ELECTRONICS AND ELECTRICAL ENGINEERING
ISSN 1392 – 1215 2007. Nr. 4(76)
ELEKTRONIKA IR ELEKTROTECHNIKA

T 171 MICROELECTRONICS
MIKROELEKTRONIKA

Investigation of Silicon Defects Parameters in Electron Irradiated Diodes

J. Višniakov
Semiconductor Physics Institute
Goštauto str. 11, LT-01108 Vilnius, Lithuania, tel. +370 683 69371, e-mail: j.visniakov@post.skynet.lt

A. J. Marcinkevičius
Computer Engineering Department, Vilnius Gediminas Technical University
Naugarduko str. 41–437, LT–03227 Vilnius, Lithuania. tel. +370 5 2744772, e-mail: Albinas.Marcinkevicius@el.vtu.lt

Introduction

The use of damage factors in semiconductors is of great practical interest. But they are only relevant for a given type of device or technology. Therefore, a minimum radiation testing has to be performed for each new technology generation or device type, in order to model the radiation response. On the other hand, the development of truly predictive tools is based on a thorough understanding of the fundamental radiation damage mechanisms. This could be done by analyzing energy values of electrically active levels and concentration of traps dose dependences, which could be measured by deep level transient spectroscopy (DLTS). This investigation determined and ranked the typical silicon irradiation defects.

Transient spectroscopy is widely used because of its high sensitivity, possibility to determine parameters of deep levels and can be adapted for ready-made devices or initial semiconductor. DLTS is often applied for features studies of deep impurities, irradiation defects and deep centres.

Investigative sample

As substrate was used standard *n* type float zone (*FZ*) silicon of crystallography plane (111). Thickness of silicon *400.0 ± 10 μm* and substrate's resistivity *150 ± 25 Ωcm* were chosen to provide correct capacitance versus reverse voltage dependence and proper irradiation defects determination. Smaller dimensions of the sample (*7×7mm*) were selected to insure smaller junction capacitance.

Junction's *p+* region was formed by boron (BBr_3) diffusion, which is *34.6 μm* deep. Such boron diffusion depth is achievable only after next manufacturing operation – phosphorus diffusion that forms *n+* region of cathode. Without previous operation boron diffusion was repeated twice. Sides were covered by aluminium layer (*5.5μm*) and ohm contacts were created.

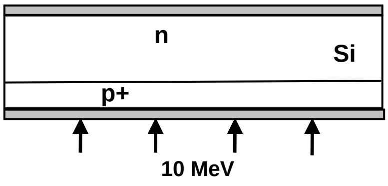

Fig. 1. pn junction of the sample and electron beam direction

The whole structure of diode was electron irradiated from anode side, as shown in fig.1. Accelerator's beam of electrons power is set to 10 MeV. Process passed at room temperature and irradiated samples from 100 kRad to 2.2 MRad dose.

DLTS measurement

The salient feature of DLTS is how transient signals are converted into a quasi-spectrum, as a function of temperature. In the original technique by *Lang*, the capacitance transient is measured at two fixed times t_1 and t_2 after the pulse and the signal $C(t_1)$-$C(t_2)$ is measured. From Fig. 2 it is easy to see that when the temperature is varied, a peak-shaped signal will result [1]. In addition, it can be demonstrated that the peak maximum corresponds with a time constant $\tau_{\max}$, only defined by the selected instrumental times t_1 and t_2, namely:

$$\tau_{\max} = (t_1 - t_2)[\ln(t_1 / t_2)]^{-1}. \quad (1)$$

The corresponding emission rate $e_{\max}=\tau_{\max}^{-1}$ is often called the emission rate window. Changing t_1 and/or t_2 will change $e_{\max}$ and hence the peak position $T_{\max}$, corresponding with a certain deep level ξ_T. Repeating the temperature scan for different well-chosen rate windows, a set of peak maxima $T_{\max}$ can be obtained.

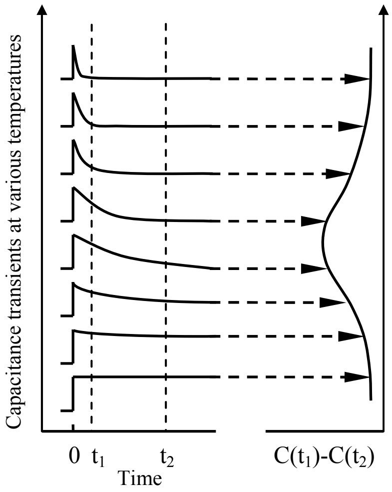

Fig. 2. DLTS rate window definition

Uniform filling of level ξ_T is set by time constant τ, called relaxation time of the level filling. It can be finding from expression:

$$\tau = r \cdot \exp\left(\frac{\xi_c - \xi_T}{kT}\right), \qquad (2)$$

where r – coefficient, depending on parameters of semiconductor and capture cross selection of electron to the level ξ_T – between conduction and valency band [2].

Therefore, τ values are different for two deep centres of the same ionization energy. Relaxation time of the level filling does not depend on deep centre concentration and depends little on electric field. Ionization energy $\Delta\xi_T = \xi_c - \xi_T$ and capture cross selection of electrons can be found out from dependence $\tau(T)$.

According to expression (2) can be drawn $\tau_{\max}$ vs. $1/T_{\max}$ in a so-called Arrhenius diagram.

For each deep level present in the material above a minimum concentration limit, one will obtain a DLTS peak. A spectrum generally consists of a series of peaks (in the temperature interval studied). For silicon, it goes from the freeze-out region (T=20-30 K) up to room temperature.

Carriers' traps spectrum analysis

DLTS spectrum of investigated diodes has been measured at Vilnius University with spectrometer DLS-82E. Typical silicon diodes peaks were obtained by changing filter frequency of phase sinchrodetector and injection pulse length. Figure 3 illustrates spectrum peaks versus dose dependence, measured at the fixed DLS-82E parameters selection. From these dependences activation energies of carrier traps have been found: E_1=0.14-0.16 eV, E_2=0.23-0.24 eV and E_3=0.41-0.44 eV. They are attributed to vacancy-oxygen complex (E_1), di-vacancy (E_2) and vacancy-phosphorus (E_3) complex – typical radiation defects.

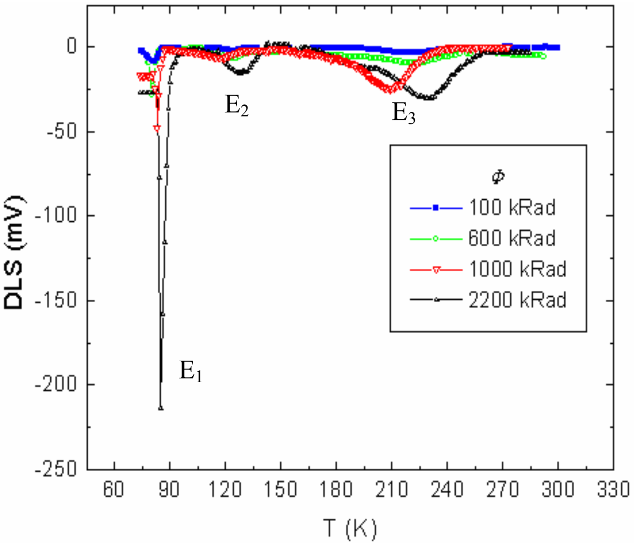

Fig. 3. Intensity variations of DLTS spectrum peaks, according to electron irradiation dose

There is separate filling relaxation time versus temperature dependence existing for each deep impurity level in the semiconductor. These dependences can be used as impurity typical feature. Unknown deep impurity is identified by comparison of its levels' $\tau(T)$ dependences with one of well known respective dependences.

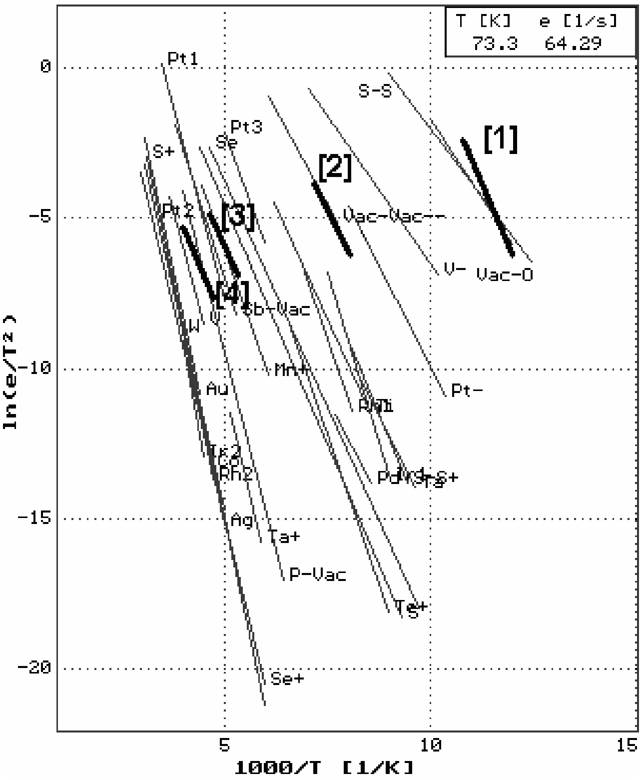

Fig. 4. Arrhenius plots for V-O (1), $V_2^{=/-}$ (2), $V_2^{0/-}$ (3) and V-P(4) traps, jointly with other traps library data

Fig. 4 shows Arrhenius diagram, from which DLS-82E spectrum analyzer estimates array of trap: activation energy, capture cross selection of majority carriers and density of traps. Then it is easy to identify trap by comparing with literature data obtained summarizing various methods (FTIR, PL, EPR, DLTS, C-V and others). For this purpose in DLS-82E is installed traps identification library (Fig. 4).

DLTS peaks intensity has been recalculated by calibrating absolute values of traps concentrations. When irradiation dose is being increased, the vacancy-oxygen and the vacancy-phosphorus complexes' concentrations approach the dopant concentration (Fig.5). Their trap concentration forms about 10% of dopant (phosphorus, n-Si) in diodes with the higher dose of irradiation. Concentration of di-vacancy trap ($V_2^{=/-}$) is twice less than vacancy-impurity complexes concentration.

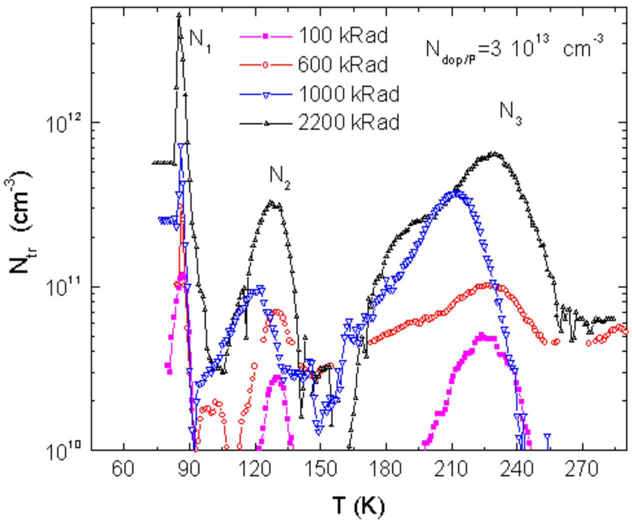

Fig. 5. Traps concentrations given for various irradiation doses

Defects creation versus dose dependences have been measured by calibrating traps concentration for peaks, as shown by figure 6. Coefficient β of defects creation rate allows scheduling defects concentration by formula:

$$N_{tr}(\Phi)= N_0+\beta\times\Phi, \qquad (3)$$

where Φ – electron irradiation dose, N_0 – defects concentration for clean sample. Following β values have been calculated: for A-centre (V-O) β_{V-O}=2×10^9 1/cm^3×kRad, for di-vacancy - β_{V2}=1.5×10^8 1/cm^3×kRad, for E-centre (V-P) β_{V-P}=5×10^8 1/cm^3×kRad. Traps attachments (A and E) are matched with DLTS centres n-Si nomenclature, as accepted in literature. Measured β coefficients values have practical interest for studying silicon material. It is important for forecast of lifetime of the carriers, leakage and current variations of non combinative-diffused components.

It can be demonstrated that the A-centres are created more efficiently by electron beam. Meanwhile, for di-vacancy formation rather large primary vacancies concentration is needed. Moreover, there is di-vacancy creation activity barrier, which determines slower generation of di-vacancy. Direct generating of di-vacancies by irradiation with electrons is less expected. Complexes of phosphorus and vacancy are created slower than oxygen complexes too. It is the way of the oxygen concentration, which even in FZ silicon is greater (>10^{16} cm^{-3}) than dopant ($N_{dop,\ P}$~3×10^{13} cm^{-3}).

Points scatter in $N_{tr}(\Phi)$ dependence for E-centre is large, as in range of this peak forms additional peak, increasing the electron irradiation dose. This additional peak is well seen in fig. 5 at the 2200 kRad dose curve and its Arrhenius plot is given in fig. 4. This peak is intersecting with E-centre plot and it is well known in DLTS n-Si spectroscopic literature. But there still exists some controversy in the literature about the exact position of the acceptor level $V^{0/-}$ (for p type silicon it should be $V^{0/+}$ donor level) for which values are reported at around E_v + 0.20 eV or E_v + 0.24 eV [3].

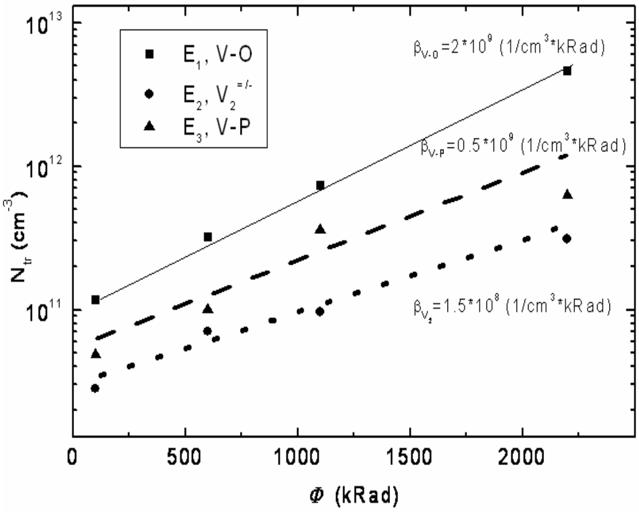

Fig. 6. Defects creation rates versus dose

This additional centre (E_4) in DLTS radiation defects nomenclature is also known as marking „170", attached to the peak temperature domination, that is to 170K. Defect originates at large doses area and often is interpreted as peak of radiation defects cluster.

However, to our mind, summarizing deeper and wider DLTS spectrum analysis for Si formations irradiated with various particles, more acceptable interpretation for additional „170" centre is related to di-vacancy duplex. It means that together with $V_2^{=/-}$ peak (at 120 K) at larger temperature range (~170K) di-vacancy centre of another electric state $V_2^{0/-}$ appears.

Concentrations of these $V_2^{0/-}$ centres are close to $V_2^{=/-}$ centres density but smaller than E–centres concentration. Therefore, this $V_2^{0/-}$ peak is highlighted from E-centre lower temperature DLTS spectrum slope only when sufficient concentration of $V_2^{0/-}$ centres is being generated, respective to E-centres density.

Conclusions

1. DLTS spectrum for investigated diodes with different irradiation dose has been obtained. Carriers traps activation energies, attributed to vacancy-oxygen, di-vacancy and vacancy-phosphorus complexes have been estimated. It was established that these are the main defects consequences the pn junction dynamics in silicon.

2. Defects Arrhenius diagram, for obtaining other trap parameters: capture cross selection of majority carriers, activation energies and traps densities, has been made. Arrhenius diagram also allows calculating of the relaxation time of the energy level filling and thus to control the lifetime of the carriers.

3. Irradiation dose dependence plots for diodes have been drawn out of measured main carriers' traps concentrations. Traps creation rates according to initial impurities concentrations have been evaluated. Therefore, the oxygen-vacancy complexes have the fastest creation in FZ silicon.

4. Defects formations coefficients versus dose dependences have been obtained and their creation rates coefficients have been calculated. It has practical interest for studying silicon material.

5. Additional centre of radiation defects was obtained at large doses, related to di-vacancy duplex. Thus, was calculated the minimum generation dose of this defect and its activation temperature.

References

1. **Claeys C., Simoen E.** Radiation Effects in Advanced Semiconductor Materials and Devices. – Springer-Verlag, Berlin, Heidelberg, New York, 2002, Chap 2. – P. 37–38.
2. **Usenko A. Y.** Irradiation-Then-Anneal processing to Improve BSIT Performance // IEEE Transactions on Electron Devices. – 1994. – Vol. 41, № 6. – P. 1055 – 1061.
3. **Vanhellemont J., Kaniava A., Simoen E. and others.** Generation and Annealing Behaviour of MeV Proton and ^{252}Cf Irradiation Induced Deep Levels in Silicon Diodes // IEEE Transactions on Nuclear Science. – 1994. – Vol. 41, № 3. – P. 479 – 486.

Submitted for publication 2007 03 05

J. Višniakov, A. J. Marcinkevičius. Investigation of Silicon Defects Parameters in Electron Irradiated Diodes // Electronics and Electrical Engineering. – Kaunas: Technology, 2007. – No. 4(76). – P. 13–16.

The electron irradiation defect's parameters, produced in n-type float zone silicon by 10 MeV electron irradiation, have been investigated on p-n junction of diode. It was manufactured suitable for measurement p-n junction and irradiating it by the different dose of electrons, from 100 kRad to 2,2 MRad defects energy spectrum was obtained. Silicon defects parameters and their dependences were determined by deep level transient spectroscopy (DLTS). It were experimentally found specific for silicon electron levels peaks and their activation energies. Obtained traps' peaks were attached to typical radiation defects: A-center, di-vacancy and E-center. Also it has been got and analyzed capacitance versus dose dependences and has been rated their meaning. Arrhenius plot was set, that allows obtaining main trap parameters: activation energy, carriers capture cross selection and trap density. Defects formation rate coefficient β was calculated that follows the forecast of lifetime of carriers and variation of current leakage of diodes. Additional „170" defect centre for largest irradiation dose was observed and attached to di-vacancy duplex with another electric state – $V_2^{0/-}$. Ill. 6, bibl. 3 (in English; summaries in English, Russian and Lithuanian).

Е. Вишняков, А. И. Марцинкевичус. Исследование параметров радиационных дефектов в электронами облученных кремниевых диодах // Электроника и электротехника. – Каунас: Технология, 2007. – № 4 (76). – С. 13–16.

Анализируются параметры радиоактивных дефектов, облучая диодный p-n переход, сформированный в кремнии зонного плавления n типа, 10 MeV энергии электронами. Сформирован подходящий для анализа радиационных дефектов p-n переход и диоды облучены разными дозами: от 100 kRad до 2,2 MRad. Параметры дефектов кремния и их характеристики зависимости установлены методом ёмкостной спектроскопии глубоких центров (DLTS). Экспериментально получены характерные кремнию пики электронных уровней и их энергии активации. Пики установленных ловушек причислены к типичным радиационным дефектам: A-центру, дивакансиям и E-центру. Также получены и проанализированы зависимости концентраций ловушек от дозы облучения. Получена Арениус диаграмма дефектов, при помощи которой находятся основные параметры ловушек: энергия активации, сечения захвата носителей и плотность дефектов. Досчитан коэффициент скорости появления дефектов β, важный при прогнозировании времени жизни носителей и изменения утечек тока. При наибольшей дозе облучения установлен дополнительный „170" центр, относящийся к дуплету дивакансии. Ил. 6, библ. 3 (на английском языке; рефераты на английском, русском и литовском яз.).

J. Višniakov, A. J. Marcinkevičius. Elektronais apšvitintų silicio diodų radiacinių defektų parametrų tyrimas // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2007. – Nr. 4(76) – P. 13–16.

Ištirtos diodų p-n sandūros, suformuotos zoninio lydymosi n tipo silicyje, radiacinių defektų parametrai, apšvitinant prietaisus 10 MeV greitintuvo elektronais. Suformuota radiaciniams defektams tirti tinkama p-n sandūra ir diodai apšvitinti įvairiomis dozėmis: nuo 100 kRad iki 2,2 MRad. Silicio defektų parametrai ir jų priklausomybių charakteristikos ištirtos gilių lygmenų talpinės spektroskopijos (DLTS) metodu. Eksperimentiškai nustatytos siliciui būdingos elektronų lygmenų smailės bei jų aktyvacijos energijos. Rastų gaudyklių smailėms priskirti tipiniai radiaciniai defektai: A-centras, divakansijos ir E-centras. Taip pat nustatytos ir išanalizuotos gaudyklių koncentracijų ir dozių priklausomybės, įvertintos jų reikšmės. Gauta defektų Arenijaus diagrama, iš kurios surandami pagrindiniai gaudyklių parametrai: aktyvacijos energija, pagrindinių krūvininkų pagavimo skerspjūvis ir gaudyklių tankis. Apskaičiuotas defektų atsiradimo spartos koeficientas β, turintis praktinę reikšmę, prognozuojant krūvininkų gyvavimo trukmės bei nuotėkio srovių dioduose pokyčius. Esant didžiausiai apšvitinimo dozei, nustatytas papildomas „170" centras priskiriamas divakansijos dupletui. Il. 6, bibl. 3 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).

DOI: 10.5755/j02.eie.10707