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Migration behaviour of Europium implanted into single crystalline 6H-SiC

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Migration behaviour of Europium (Eu) implanted into 6H-SiC was investigated using Rutherford backscattering spectroscopy (RBS), RBS in a channelling mode (RBS-C) and scanning electron microscopy (SEM). Eu ions of 360 keV were implanted into 6H-SiC at 600 °C to a fluence of 1×10^{16} cm^{-2}. The implanted samples were sequentially annealed at temperatures ranging from 1000 to 1400 °C, in steps of 100 °C for 5 h. RBS-C showed that implantation of Eu into 6H-SiC at 600 °C retained crystallinity with some radiation damage. Annealing of radiation damage retained after implantation already took place after annealing at 1000 °C. This annealing of radiation damage progressed with increasing annealing temperature up to 1400 °C. A shift of Eu towards the surface took place after annealing at 1000 °C. This shift became more pronounced and was accompanied by loss of Eu from the surface at annealing temperatures >1000 °C. This shift was accompanied by broadening of Eu peak/Fickian diffusion after annealing at temperatures >1100 °C. The migration of Eu occurring concurrently with the annealing of radiation damage was explained by trapping and de-trapping of Eu by radiation damage.

1. Introduction

The containment of fission products (FPs) is critical in the design of the nuclear reactors [1]. In Generation IV nuclear reactors, fuel kernels (UO_2) are coated by four successive layers [2]. These layers are graphite buffer, inner pyrocarbon (PyC), silicon carbide (SiC) and an outer pyrocarbon. The main function of the low density PyC layer, (the buffer layer) is to attenuate fission recoils and to provide voids for gaseous FPs and carbon monoxides that are produced. The inner PyC retains gaseous FPs. The SiC layer retains solid fission products or acts as barrier to solids fission products and provides adequate structural stability during fuel compact fabrication. The outer high-density PyC protects SiC layer mechanically. This coated particle is known as tri-isotropic (TRISO) particle.

TRISO particles retain most of the FPs well with the exception of silver (Ag), strontium (Sr) and Europium (Eu) during operation [2,3]. Generation IV Reactor program includes high temperature reactors (HTR's), operating at temperatures well above 1000 °C to enhance their efficiency, especially in view of process heat applications for hydrogen generation [4]. Extensive investigations have been performed in the migration behaviour of Ag in SiC in the temperatures below and above 1000 °C [5]. Very little has been reported on the migration behaviour of Eu in SiC [1,6]. Europium is a highly reactive metal which react with Si to form a stable silicide and with carbon to form a stable carbide. Consequently, one would expect that at high temperatures (like those used in this study) and at the concentration levels used in this study (i.e. a maximum 2 atomic percent) that Eu would dissolve in the SiC. Eu is toxic to lungs and mucous membrane if inhaled, it is corrosive and an irritant to skin [7]. In the reported studies of the migration behaviour of Eu in SiC, the influence of radiation damage has not been investigated. In the nuclear reactor environment, SiC is continuously exposed to irradiation, hence the influence of radiation damage in the migration of Eu in SiC is crucial.

In this study we report, on the investigation of influence of radiation damage in the migration behaviour of Eu implanted into 6H-SiC to a fluence of 1×10^{16} cm^{-2}. The radiation damage retained after implantation played a major role in the migration behaviour of implanted Eu.

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2. Experimental method

Single crystalline 6H-SiC wafers from Valley design Corporation were used in this study. Implantation was performed with 360 KeV Eu ions at 600 °C to a fluence of 1×10^{16} cm^{-2}. To avoid channelling, implantation was done at an angle of 7° relative to normal incidence. The implanted wafers were isochronal annealed in vacuum using a computer controlled *Webb 77* graphite furnace at temperatures ranging from 1000 to 1400 °C, in steps of 100 °C for 5 h. Eu distribution before and after annealing was monitored by Rutherford backscattering spectroscopy(RBS) at room temperature by the production of a collimated beam of He^+ particles with energy 1.4 MeV at a scattering angle of 165°. The same set-up was also used to investigate radiation damage in the single crystalline samples by Rutherford backscattering spectroscopy in a channelling mode spectroscopy (RBS-C). The backscattered energy in channels were converted into depth (in nm) using the energy loss data and the density of pristine SiC i.e. 3.21 gcm^{-3}. Samples surfaces before and after annealing were investigated by field emission scanning electron microscopy (FEG-SEM) employing a Zeiss Ultra 55 instrument fitted with the usual SEM detectors and an in-lens detector.

3. Results

RBS spectra (both Random and aligned) of Eu implanted 6H-SiC at 600 °C are shown inFig. 1. The un-implanted 6H-SiC (virgin) spectrum is included for comparison. Arrows in Fig. 1 indicate the surface energy positions in channels of the elements. Implantation at 600 °C resulted in the appearance of the broad peak around channel 230. This peak indicates the amount of radiation damage retained after implantation. The radiation damage peak in Fig. 1 does not overlap the random spectrum, indicting the absence of amorphous material. The lack of amorphization is due to the availability of thermal energy to the displaced atoms that increase the probability of recombination. Similar results have been reported for other implanted FPs surrogates at the same implantation temperature [8–14].

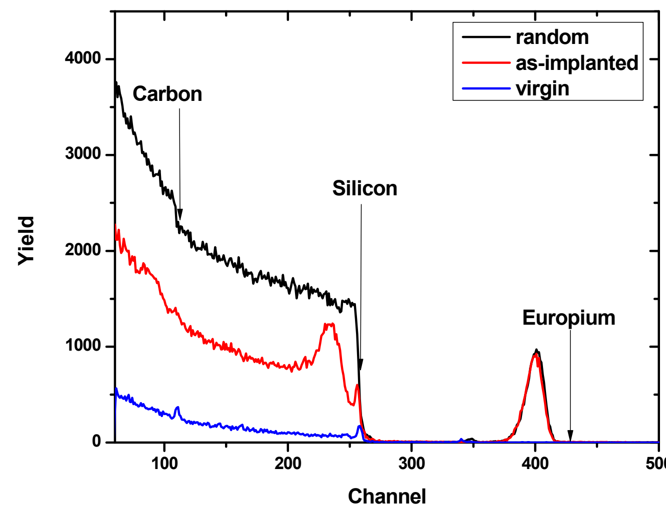

Fig. 1. RBS spectra of 6H-SiC implanted with 360 keV Eu ions (both Random and aligned) at 600 °C and the virgin spectra is included.

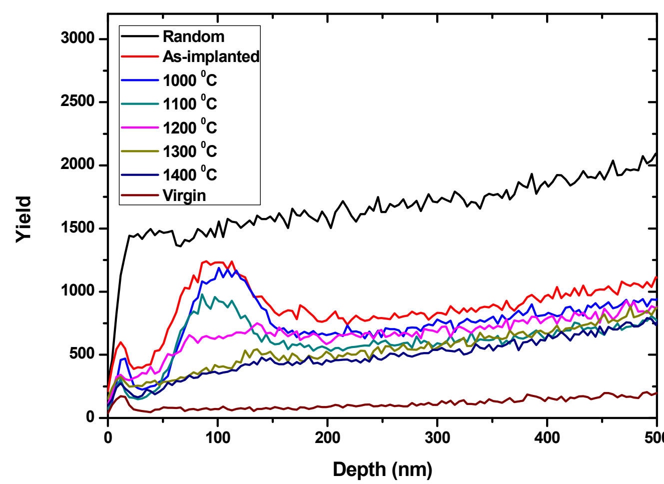

Fig. 3. Si depth profile of Eu implanted into SiC by 360 keV Eu ions and annealed at various temperatures.

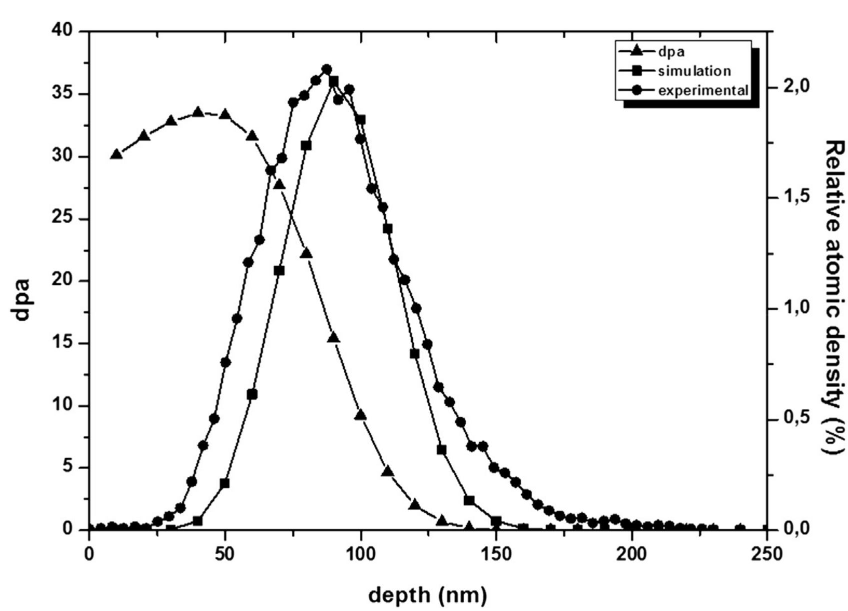

Fig. 2. The as-implanted Eu(360 keV) depth profile(from RBS), TRIM simulated Eu depth profile and displacement per atom(dpa).