Electrical Characterization of Electron Beam Exposure Induced Defects in Epitaxially Grown n-type Silicon

H. T. Danga[1, a)], F. D. Auret[1], S. M. Tunhuma[1], E. Omotoso[1],
E. Igumbor[1], and W. E. Meyer[1]

[1]*University of Pretoria, Lynnwood Road, Pretoria 0002, South Africa*

a)helga.danga@up.ac.za

Abstract. In this paper, we report on defects introduced in epitaxially grown n-type silicon (Si) during electron beam exposure. The defects observed were electrically characterized using deep-level transient spectroscopy (DLTS) and high-resolution Laplace DLTS. In this process, Si samples were first exposed to the conditions of electron beam deposition (EBD) without depositing a metal. In this paper, this process is called electron beam exposure (EBE). After 50 minutes of EBE, gold Schottky contacts were fabricated using a resistive deposition method. The defect levels E(0.11) and E(0.17) seem to be associated with the carbon interstitial-substitutional pair C_iC_s. The C_iC_s-defect is a bistable defect with an amphoteric character in two defect configurations: A and B. The transition from configuration A to B and vice versa is made possible by a simple bond-switching transformation. A defect level E(0.21) was observed, but the defect's structure is not clear. E(0.41) and E(0.45) were also observed, associated with a divacancy and a phosphorous interstitial, respectively. E(0.47) and E(x) were observed, but their structures are still a subject of speculation.

INTRODUCTION

Electron beam deposition (EBD) of metals in a vacuum system is important in the semiconductor technology industry [1, 2]. This method is useful for depositing materials that have a high melting point and therefore cannot be evaporated by resistive heating because of limitations of the power input. The disadvantage of EBD is that this technique introduces defects in n-type silicon (Si) close to the metal-silicon interface [3]. These defects influence device performance and alter the barrier heights of the contacts. The defects responsible for these changes are formed when energetic particles reach the semiconductor surface and interact with it, causing lattice damage [2, 4]. Depending on the application of the device, these defects may either be useful or detrimental for optimum functioning [4]. This investigation is important because it is known that the low-energy ions used in the EBD process introduce defects at and close to the metal-semiconductor junction [5]. Understanding the physical properties and occurrence of defects will potentially lead to improved device designs [6]. The main aim of developing the electron beam exposure (EBE) technique was to see whether EBD-induced defects could be introduced in a controlled manner. Excessive exposure would reduce the functionality of diodes for further study, thus putting a limit on how much damage could be introduced. Energetic particles that cause EBD damage are present during EBE but interact directly with the semiconductor material, whereas during EBD this interaction mostly occurs via the metal used as a contact [2]. Auret and colleagues did a similar study in which they compared their results to defects created by EBD and high energy electron irradiation. In the current work, we concentrate on defect formation by EBE on n-type Si.

EXPERIMENTAL PROCEDURE

Epitaxially grown P-doped n-type Si <111> grown on a highly doped Si substrate was investigated. Before metallization, the samples were first degreased and then dipped in hydrofluoric acid for 1 minute to etch off the native oxide layer. Immediately after cleaning, the samples were inserted into a vacuum system. Vacuum pumping was

Women in Physics
AIP Conf. Proc. 2109, 080003-1–080003-4; https://doi.org/10.1063/1.5110130
Published by AIP Publishing. 978-0-7354-1841-7/$30.00

carried out by a dry pump in series with a turbo molecular pump to lower the H_2 concentration. To improve the vacuum, tungsten (W) was deposited in the chamber with the sample rotated away from the evaporation source. The predeposition vacuum was typically 5×10^{-7} mbar, which was increased to approximately 3×10^{-6} mbar during the evaporation process. Because the vacuum conditions vary greatly during EBD, forming gas H15, with a composition of N_2:H_2 of 85%:15% by volume, was also used to raise the pressure in the vacuum chamber to 10^{-4} mbar and keep it constant during processing of samples selected for EBE. Electron beam exposure of samples and the fabrication of contacts using electron beam deposition were done using a 10 kV source (MDC model e-Vap 10CVS) with the samples positioned 50 cm above the crucible [3].

During EBE without metal deposition, the samples were exposed for 50 minutes; while the beam heated a tungsten source using a beam current of 100 mA, which is insufficient to evaporate tungsten, thus exposing the samples to electron beam conditions comparable to those experienced during deposition. Gold (Au) diodes were used for all the samples prepared for this study because this metal can be evaporated resistively, a process that is known to not introduce defects in concentrations measurable by deep-level transient spectroscopy (DLTS) [3]. A control sample was prepared by resistively depositing Au contacts onto n-type epitaxial material without using EBE. DLTS and high-resolution Laplace DLTS were used to characterize the defects introduced in epitaxially grown n-type Si during EBE.

RESULTS AND DISCUSSION

Figure 1 shows the seven defect levels that were observed. “E” means “electron trap,” and the number after E is the activation enthalpy in eV. The activation enthalpy and the apparent cross section were calculated from the gradient and the intercept of the Arrhenius plot (shown in Fig. 2), respectively [7]. The defect levels E(0.11) and E(0.17) seem to be associated with the carbon interstitial-substitutional pair C_iC_s [8]. The C_iC_s defect is a bistable defect with amphoteric character in two defect configurations: A and B. The transition from configuration A to B and vice versa is made possible by a simple-bond switching transformation [9]. A defect with the label E(0.21) was observed. Asghar and colleagues [10] have also measured and calculated E(0.21), but the defect’s structure is not clear. E(0.41) was associated with a divacancy [8]. E(0.45) was also observed and could be attributed to the E-center [3]. E(0.47) was observed, but the defect’s structure is not yet known. E(x) has not yet been resolved. Measurements to identify this defect are ongoing.

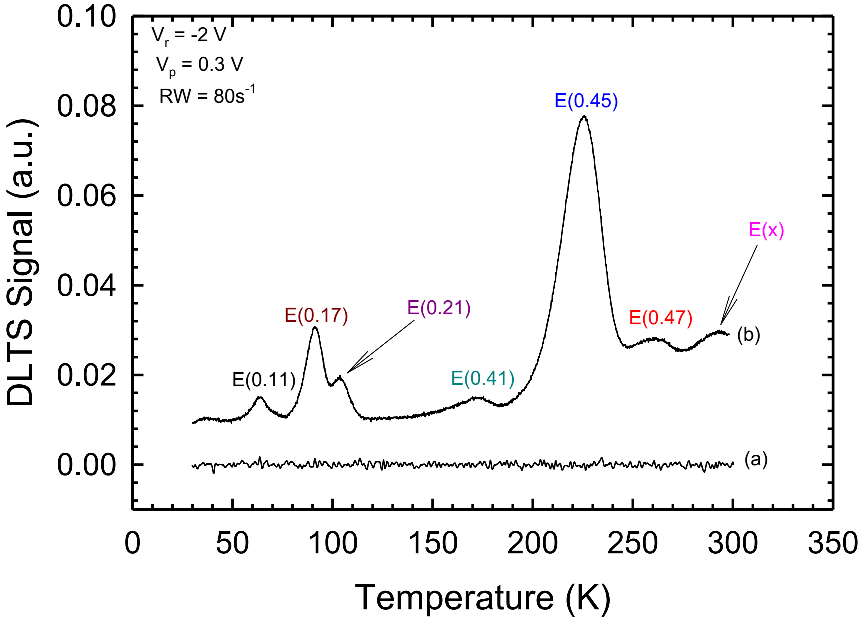

FIGURE 1. DLTS spectra: (a) a control spectrum measured from aluminum Schottky diodes fabricated using resistive deposition, and (b) a spectrum measured from nickel Schottky diodes fabricated after EBE.

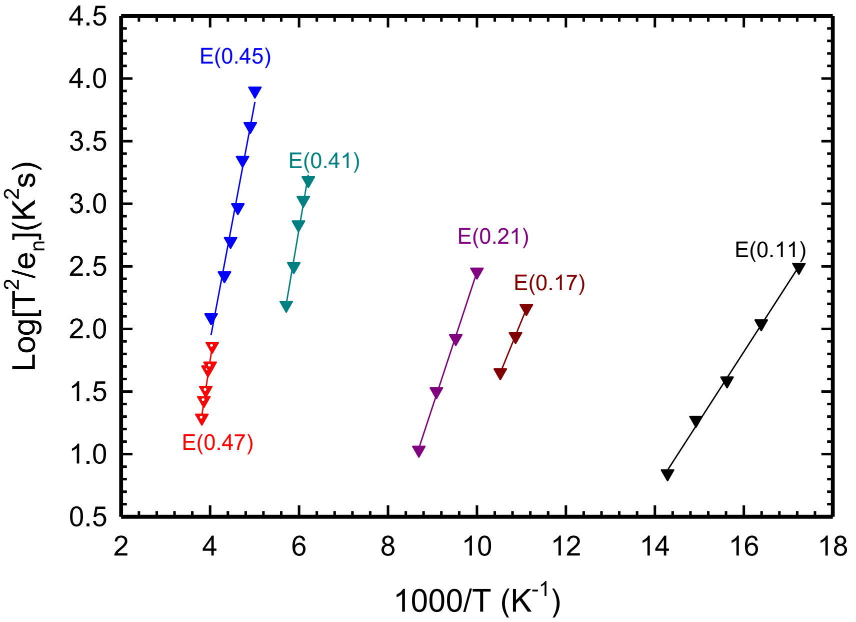

Figure 2. Arrhenius plots for defects introduced after samples were exposed to electron beam conditions (EBE) and then Au Schottky diodes were fabricated.

CONCLUSION

The defect levels E(0.11) and E(0.17) seem to be associated with the carbon interstitial-substitutional pair C_iC_s. The C_iC_s defect is a bistable defect with amphoteric character in two defect configurations: A and B. A defect level E(0.21) was observed, but the defect's structure is not clear. E(0.41) and E(0.45) were also observed, associated with a divacancy and the E-center, respectively. E(0.47) and E(x) were observed, but their structures are still a subject of speculation.

ACKNOWLEDGMENTS

This work is based on the research supported by the National Research Foundation (NRF) of South Africa under grant number 98961. Opinions, findings, and conclusions or recommendations are those of the authors, and the NRF accepts no liability whatsoever in this regard. The authors would like to thank the University of Pretoria for financial support. We also thank Mr. P. J. Janse van Rensburg for his technical assistance. The Laplace DLTS software and hardware used here was received from L. Dobaczewski (Institute of Physics, Polish Academy of Science) and A. R. Peaker (Centre for Electronic Materials Devices and Nano-structures, University of Manchester)."

REFERENCES

1. S. M. M. Coelho, F. D. Auret, P. J. Janse van Rensburg, and J. M. Nel, "Electrical characterization of defects introduced in n-Ge during electron beam deposition or exposure," Journal of Applied Physics **114**(17), 173708 (2013).
2. H. T. Danga, F. D. Auret, S. M. M. Coelho, and M. Diale, "Electrical characterisation of electron beam exposure induced defects in silicon," Physica B: Condensed Matter **480**, 206–208 (2016).
3. F. D. Auret, S. M. M. Coelho, J. M. Nel, and W. E. Meyer, "Electrical characterization of defects introduced in n-Si during electron beam deposition of Pt," Physica Status Solidi (A) **209**(10), 1926–1933 (2012).

4. F. D. Auret, S. M. M. Coelho, M. Hayes, W. E. Meyer, and J. M Nel, "Electrical characterization of defects introduced in Ge during electron beam deposition of different metals," Physica Status Solidi (A) **205**(1), 159–161 (2008).
5. F. D. Auret, S. M. M. Coelho, G. Myburg, P. J. Janse van Rensburg, and W. E. Meyer, "Electronic and annealing properties of the E 0.31 defect introduced during Ar plasma etching of germanium," Physica B: Condensed Matter **404**(22), 4376–4378 (2009).
6. S. M. Tunhuma, F. D. Auret, M. J. Legodi, and M. Diale, "The fine structure of electron irradiation induced EL2-like defects in n-GaAs," Journal of Applied Physics **119**(14), 145705 (2016).
7. F. Danie Auret and Prakash N. K. Deenapanray, "Deep level transient spectroscopy of defects in high-energy light-particle irradiated Si," Critical Reviews in Solid State and Materials Sciences **29**(1), 1–44 (2004).
8. H. K. Nielson, "Capacitance transient measurements on point defects in silicon and silicon carbide," PhD Thesis, KTH Royal Institute of Technology, Stockholm, Sweden, 2005.
9. L. W. Song, X. D. Zhan, B. W. Benson, and G. D. Watkins, "Bistable interstitial-carbon–substitutional-carbon pair in silicon," Physical Review B **42**(9), 5765 (1990).
10. M. Asghar, M. Zafar Iqbal, and N. Zafar, "Study of alpha-radiation-induced deep levels in p-type silicon," Journal of Applied Physics **73**(9), 4240–4247 (1993).