Characterization of process and radiation induced defects in Si and Ge using conventional deep level transient spectroscopy (DLTS) and Laplace-DLTS

By

Cloud Nyamhere

Submitted in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY (PH.D) {PHILOSOPHIE DOCTOR} in Physics

in the Faculty of Natural and Agriculture Sciences at the University Of Pretoria

September 2009

Supervisor/Promoter: Prof. F.D. Auret

Co-supervisor: Dr W.E. Meyer

Characterization of process and radiation induced defects in Si and Ge using conventional deep level transient spectroscopy (DLTS) and Laplace-DLTS

by

Cloud Nyamhere

Submitted in partial fulfillment of the requirements for the degree of (PH.D) in Physics in the Faculty of Natural and Agricultural Science, University of Pretoria

Supervisor/Promoter: Prof. F.D. Auret
Co-Supervisor: Dr. W.E. Meyer

Defects in semiconductors are crucial to device operation, as they can either be beneficial or detrimental to the device operation depending on the application. For efficient devices it is important to characterize the defects in semiconductors so that those defects that are bad are eliminated and those that are useful can be controllably introduced.

In this thesis, deep level transient spectroscopy (DLTS) and high-resolution Laplace-DLTS (LDLTS) have been used to characterize deep level defects introduced by energetic particles (electrons or Ar ions) and during metallization using electron beam deposition on silicon and germanium. Schottky diodes were used to form the space-charge region required in DLTS and LDLTS measurements. From the DLTS and LDLTS measurements the activation enthalpy required to ionize a trap, E_T, and defect carrier capture cross-section σ were deduced. LDLTS proved particularly useful since it could separate deep levels with closely spaced energy levels (the limit being defects with emission rates separated by a factor greater than 2), which was not possible by conventional DLTS.

The majority carrier traps in gallium-, boron- and phosphorus-doped silicon introduced after MeV electron irradiation and during electron beam deposition have been characterized, and several defects such as the divacancy, *A*-center and *E*-center and other complex defects were observed after the two processes. Annealing studies

have shown that all deep levels are removed in silicon after annealing between 500˚C - 600˚C.

Both electron and hole traps introduced in n-type germanium by electron irradiation, Ar sputtering and after electron beam deposition have been characterized using DLTS and LDLTS. The *E*-center is the most common defect introduced in germanium after MeV electron irradiation and during electron beam deposition. Annealing shows that defects in germanium were removed by low thermal budget of between 350˚C - 400˚C and it has been deduced that the *E*-center (V-Sb) in germanium anneals by diffusion.

The identification of some of the defects was achieved by using defect properties such as defect signature, introduction rates, annealing behavior and annealing mechanisms, and then comparing these properties to theoretical defect models and results from other techniques.

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Acknowledgements

I would like to acknowledge the following people for their valuable contribution towards the completion of my Ph.D work.

- My academic promoter, Prof. F.D. Auret and co-promoter Dr. W.E. Meyer for their tireless guidance, discussions and support.

- The head of department, Prof. J.B. Malherbe, for arranging some part-time work in the department, which supported my studies financially.

- The South African National Research Foundation and Oppenheimer Memorial Trust for the Bursaries that enabled my study to progress smoothly.

- Fellow senior students in the physics department, M. Diale, A. Chawanda, W. Mtangi, P.J. Janse van Rensberg, S. Coehlo and G. Webb amongst others for the encouragement and moral support.

- My parents and family for their never ending love and encouragement throughout my studies and beyond.

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Contents

Chapter 4: DLTS and Laplace-DLTS Aspects

Chapter 5: Experimental Techniques

Chapter 6: Results

Radiation-induced defects in Ga- or B-doped silicon by 1 MeV electron irradiation

Chapter 7: Results

Defects introduced in n- and p-type Si during contacts fabrication by electron beam deposition (EBD)

Chapter 8: Results

Radiation-induced defects in antimony-doped Ge after electron irradiation

Chapter 9: Results

Defects introduced in antimony-doped germanium during metallization by electron beam deposition

Chapter 10: Results

Defects introduced in antimony-doped germanium after sputtering by 3 keV Ar ions