Simulations of Proton Implantation in Silicon Carbide (SiC)

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Abstract: *We report on exploratory research effort with preliminary results on investigating fundamental radiation effects in micromachined silicon carbide (SiC) structures and devices. In this technical digest, we briefly present a computer simulation study on the effects of implanting protons (hydrogen ions, H^+) into SiC thin layers on silicon (Si) substrate, and explore the ion implantation conditions that are relevant to experimental radiation of SiC layers.*

Keywords: silicon carbide (SiC); radiation effects; ion implantation; proton; stopping and range of ions in matter (SRIM); transport of ions in matter (TRIM); ion energy; implant depth; defect generation; vacancy; backscattered ions; sputtering yield.

Introduction

Silicon carbide (SiC) is a technologically important wide-bandgap semiconductor, with a wide bandgap ranging from ~2.3eV to ~3.3eV, and excellent optical transparency from visible to near-infrared. It has a high young's modulus of E_Y ~ 400GPa, excellent thermal conductivity, chemical inertness, and outstanding biocompatibility and stability in various liquid-phase solutions [1-3]. In addition to these properties, SiC can be processed by using micromachining techniques similar to those used in silicon, making SiC an excellent choice for MEMS/NEMS applications involving harsh environments and extreme conditions.

Implanting protons (H^+) into SiC is an important step in performing a smart-cut process to create SiC-on-insulator (SiC-on-SiO_2) films and structures [4,5]. It is important to understand and control the implantation depth. Presented here are computer simulations based on transport of ions in matter (TRIM), and stopping and range of ions in matter (SRIM). TRIM is a Monte Carlo simulator that can provide insight into the behavior of H+ ions implanted into the SiC layers [6-8].

Preliminary Results and Discussions

We have conducted TRIM and SRIM computer simulations (TRIM) for SiC of varying thickness on a Si substrate. The SiC thicknesses are 3000 angstroms (300nm), 4000 angstroms (400nm), and 5000 angstroms (500nm). The Si thickness is 50,000 angstroms (5μm). One thousand (1000) hydrogen ions (H^+) are used in the simulations, resulting in an accuracy confidence greater than 90% [8]. The ion implantation energy is varied from 0.01 keV to 450 keV. We examine the ion implantation depth, the backscattered ions, vacancies created per ion, and the sputtering yield.

Figure 1 demonstrates the hydrogen ions (H^+) implantation profile of trajectories for a 300nm-thick SiC film on Si. Two different energies are used, 30 keV and 120 keV, for 30 keV all the ions stay within the SiC, while 120 keV is high enough energy for the ions to be implanted down into the Si underneath the SiC layer.

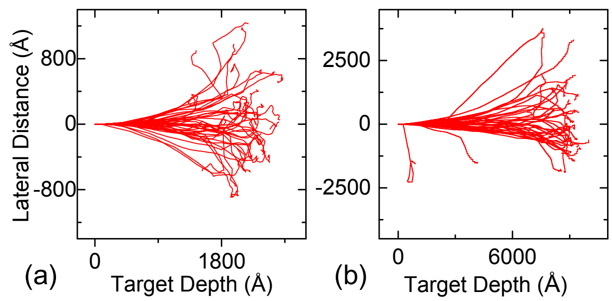

Figure 1. The implantation profile with ion trajectories. (a) All the protons are contained within the SiC layer, with the implant energy at 30keV. (b) The implant profile for 120 keV, high enough energy for the H^+ ions to implant into the Si substrate. The SiC thickness is 300nm.

Figure 2 shows the implant depth versus the ion energy. This has been carried out for each of the three SiC film thicknesses, namely 300nm, 400nm, and 500nm.

The implant depth versus ion energy plots can be divided into two distinct regimes, as is seen through the change in the slope in Fig. 2. The two regimes correspond to implant depths within the SiC and within the Si. Once in Si, there is less retardation of the ions, than in the top SiC layer, due to the differences in the materials' density values.

As the ion energy increases, there is an increase in the vacancies created per implanted ion. The increase in vacancies per ion is expected due to the increase in the proton's momentum. Additionally, there is a reduction in the number of backscattered ions.

Sputtering occurs when an atom gains enough energy imparted onto it, so that it leaves the target. Thus here the sputtering yield is defined as the number of ejected atoms per ion (see Fig. 3 for simulation data).

Summary

We have performed simulations on implanting protons (H^+) into SiC thin layers on Si substrate. We have found the implant depth, the defects created in the form of vacancies, as functions of the implant energy; and we have quantified the trajectory profiles within the target (SiC on Si).

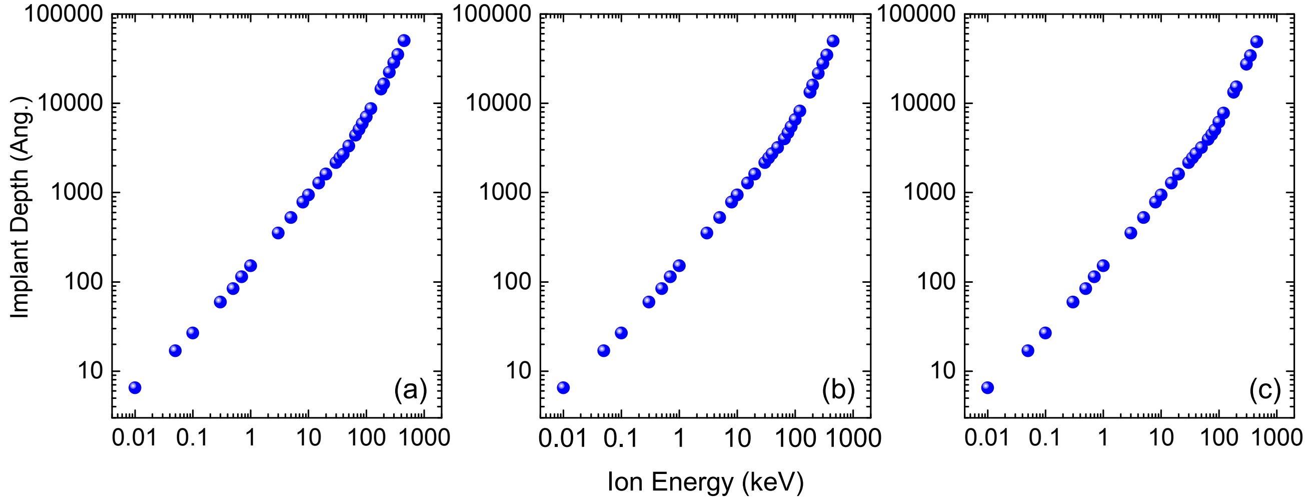

Figure 2. Implant depth as a function of ion energy for (a) 300nm-thick, (b) 400nm-thick, and (c) 500nm-thick SiC layers on a Si substrate, respectively. There are two distinct regimes, as indicated by the different slopes. The SiC regime and the Si regime.

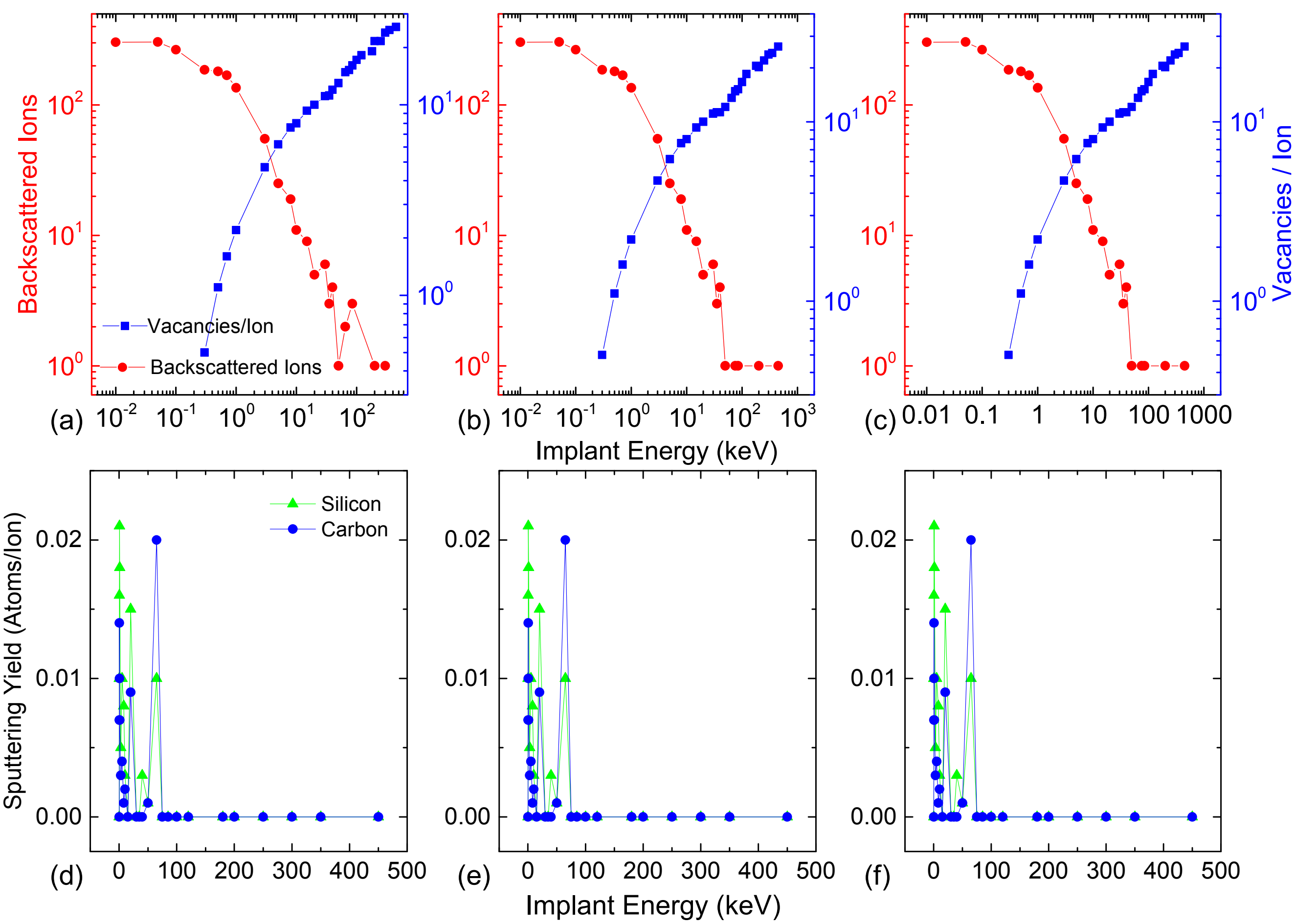

Figure 3. The backscattered ions versus implanting ion energy and the vacancies created per ion versus ion implantation energy for (a) 300nm-thick, (b) 400nm-thick, and 500nm-thick SiC layers on a Si substrate, respectively. (d), (e), and (f) show the sputtering yield at silicon (Si) sites and at carbon (C) sites as a function of ion implantation energy for (d) 300nm-thick, (e) 400nm-thick, and (f) 500nm-thick SiC layers on a Si substrate, respectively.

Acknowledgements

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