Abstract

The interaction of ions with solids has been investigated for decades due to widespread application of ion sputtering in thin film microanalysis, ion implantation in doping semiconductors, and dry etching and sputter deposition in semiconductor microelectronic device fabrication. The creation of ion damage and other bulk volume defects (precipitates and cavities) during ion irradiation in a semiconductor crystal has technological implication in semiconductor microelectronic device fabrication, since controlling those bulk volume defects will become even more crucial as the size of semiconductor microelectronic devices becomes smaller. Also, understanding the creation of surface defects and the evolution of surface morphology during ion irradiation is important in understanding ion sputtering processes in thin film microanalysis and in preparation of clean surfaces for surface science experiments.

In chapter 1, theories and previous experiments on diffusion of implanted atoms, formation and migration of nanocavities, and surface instability during ion irradiation are reviewed. In chapter 2, experimental details are discussed including the ion source, STM (Scanning Tunneling Microscopy), TEM (Transmission Electron Microscopy) and RBS (Rutherford Backscattering Spectrometry). The following three chapters cover microstructure of Ge under high energy ion irradiation, interaction of keV ions with the microstructure, and surface roughening during ion irradiation.

In chapter 3, bulk volume defects, called nanocavities, in Ge(111) produced by 5 keV Xe ion irradiation are characterized by TEM and RBS. The formation of
nanocavities depends strongly on temperature since the formation of nanocavities depends on kinetics of bulk point defects (vacancies and interstitials) produced by ion irradiation. More nanocavities are formed deeper inside the crystal at 500 °C compared to 400 °C, while much smaller number of nanocavities are formed at 600 °C. Due to the low mobility of bulk point defects at 400 °C, not all the implanted Xe atoms are contained in the observed nanocavities, while probably almost all the implanted Xe atoms are contained in the nanocavities at 500 °C. At 600 °C, the areal density of implanted Xe atoms is small and no Xe peak is detected by RBS due to the high mobility of bulk point defects and Xe atoms.

In chapter 4, surface defects, called pits, on Ge(111) and Ge(001) produced by keV Xe ions are characterized by STM. Large pits, which are more than several bilayers deep, are formed on Ge even when less than a bilayer of surface material is removed. The number of large pits initially increases and then decreases with increasing ion fluence, and even 650 eV Xe ions can create large pits on Ge. Large pits are formed on Ge due to the annihilation of nanocavities on the Ge surface by the interaction of displacement cascades of keV Xe ions with nanocavities. 20 keV Xe ions can create small pits on Ge(111), which are more than a bilayer deep, as well as large pits. The creation of small pits is due to surface damage creation process by single 20 keV Xe ions.

In chapter 5, the surface morphology evolution of Ge(111) during 5 keV Xe ion etching is characterized by STM and AFM (Atomic Force Microscopy). Surface patterns of pits (different pits from those in chapter 4) or valleys and mounds are observed at 250 °C and 275 °C due to the asymmetric kinetics of surface vacancies at step edges, while no
surface pattern formation is observed at room temperature. Also, model of Politi and Villain agrees relatively well with the roughening and coarsening of the Ge(111) surfaces etched by 5 keV Xe ions at 250 °C and 275 °C. At 300 °C, a surface pattern is observed only when the incident ion direction is parallel to the step direction; this surface pattern is the ripple morphology produced by curvature dependent sputtering yield.
To my wife, Laura,

and my sons, Haven and Maven
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