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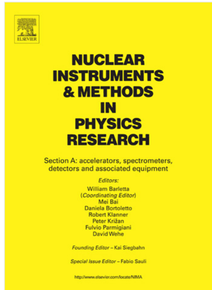

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Fast neutron detection at near-core location of a research reactor with a SiC detector

Lei Wang[1,2], Josh Jarrell[1], Sha Xue[1], Chuting Tan[1], Tom Blue[1], Lei R. Cao[1,*]

1. *Department of Mechanical and Aerospace Engineering, The Ohio State University, Columbus, Ohio, 43210,*
2. *State Key Laboratory of Geohazard Prevention and Geoenvironment Protection, Chengdu University of Technology, Chengdu, Sichuan, 610059, China*

**Email: Cao.152@osu.edu*

Abstract

The measurable charged-particle produced from the fast neutron interactions with the Si and C nucleuses can make a wide bandgap silicon carbide (SiC) sensor intrinsically sensitive to neutrons. The 4H-SiC Schottky detectors have been fabricated and tested at up to 500℃, presenting only a slightly degraded energy resolution. The response spectrum of the SiC detectors were also obtained by exposing the detectors to external neutron beam irradiation and at a near-core location where gamma-ray field is intense. The fast neutron flux of these two locations are ~4.8×10^4 $cm^{-2} \cdot s^{-1}$ and ~2.2×10^7 $cm^{-2} \cdot s^{-1}$, respectively. At the external beam location, a Si detector was irradiated side-by-side with SiC detector to disjoin the neutron response from Si atoms. The contribution of gamma ray, neutron scattering, and charged-particles producing reactions in the SiC was discussed. The fast neutron detection efficiencies were determined to be 6.43×10^{-4} for the external fast neutron beam irradiation and 6.13×10^{-6} for the near-core fast neutron irradiation.

Keywords

Silicon carbide, High temperature, Fast neutron, Near-core irradiation, Fission reactor

1. Introduction

Neutron detection, mainly in the thermal energy region, is normally conducted through deployment of neutron conversion materials such as ^{235}U, ^{10}B, ^{6}Li, ^{3}He or gadolinium in a gas format (*e.g.*, BF_3 proportional tube, He-3 tube) or in a solid-state format (*e.g.*, coated or doped structure [1]). Detection of fast neutrons will mostly rely on the elastic scattering process. Among wide band-gap semiconductor materials, diamond, silicon carbide (SiC), and gallium nitride (GaN) are the most explored for applications of radiation detection in harsh environments [2-5]. Furthermore, the SiC based detectors are in the most developed category for detection of alpha particles, X-ray, charged particles, and neutrons [5-13] mainly due to the commercial availability of high quality crystals at a relatively low cost, as well as its wide bandgap (3.25eV) and a high displacement energy. The large elastic and inelastic neutron cross-section of carbon have also made SiC or diamond intrinsically sensitive to neutrons, without having to apply the aforementioned neutron conversion material, which is especially beneficial in the case of high flux environments or fast neutron detection. As early as 1971, the neutron induced reactions in Si semiconductor detectors have been measured [14]. In the 2000s, the fast neutron response of SiC detectors showed that SiC is sensitive to fast neutrons [8, 15-16]. Further development has been focused on SiC detector's fast neutron response measurements under a mono-energetic neutron source in order to identify the neutron reactions [8]. Despite plentiful experimental evidence of fast neutron detection [17-21], SiC detectors have not seen a practical application in a nuclear reactor environment. While it is true that the transmutation of Si is a real concern for a long term in-core deployment, near-core or ex-core applications may have a role to play in advanced reactor concepts. Furthermore, in a special application where a fast-neutron hodoscope is used to detect nuclear fuel motion within test samples inserted in the core of the Transient Reactor Test Facility (TREAT), a wide band-gap semiconductor such as SiC could be a good candidate because of its fast response time and the miniature device size.

In a nuclear reactor environment, SiC's gamma sensitivity must be reevaluated. While SiC is believed to be insensitive to gamma rays because of the low z-numbers of Si and C as well as the thin-film nature of the device, the gamma heating and the stray gamma-rays coming from the sides could still deposit much of the initial gamma ray energy inside the device, which is especially true in a nuclear reactor environment where gamma radiation is abundant and isotropic.