively utilized for the irradiation tests requested by numerous users [1]. Continuing efforts to improve the capabilities and instrumentation of the facilities have been in progress at KAERI [2,3]. The irradiation facilities have been mostly utilized for the KAERI nuclear research projects relevant to a commercial nuclear power reactor such as the ageing management and safety evaluation of the components. Based on the accumulated experience, HANARO has recently supported national R&D projects relevant to new nuclear systems including the System-integrated Modular Advanced Reactor (SMART), research reactors, and future nuclear systems [4].

As neutron irradiation affects the structure of a material, radiation induced modification of materials has become a perspective method for the purposeful changes in material properties. Some irradiation tests of electro-magnetic materials were also performed at HANARO for scientific research of universities [5-9] and the demand for neutron irradiation of the materials is increasing rapidly. Another research reactor that will specialize in radio-isotope and neutron transmutation doping (NTD) Si production and the demonstration of reactor design is under construction in Korea. Therefore, HANARO will specialize more on irradiation research. Based on its accumulated irradiation experience, HANARO has recently started new support of R&D relevant to the irradiation of electro-magnetic materials.

In this paper, the status of utilization of the HANARO irradiation facilities for non-nuclear materials and the possibility of researches on new electro-magnetic materials using neutron irradiation are surveyed to encourage the utilization of HANARO.

2. Irradiation of Electro-magnetic Materials at HANARO

2.1 Irradiation Tests of Electro-Magnetic Materials

As a national platform for basic and nuclear research, HANARO irradiation facilities have been used for irradiation tests of electro-magnetic materials requested by users from research institutes and universities as shown in Table 1. Most irradiation tests requested from users have been sponsored by the National Project for Active Utilization of HANARO since 2000. The project has a call for research proposals every year. Proposals submitted through the homepage (http://www.nrf.re.kr) of the National Research Foundation of Korea (NRF) are competitively selected on the basis of an independent peer review that utilizes expert reviews from universities, national laboratories, and industry.
Various specimens such as nuclear fuels and materials, and non-nuclear materials including conductors and electro-magnetic materials have been irradiated using capsule and rabbit systems. Several remarkable results of the effects of neutron irradiation on the physical properties of various functional materials that were irradiated at HANARO have been published in the literature [5-9].

Table I: Neutron irradiation tests of electro-magnetic materials at HANARO

Research Field	Materials & Topics
Broad Banded Semi-Conductor Defect	WBG Semi-Conductor(ZnO, GaN) Lighting Semi-Conductor
Pure Silicon Crystal Irradiation Point Defects	Mass Production of Uniform Semi-conductor P Distribution / Uniformity
Degradation of Dielectric Devices	Si Semiconductor, Performance & Credibility
Irradiation of Oxide Transistor	Oxide TFT, Degradation mechanism
Improvement of Superconductivity	YBCO, MgB_2 / Electromagnetic properties
Superconductivity of MgB_2 by thermal neutron	MgB_2 / Surface Resistivity & Conductivity
Optical / Electro-magnetic material Irradiation	$SrTiO_3$, MgO, ZnO Nano lattice defect measurement
Amorphous Ribbon/Wire Magnetic	Fe-Zr amorphous ribbon / Fe-based wire
Magnetic Semi-Cond. Irradiation	GaMnAs, GaMnN, ZnO Magnetic Semi-Con.
Multiferroics	$LiFePO_4$, $Li(Ni\text{-}Mn)O_4$, $Cu(Fe\text{-}Ga)O_2$
Stress Evaluation of Irradiated Graphite	Graphite, Physical Properties
Development of Neutron Detectors	Si/SiC Semiconductor, Severe Environments

2.2 Possibility of Researches on Electro-Magnetic Materials Using Neutron Irradiation

The electro-magnetic and optical properties of the materials are closely dependent on the size and density of their internal defects, and neutron irradiation is a very effective method to produce micro-defects in these materials. Therefore, neutron technology can be applied effectively toward the development of new materials.

Neutron irradiation provides 1) the preservation of stoichiometric composition and the average number of electrons per atom, 2) the opportunity of preservation of macro- and micro-homogeneity of the samples, and 3) the opportunity of making of defects of various sorts with a smooth change in their concentration. These opportunities of neutron irradiation are unattainable by using any other traditional technological methods. Therefore, the study of a response of a crystal to irradiation influence allows observing unique information about electron states, magnetic interaction, etc.

Neutron interactions with matter occur as collisions, called scattering events creating defects, or in capture events called neutron transmutation. The electrical and magnetic properties of electronic materials are extremely dependent upon disorder in lattice structure. Neutron irradiation of these materials greatly increases this disorder through the creation of various defects. Thermal neutron damage is thought to consist of point defects such as di-vacancies, di-interstitials, and vacancy-impurity clusters. Fast neutron damage consists of extended defect clusters, which may contain as many as 1,000 defects [10].

Although several impressive effects of neutron irradiation on the properties of electronic materials were reported at HANARO [5-9], it was difficult to interpret clearly their behaviors due to the broad energy spectrum of the neutron, as shown in Fig. 1. The undesirable effects due to thermal and fast neutrons should be reduced to separate each neutron's effect on the properties of the sample.

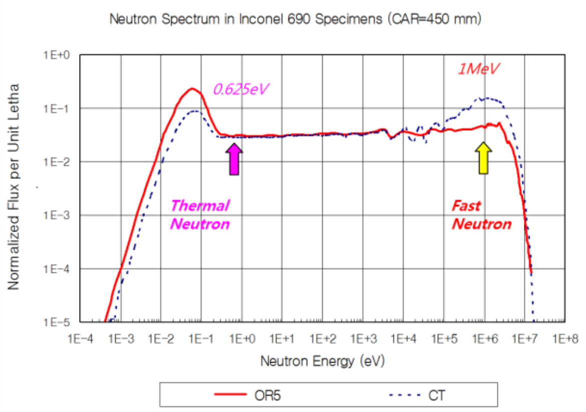

Fig. 1. Neutron energy spectrum at HANARO.

Following the experience with HANARO, KIJANG research reactor (KJRR) is now being constructed by KAERI, which is dedicated to increasing the national radio-isotopes supply capacity including the self-sufficiency of Mo-99. In addition, the KJRR is also expected to have the capability to provide the neutron irradiation service for power semiconductor production in a large scale. This service includes not only NTD facility for ingot irradiation, but also fast neutron irradiation (FNI) facility for wafer irradiation, as shown in Fig. 2. Fast neutron irradiation for a wafer is a promising technology for the efficiency gain and life extension of a power semiconductor. The FNI facility can be effectively utilized on the study of the separated effect of fast neutron irradiation on the properties of electro-magnetic materials.

The foundation for the research of materials using neutron irradiation seems to have a great possibility in the field of original information of electro-magnetic materials.

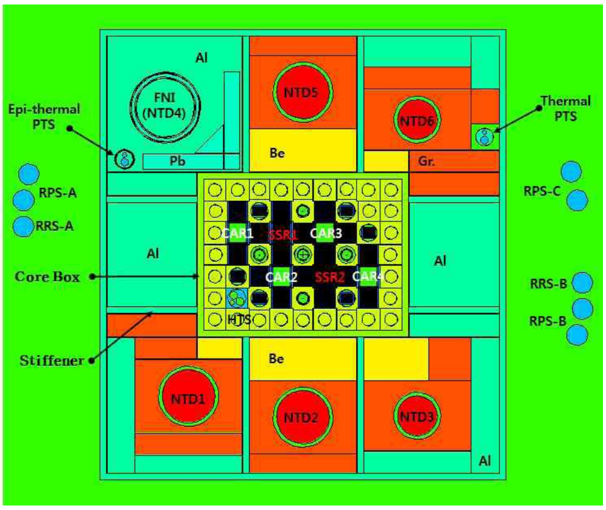

Fig. 2. Plan view of the KJRR core.

3. Conclusions

HANARO irradiation facilities have been actively utilized for various material irradiation tests requested by users. Although most irradiation tests have been related to national R&D relevant to nuclear power, demand for neutron irradiation of electro-magnetic materials is rapidly increasing at HANARO. Another research reactor, the KIJANG research reactor (KJRR), is under construction in Korea. New irradiation facilities including Neutron Transmutation Doping (NTD) facilities for power semiconductor production in a large scale and fast neutron irradiation (FNI) facility for fast neutron irradiation were designed in the KJRR. The NTD and FNI facilities in the KJRR reactor can be effectively utilized on the study of separate effect of thermal and fast neutron irradiations on the properties of electro-magnetic materials.

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