Electrical characterization of process, annealing and irradiation induced defects in ZnO

by

Wilbert Mtangi

Submitted in partial fulfilment of the requirements for the degree of

DOCTOR OF PHILOSOPHY (PhD) IN PHYSICS

in the Faculty of Natural and Agricultural Sciences

University of Pretoria

Pretoria

August 2012

Supervisor/Promoter: Prof. F. D. Auret

Co-supervisor: Dr. J. M. Nel

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A study of defects in semiconductors is vital as defects tend to influence device operation by modifying their electrical and optoelectronic properties. This influence can at times be desirable in the case of fast switching devices and sometimes undesirable as they may reduce the efficiency of optoelectronic devices. ZnO is a wide bandgap material with a potential for fabricating UV light emitting diodes, lasers and white lighting devices only after the realization of reproducible p-type material. The realization of p-type material is greatly affected by doping asymmetry. The self-compensation behaviour by its native defects has hindered the success in obtaining the p-type material. Hence there is need to understand the electronic properties, formation and annealing-out of these defects for controlled material doping.

Space charge spectroscopic techniques are powerful tools for studying the electronic properties of electrically active defects in semiconductors since they can reveal information about the defect "*signatures*". In this study, novel Schottky contacts with low leakage currents of the order of 10^{-11} A at 2.0 V, barrier heights of 0.60 – 0.80 eV and low series resistance, fabricated on hydrogen peroxide treated melt-grown single crystal ZnO samples, were demonstrated. Investigations on the dependence of the Schottky contact parameters on fabrication techniques and different metals were performed. Resistive evaporation proved to produce contacts with lower series resistance, higher barrier heights and low reverse currents compared to the electron-beam deposition technique.

Deep level transient spectroscopy (DLTS) and Laplace-DLTS have been employed to study the electronic properties of electrically active deep level defects in ZnO. Results revealed the presence of three prominent deep level defects (E1, E2 and E3) in the as-received ZnO

samples. Electron-beam deposited contacts indicated the presence of the E1, E2 and E3 and the introduction of new deep level defects. These induced deep levels have been attributed to stray electrons and ionized particles, present in the deposition system during contact fabrication.

Exposure of ZnO to high temperatures induces deep level defects. Annealing samples in the 300°C – 600°C temperature range in Ar + O_2 induces the E4 deep level with a very high capture cross-section. This deep level transforms at every annealing temperature. Its instability at room temperature has been demonstrated by a change in the peak temperature position with time. This deep level was broad, indicating that it consists of two or more closely spaced energy levels. Laplace-DLTS was successfully employed to resolve the closely spaced energy levels.

Annealing samples at 700°C in Ar and O_2 anneals-out E4 and induces the Ex deep level defect with an activation enthalpy of approximately 160 – 180 meV. Vacuum annealing performed in the 400°C – 700°C temperature range did not induce any deep level defects.

Since the radiation hardness of ZnO is crucial in space applications, 1.6 MeV proton irradiation was performed. DLTS revealed the introduction of the E4 deep level with an activation enthalpy of approximately 530 meV, which proved to be stable at room temperature and atmospheric pressure since its properties didn’t change over a period of 12 months.

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Declaration

I Wilbert Mtangi declare that the thesis, which I hereby submit for the degree Doctor of Philosophy (PhD) in Physics at the University of Pretoria, is my own work and has not previously been submitted by me for a degree at this or any other tertiary institution.

Signature……………………… Date………………………….

Acknowledgements

For the success of this PhD study, I would need to extend my appreciation to the following people:

- My academic promoter Prof. F. D. Auret for all the guidance, motivation, encouragement, support and all discussions, and my co-promoter Dr. J. M. Nel for the guidance, discussions and support as well.
- Dr. W. E. Meyer for some of the ideas and several discussions we had.
- The head of department Prof. C. Theron and former head of department, Prof. J. B. Malherbe for organizing some part-time work in the department to enable me to supplement my finances.
- The South Africa National Research Foundation (NRF) and the University of Pretoria for financial support.
- Prof. A. Chawanda, Dr. C. Nyamhere, Dr. M. Diale, Dr. C. Zander and Dr. T. T. Hlatshwayo for the encouragement and support.
- Dr. M. Schmidt for the interesting discussions and ideas on defects in ZnO.
- Mr. P. J. Janse van Rensburg for all the assistance with the measuring equipment and discussions in the laboratory.
- Mr. M. J. Legodi for some discussions on defects in ZnO.
- Mr. S.M. M. Coelho for the help with electron beam deposition of contacts.
- Mr. H. de Meyer for his support during the long nights of measurements in the laboratory and also for helping me in the use of Solid Edge which was used to draw some of the diagrams in this thesis.
- Fellow senior students in the Physics department, R. J. Kuhudzai, L. van Schalkwyk, P. N. M. Ngoepe, Mr. E. Njoroge, Mr. R. E. Mapasha, Mr. M. Mkhawana and Ms. J. Kabini for their encouragement.
- My parents and family for their patience, love and unwavering support during my years of study.

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