Contents lists available at ScienceDirect

Physica B

journal homepage: www.elsevier.com/locate/physb

Effect of alpha-particle irradiation on the electrical properties of n-type Ge

K.T. Roro *, P.J. Janse van Rensburg, F.D. Auret, S. Coelho

Department of Physics, University of Pretoria, Pretoria 0002, South Africa

ABSTRACT

Deep-level transient spectroscopy was used to investigate the effect of alpha particle irradiation on the electrical properties of n-type Ge. The samples were irradiated with alpha particles at room temperature using an americium-241 (Am-241) radionuclide source. The main defects introduced were found to be electron traps with energy levels at $E_C-0.38$, $E_C-0.21$, $E_C-0.20$, $E_C-0.15$, and $E_C-0.10$ eV, respectively. The main defects in alpha particle irradiation are similar to those introduced by MeV electron irradiation, where the main defect is the E-center. A quadratic increase in concentration as a function of dose is observed.

1. Introduction

Recently, germanium (Ge) has attracted attention in the semiconductor industry for future silicon-compatible optoelectronic and advanced CMOS devices. This interest is motivated by the low effective mass of carriers and the higher carrier mobility in Ge compared to Si [1]. This results in renewed interest in the properties of defects in Ge because defects ultimately determine the performance of devices. In recent studies the properties of the defects introduced during high-energy gamma-, electron- and heavy ion irradiation of Ge were reported [2–8]. However, little data are available regarding the electronic properties of defects introduced by radionuclide irradiation. Despite a number of attempts [2–8], the respective origin of several irradiation-induced defects in Ge is not well understood. It has been previously reported that the use of radionuclides is a convenient and powerful, yet inexpensive, method to introduce and study radiation-induced defects in semiconductors [9]. To the best of our knowledge, most of the alpha particle irradiation induced defects reported so far in the literature have been generated in accelerators. In this paper, we report for the first time on the effect of alpha particle irradiation from radionuclide sources on the electronic properties of defects introduced in n-type Ge. In general, irradiation induced defects will influence device performance, but neither the nature nor their influence on devices has yet been established for Ge. It is shown that alpha particle irradiation introduces one prominent electron and one prominent hole trap and several other electron traps on the dose range studied. The two prominent alpha particle induced trap levels were found to be the V–Sb center that was also previously observed during high energy electron irradiation on the same material.

2. Experimental methods

The samples studied in this work were bulk-grown, (111) oriented, n-type Ge doped with Sb to a level of $2\times10^{15}\,cm^{-3}$. Before metallization, the samples were first degreased and subsequently etched in a mixture of H_2O_2:H_2O (1:5) for 1 minute. Immediately after cleaning, they were inserted into a vacuum chamber where AuSb (0.6% Sb) was resistively deposited on their back surfaces as Ohmic contacts. The samples were then annealed at 350 °C in Ar for 10 min to minimize the contact resistivity of the Ohmic contacts. Before the Schottky contact fabrication, the above cleaning procedure was repeated. Thereafter, 100 nm thick Pd Schottky circular contacts, 0.6 mm in diameter, were deposited by resistive evaporation on the polished side of the material. Before irradiation current–voltage (*I–V*) and capacitance–voltage (*C–V*) measurements at room temperature were used to evaluate the electrical properties of the diodes. The samples were then irradiated by 5.4 MeV alpha particles from an Am-241 radionuclide source for time periods of 1–4 h to obtain the low radiation doses. The activity of the radionuclide is 192 μCi cm^{-2}, and the dose rate when it is in contact with the sample is $7.1\times10^6\,cm^{-2}s^{-1}$. After each irradiation, *I–V* and *C–V* measurements were also repeated. For each dose, 4 samples were irradiated in order to achieve a reasonable averaging. Both conventional and high-resolution Laplace deep level transient spectroscopy (DLTS) was used to investigate the defects introduced in Ge during alpha particle irradiation. The activation energies, E_T, and apparent capture cross section for electrons, σ_{na}, and holes σ_{pa}, (i.e. the DLTS "signatures") of the alpha particle induced electron traps were determined from the conventional

* Corresponding author.
E-mail address: kittessa.roro@up.ac.za (K.T. Roro).

0921-4526/$ - see front matter © 2009 Published by Elsevier B.V.
doi:10.1016/j.physb.2009.09.033

DLTS Arrhenius plots. In order to identify the defects introduced by alpha particles, a comparison was made with defects introduced by high-energy (MeV) electron irradiation from a Sr^{90} source on the same material.

3. Results and discussion

3.1. DLTS measurements

Fig. 1 depicts the DLTS spectrum showing electron traps obtained after alpha particle irradiation. No deep level defects were detected before irradiation. The most significant electron traps are $E_{0.38}$, E_x, $E_{0.21}$, $E_{0.20}$, $E_{0.15}$, and $E_{0.10}$ which corresponds to levels at $E_C-0.38$, $E_C-0.21$, $E_C-0.20$, $E_C-0.15$, and $E_C-0.10$ eV, respectively. In the nomenclature used here "E" means electron trap and the number following it is the energy level of this trap below the conduction band. The peak labelled E_x was found to be asymmetric due to the presence of the peak with much higher intensity on the high temperature side. Therefore it was not possible to accurately determine the energy for this trap. It is evident from the figure that the concentration of the defects increases with dose. The electronic properties of all the induced defects are summarized in Table 1. The dominant electron trap, $E_{0.38}$, with a maximum at about 190 K has already been identified as being due to the double negatively charged state of the E-center or $SbV^{=/-}$, which is a secondary defect resulting from the trapping of a mobile vacancy (primary defect) by antimony [4,5]. It was also observed that the free carrier concentration (not shown) decreases with dose from 1.9×10^{15} to 0.9×10^{15} cm^{-3}.

Fig. 2 shows a conventional DLTS spectrum obtained with the application of "injection" pulses using forward bias pulsing, revealing hole traps introduced into the material. The most significant defect introduced is $H_{0.31}$ with a level at E_V+0.31 eV at about 145 K. The nomenclature "H" means hole trap and the number following it is the energy level of this trap above the valence band. A similar trap with the same energy level has been detected after electron irradiation of Sb doped Ge crystals [2,3]. The defect has recently been identified as the first acceptor state of the Sb–V complex [6].

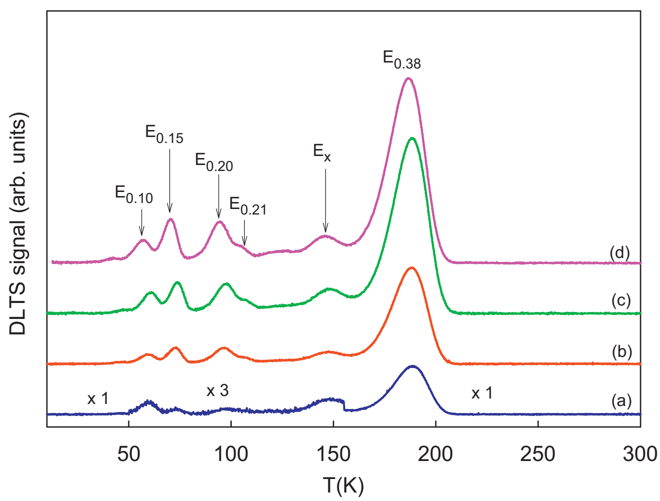

Fig. 1. DLTS spectra of 5.4 MeV alpha-particle irradiated n-type Ge with increasing doses: (a) 2.56×10^{10} cm^{-2}, (b) 5.12×10^{10} cm^{-2} , (c) 7.68×10^{10} cm^{-2} and (d) 10.24×10^{10} cm^{-2}. These spectra were recorded at a rate window of 80 s^{-1} and quiescent reverse bias of −2 V with a filling pulse of 2 V. The spectra are vertically displaced for clarity.

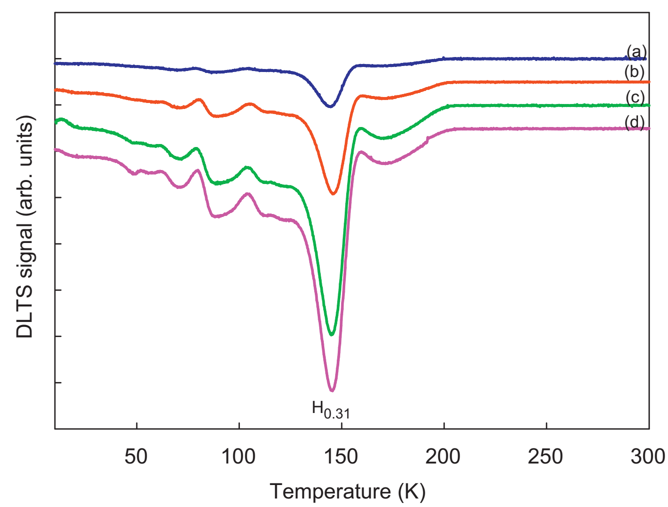

Fig. 2. DLTS spectra of 5.4 MeV alpha-particle irradiated n-type Ge with different doses: (a) 2.56×10^{10} cm^{-2}, (b) 5.12×10^{10} cm^{-2} , (c) 7.68×10^{10} cm^{-2} and (d) 10.24×10^{10} cm^{-2}. Hole trap spectra were recorded at a rate window of 80 s^{-1} and quiescent reverse bias of −2 V with a filling pulse of 5 V.

Table 1
Comparison between the prominent defects introduced in n-type Ge during α and electron irradiation.

Defect	E_T (eV)	σ_a (cm^2)	T_{peak} (K)	Similar defects	Ref.
α-irradiation defects					
$E_{0.10}$	$E_C-0.10$	7×10^{-16}	57	?	
$E_{0.15}$	$E_C-0.15$	3×10^{-14}	71		
$E_{0.20}$	$E_C-0.20$	2×10^{-14}	95		
$E_{0.21}$	$E_C-0.21$	1×10^{-14}	106		
E_x	?	?	147		
$E_{0.38}$	$E_C-0.38$	6×10^{-15}	57	$E_{0.377}$, $E_{0.37}$	[5,4]
$H_{0.31}$	E_v+0.31	1×10^{-12}	57		
MeV electron irradiation defects					
$E_{0.15}$	$E_C-0.15$	5×10^{-14}	77		
$E_{0.20}$	$E_C-0.20$	1×10^{-14}	100	$E_{0.19}$	
$E_{0.21}$	$E_C-0.21$	4×10^{-14}	109	$E_{0.21}$	
$E_{0.38}$	$E_C-0.38$	1×10^{-14}	191	$E_{0.377}$, $E_{0.37}$	[5,4]
$H_{0.31}$	E_v+0.31	1×10^{-12}	145	$H_{0.307}$, $H_{0.300}$	[5,4]

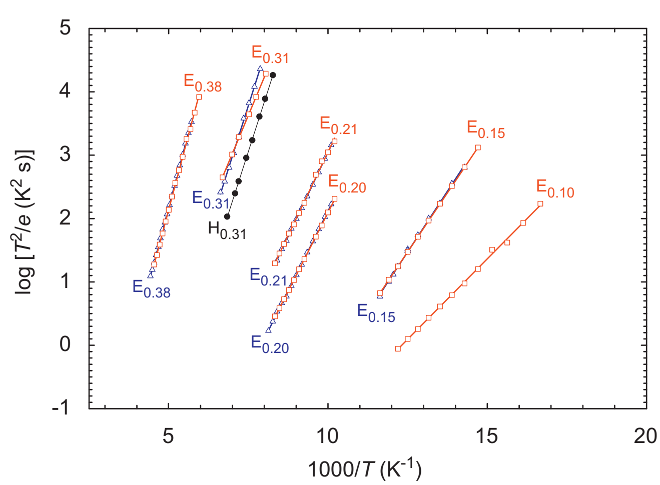

Fig. 3. Arrhenius plots for defects introduced by 5.4 MeV alpha-particle irradiation in to Ge (open Square) and MeV electron irradiated Ge (open triangle). The solid circles represent measurements for the hole trap.

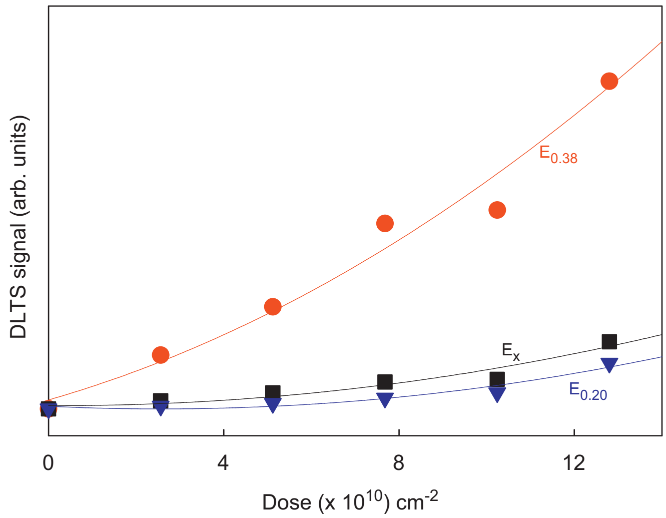

Fig. 4. DLTS amplitude changes of the $E_{0.38}$, E_x, and $E_{0.20}$ levels as a function of alpha-particle irradiation dose. The solid lines indicate a quadratic fit to the data points.

In order to establish the possible nature of the alpha particle induced defects, a comparison of defects induced during alpha particle irradiation to those detected in the same material after electron irradiation with MeV electron from a ^{90}Sr radionuclide were done. It is evident that, from the Arrhenius plots in Fig. 3, the defects introduced are similar with the exception of $E_{0.10}$. The similarities of the DLTS "signature" obtained for $E_{0.38}$, $E_{0.21}$, $E_{0.20}$, and $E_{0.15}$ to the MeV electrons imply that their electronic structures are the same. Therefore, it is concluded that the most prominent alpha irradiation induced defects in the Ge sample are the same as those introduced during electron irradiation of the same material. Alpha particle irradiation introduces additional electron trap, $E_{0.10}$ at about 57 K, which do not correspond to any of the defects introduced during electron irradiation. This suggests that the trap could be related to higher order vacancy complex. Similar defect has been reported recently [2] from defects introduced during electron beam deposition of Pd Schottky contacts.

Fig. 4 shows the DLTS amplitude changes of the three dominant electron traps, $E_{0.38}$, E_x and $E_{0.20}$, as a function of dose. It is evident from the figure that the concentration of the three traps varies quadratically as a function of alpha particle irradiation dose. Kolkovsky et al. [10] reported a similar result on the quadratic dependence of the DLTS signal for the trap, $E_{0.29}$, as a function of dose. They suggested that the defect could be a multivacancy complex. Similarly, the defects $E_{0.38}$, E_x, and $E_{0.2}$ can also be associated with higher order complex structures.

4. Conclusions

Deep level transient spectroscopy has been used to investigate the effect of alpha particle irradiation from radionuclide sources on the electronic properties of defects introduced in n-type Ge. A comparison of these defects with those introduced in the same material during high-energy electron irradiation has also been done. The results of this study shows that the most dominant electron and hole traps introduced in Ge during alpha particle irradiation is $E_{0.38}$ and $H_{0.31}$, respectively, which is identified as the E-center. The other defects observed are similar to that observed after electron irradiation, except $E_{0.10}$.

Acknowledgments

The financial assistance from the South African National Research Foundation is greatly acknowledged. One of us (KTR) acknowledges the Claude Leon Foundation for a fellowship.

References

[1] R. Hull, J.C. Bean (Eds.), Germanium Silicon: Physics and Materials, Semiconductors and Semimetals, vol. 56, Academic press, San Diego, 1999.
[2] F.D. Auret, W.E. Meyer, S. Coelho, M. Hayes, Appl. Phys. Lett. 88 (2006) 242110.
[3] F.D. Auret, P.J. Janse van Rensberg, M. Hayes, J.M. Nel, W.E. Meyer, Appl. Phys. Lett. 89 (2006) 152123.
[4] J. Fage-Pedersen, A.N. Larsen, A. Mesli, Phys. Rev. B 62 (2000) 10116.
[5] V.P. Markevich, I.D. Hawkins, A.R. Peaker, K.V. Emtsev, V.V. Emtse, V.V. Litvinov, L.I. Murin, L. Dobaczewiski, Phys. Rev. B 70 (2004) 235213.
[6] V.P. Markevich, A.R. Peaker, V.V. Litvinov, V.V. Emtsev, L.I. Murin, J. Appl. Phys. 95 (2004) 4078.
[7] C.E. Lindberg, J. Lundsgaard Hansen, P. Bomholt, A. Mesli, K. Bonde Nielsen, A. Nylandsted Larsen, Appl. Phys. Lett. 87 (2005) 172103.
[8] A.R. Peaker, V.P. Markevich, L.I. Murin, N.V. Abrosimov, V.V. Litivov, Mater. Sci. Eng. B 124 (2005) 166.
[9] F.D. Auret, S.A. Goodman, G. Myburg, W.E. Meyer, Appl. Phys. A 56 (1993) 547.
[10] V.I. Kolkovsky, M.C. Peterson, A.N. Larsen, Appl. Phys. Lett. 90 (2007) 112110.

Please cite this article as: K.T. Roro, et al., Physica B (2009), doi:10.1016/j.physb.2009.09.033