Analysis of Radiation Effects in Silicon using Kinetic Monte Carlo Methods

SAND2014-15512D

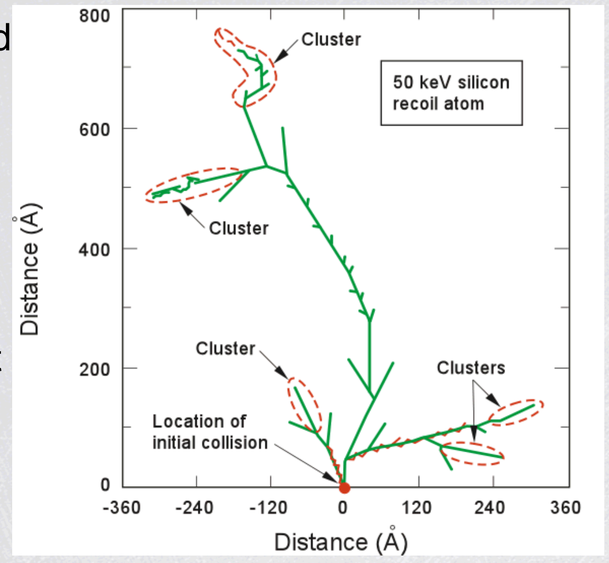
Sandia National Laboratories

Sandia National Laboratories

Brian D. Hehr

Introduction

- The transient degradation of semiconductor device performance under irradiation has long been an issue of concern.
- Typically, the initial defect formation phase is followed by a recovery phase. Clustering of defects, in particular, can have a significant impact on the annealing process.
- The purpose of this project is to develop a kinetic Monte Carlo (KMC) code capable of modeling both thermal and carrier injection annealing.

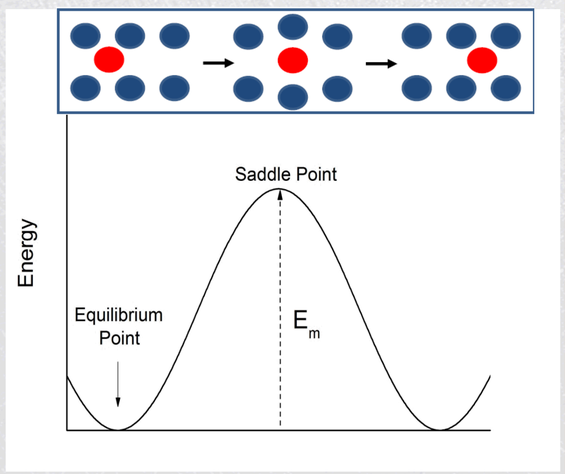


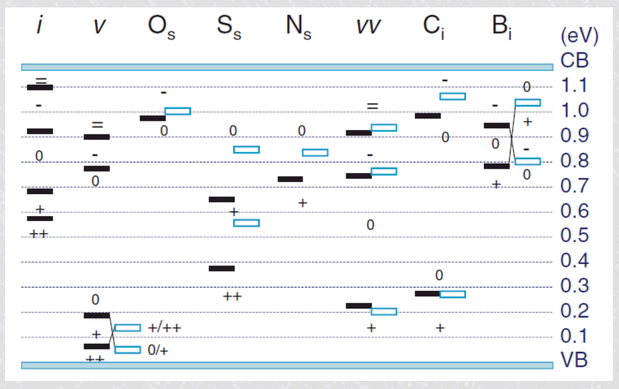
Ref. [1]

Approach

Modeled phenomena include:

- Thermal migration
- Athermal (Bourgoin-Corbett) migration
- Charge state transitions and dependencies
- Defect-defect and defect-impurity reactions





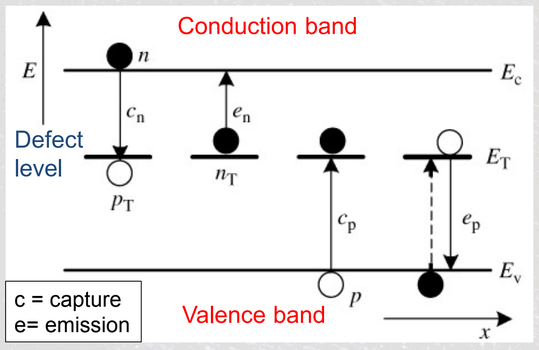
Ref. [2]

Can determine, as a function of time:

- Defect populations and positions
- Carrier recombination rate
- Carrier concentrations, consistent with periodic boundaries (no device model coupling yet)

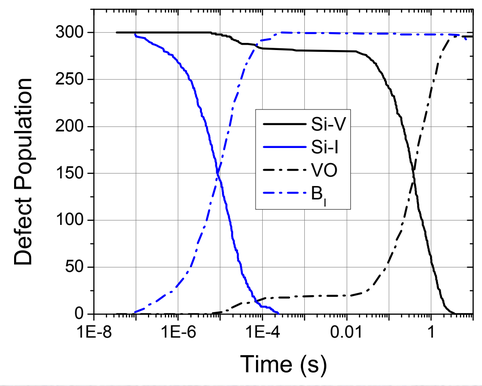
Problem definition:

- Initial defect arrays obtained from MARLOWE binary collision code
- Defect cluster surrounded by array of discrete impurity atoms
- Boundary conditions can be cubic or ellipsoidal

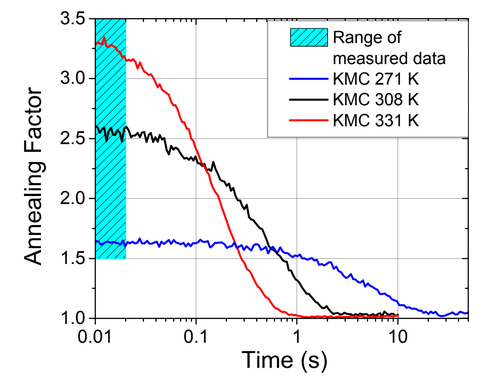


KMC Results

Electron irradiation (bulk p-type silicon)



Impact

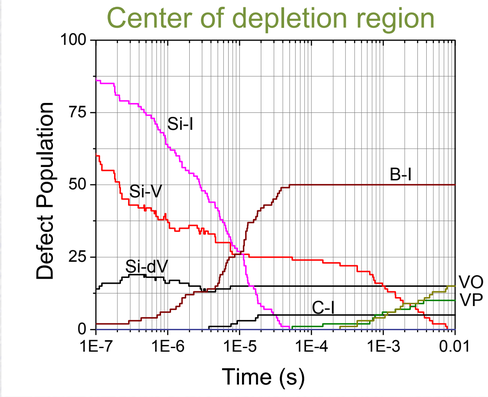


Electron irradiation: Annealing factor impact determined by carrier parameters of V, VO

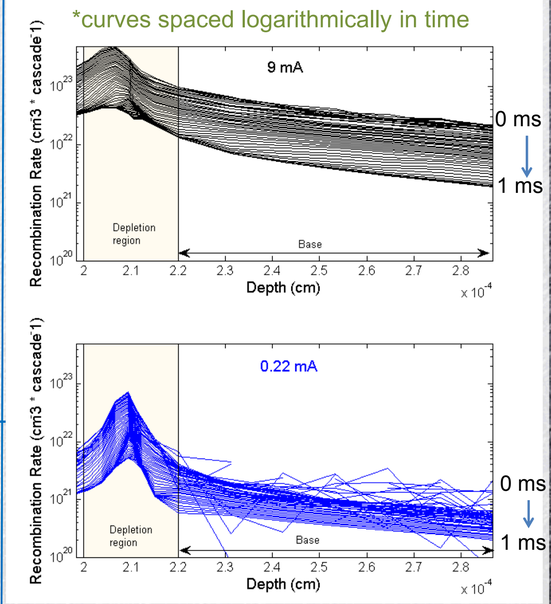
Neutron BJT irradiation: Base current influenced mainly by carrier parameters of V, VP

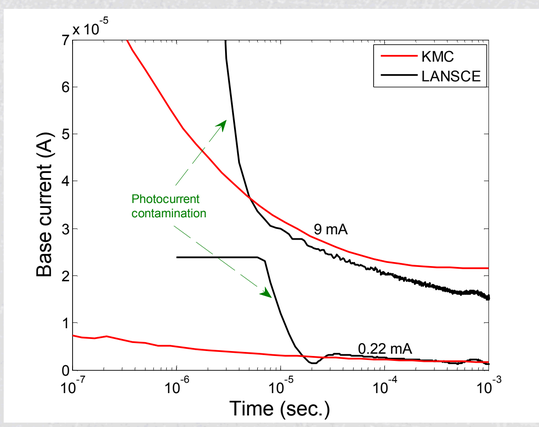
→ consistent adjustments to carrier capture cross sections of V, VO, and VP to match measured data

Neutron irradiation at LANSCE (2N2222 silicon BJT)



Impact





Significance

A kinetic Monte Carlo code has been developed with specific features to enable exploration of semiconductor device degradation under irradiation. The code has proven useful not only in modeling the degradation itself, but also in converging on a consistent set of defect parameters when large uncertainties exist. In particular, it was shown that adjustments were needed in the V, VO, and VP carrier capture cross sections (known beforehand to about an order of magnitude) in order to simultaneously match results from two rather dissimilar irradiation experiments.

[1] S. Kayali, "Space Radiation Effects on Microelectronics." JPL, Section 514.
[2] P. A. Schultz. *Phys. Rev. Lett.*, **96**, 246401 (2006).

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

U.S. DEPARTMENT OF ENERGY

LDRD LABORATORY DIRECTED RESEARCH & DEVELOPMENT