ATOMIC DISPLACEMENT EFFECTS IN NEUTRON TRANSMUTATION DOPING*

H. J. Stein

Sandia Laboratories**

Albuquerque, NM 87185

ABSTRACT

The production of defects in silicon by neutron irradiation and the effects of subsequent thermal annealing are reviewed for their impact on neutron transmutation doping. Recoiling atoms from fast neutron interactions are the dominant contribution to the energy available for producing atomic displacements. Energy deposition considerations indicate that defect clusters are created but amorphous zone formation is highly unlikely. Extensive defect reordering occurs at room temperature with resultant vacancy-vacancy, vacancy-impurity, interstitial-interstitial, and interstitial-impurity interactions. Many irradiation-produced defects have been characterized and identified for annealing temperatures < 500°C, and the role of impurities is pervasive. For temperatures near 500°C defect evolution processes yield vacancy and interstitial loops with impurities still participating. Additional work is needed to more fully characterize and identify residual lattice imperfections which remain in irradiated silicon after annealing to temperatures > 500°C, and to understand the interaction processes in their formation. Although the concentrations of residual defects are relatively low, these residual defects are of primary importance for neutron transmutation doping and also for ion implantation.

1. INTRODUCTION

The introduction of particle irradiation into the processing of semiconductor materials and devices creates a new need for additional understanding of atomic-displacement-produced defects in semiconductors. Irradiation-produced-defect studies have been
supported over a long period of time by space and military agencies. That support, however, peaked in the late 1960's partly because of the success of the studies, and partly because ionization-associated irradiation effects became a more urgent problem in space and military hardware. The renewed interest in displacement-produced defects, which has been stimulated by neutron transmutation doping (NTD) as well as by ion implantation, is primarily concerned with residual defects remaining after material and device processing at temperatures > 500°C. There might, at first, be some question about the applicability to NTD of results from previous studies directed largely at defects produced at device operating temperatures because most of those defects anneal out at temperatures < 500°C. But the situation is viewed as one of evolution so that residual defects remaining at temperatures > 500°C are products of primary and secondary defects through interactions with each other and with impurities and imperfections in the host crystals. Therefore, the previously obtained information is applicable, and new information from studies in support of NTD should add to the existing knowledge of displacement-produced defects.

This paper is intended to highlight basic ideas on neutron displacement effects and is not intended to be an exhaustive review. The discussion is centered on silicon because more detailed information is available on irradiation-produced defects in silicon than for any other material.

Based upon energy deposition, it is shown that fast neutrons dominate the displacement-damage effects for typical thermal-to-fast neutron ratios used in NTD processing of silicon. The clustered nature of neutron damage, and the possibility of overlapping clusters are considered. Defects identified in neutron damage are briefly reviewed and results from fast neutron damage are combined with results from ion implantation studies to discuss the defects remaining in NTD silicon at temperatures > 500°C.

2. NEUTRON-PRODUCED ATOMIC DISPLACEMENTS

2.1. Energy Deposition into Displacement Processes

Recoil atoms from gamma ray or particle emissions after thermal neutron capture, and recoil atoms from elastically and inelastically scattered fast neutrons, produce atomic displacements in solids. The relative importance of the displacement damage produced by thermal and fast neutrons can be estimated by using isotope concentrations, capture or scattering cross-sections, and recoil energies. Such an estimate has been made for silicon and the results are presented in Table 1. The first three columns list