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DLTS INVESTIGATIONS OF THE CARBON-RELATED CENTERS IN Si

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ABSTRACT

We report DLTS studies of the carbon interstitial (Ci),H(0.28) defect and a carbon-related center,H(0.37) in electron irradiated Cz-Si.An inverse annealing stage of the Ci signal observed in the range of ~275K is consistent with other observations showing that the concentration of the H(0.37) peak,arising in the spectra when H(0.28) peak begin to decay,is larger than that of the latter defect.Investigations of the temperature-dependence of the capture cross-sections of the two defect states contributing in the H(0.37) peak are discussed.

INTRODUCTION

Carbon is one of the dominant impurities unintentionally added in the Si lattice during processing.Since its presence affects the yield and properties of Si devices it becomes imperative to know its general behavior,its electrical and optical properties,its tendency in forming complexes and any other information.Carbon which is substitutionally incorporated in as-grown Si,is electrically inactive.However,after irradiation it forms electrical active pairs and complexes.The Ci for example,creating through the Watkins displacement mechanism is an amphoteric impurity in Si (1,2) giving a donor level ~Ev+0.27eV and an acceptor level ~Ec-0.12eV. At around room temperature Ci begins to migrate forming various complexes like Ci-Cs , Ci-Oi and C-O-V depending upon the C and O content of the Si material and the conditions of irradiation.All these defects was thought until recently that form a majority state in the gap positioned ~Ev+0.35eV above the valence band in p-Si (3,4,5).However,it has been found lately (6,7) that Ci-Cs pair is a metastable defect which in p-Si exhibits two levels in the gap at ~Ev+0.09eV and at ~Ev+0.05eV.It has also be shown (8) that only the Ci-Oi pair can be considered for certain as having a state at ~Ev+0.36eV.Moreover,a number of authors (4,5,6,7) have reported capture cross-section measurements indicating that two defects contribute in the

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DLTS peak with energy ~Ev+0.35eV.It is evident that the whole picture concerning the identity of the above defect state is far from considered complete.

In this work, measurements have been undertaken,by using the DLTS technique,to study some of the properties mainly of the Ev+0.36eV level in p-Si.

EXPERIMENTAL

Schottky diodes fabricated by Aluminum evaporation on prepolished boron-doped Si samples (3-5 Ωcm) were irradiated in-situ with 1.5MeV electrons.Measurements were caried out by a standard DLTS equipment as that described by Lang(11).Temperature scans were performed for various rate windows ($0.4-2500s^{-1}$) both with increasing and decreasing temperature in the range of 80-300K,at a constant heating or cooling rate.Energy levels were determined from Arrhenious plots ($\ln e/T^2$ vs $1/T$).Concentrations N_T were calculated from the well-known relation (11)

$$N_T = 2\Delta C/C \,.(N_A-N_D)$$

where ΔC is the DLTS output,C is the quiescent capacitance of the reverse-bias diode and N_A-N_D is the uncompensated acceptor concentration.Capture cross- sections σ were determined by monitoring the amplitudes ΔC of the peaks as a function of the filling pulse width t_p (11) and then employing the relation

$$\Delta C = \Delta C_\infty(1-\exp(t_p/\tau)$$

where ΔC_∞ is the saturated amplitude of the peak for very long pulse durations and

$$\tau = p\,v\,\sigma$$

where $p \simeq (N_A-N_D)$ and v the carrier velocity.

EXPERIMENTAL RESULTS AND DISCUSSION

The solid curve of fig.1 displays the post irradiation spectrum received after the migration of the vacancy peak at ~Ev+0.13eV (12).The two peaks H_1(0.20) and H_2(0.28) are associated with the well-known levels of thedivacancy and the Ci respectively. Peak H_3(0.34) is an oxygen-dependent,vacancy-related peak (13) annealing out at around room temperature , which is not our concern in the present work.The dotted curve displays the spectum after an anneal at 450K for 90 minutes.Peak H_2(0.28) has disappeared while peak H_4(0.37) has emerged.Although it is reasonable to claim that the latter defect is carbon-related the fact that the observed amplitude of the H_4(0.37) peak is larger than that of the H_2(0.28) is not consistent with thw above argument.This result needs further examination.

Isochronal annealing studies of the Ci signal were performed below the temperature where the defect begins to migrate.The measurements showed the presence of a positive annealing stage (I) followed immediately by a negative annealing one (II) in the temperature range of 275K (fig.2).

The observed negative annealing stage presupposes the existence of an unidentified source of Ci's.Such a source might be an electrically inactive center which comprising Ci's in its structure, it provides them presumably by dissociation.Another possibility is that Si_i liberated from some unknown defects may provide Ci's through the reaction,$C_s+Si_i \rightarrow C_i$, i.e. by knocking out substitutionally incorporated carbon atoms (C_s).It is worth noticing that an

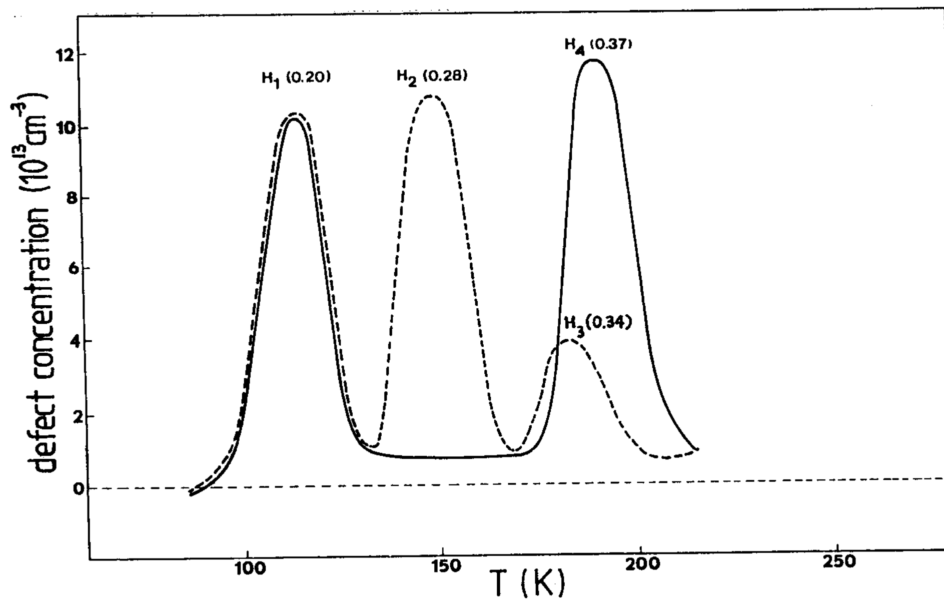

Fig.1 DLTS spectra of boron-doped Cz-Si immediately after the 80K electron irradiation and the migration of the vacancy (solid curve) and after an anneal at 450K for 90 minutes (dotted curve)

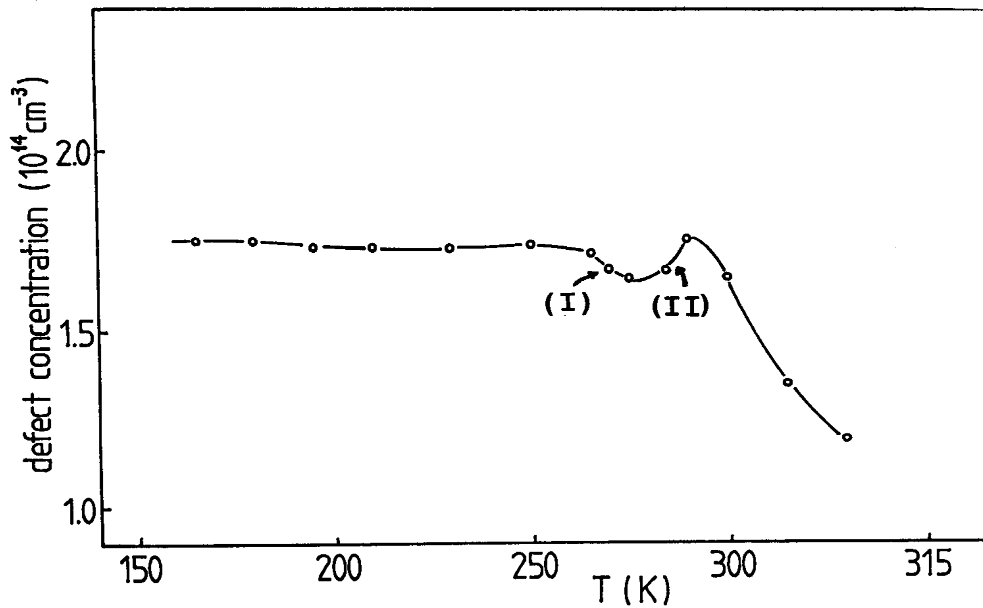

Fig.2. 15 minutes isochronal annealings of the C_i signal

increase in the strengh of the C(1) band in n-Si at low temperatures has been attributed (14) in this mechanism. In any case this increase of the Ci's is consistent with the observed larger concentration of the $H_4(0.37)$ peak in connexion with that of the $H_2(0.28)$ one.

We should also notice that the decrease of the Ci signal (positive stage) has not be seen to be followed by the begining of the emergence of the $H_4(0.37)$ peak or any other peak in the spectra. This presumably means that the liberated Ci's at this stage may go to some unknown defects to form electrically neutral complexes. Remarkably, optical studies (15) have shown the presence of an intermediate defect configurations (precursor defects) when the Ci begin to migrate until its final product.

A capture cross-section analysis by employing the pulse-width variation method gave for $H_4(0.37)$ two branches indicating that two defects contribute in the corresponding DLTS paek ($\sigma_1=1.4\times10^{-16}cm^2$ $\sigma_2= 4.9\times10^{-18}cm^2$).

In the last years the temperature dependence of the capture cross-sections attracts significant interest since it can provide information about the mechanisms involving in the dissipation of energy during the capture transition. There are various madels in the literature describing nonratiative carrier capture processes in defect states in semiconductors.

a) <u>The Auger model</u>: In this model (16) the energy which the carrier lost in the capture process is transferred to nearby carriers. This mechanism has a possibility to occur in heavily doped semiconductors.

b) <u>The Multiphonon emission model</u>. This model (17) anticipates a coupling of the defects with the surrounding lattice. The dissipation of energy occurs with phonon emission. The temperature-dependence of the capture cross-section σ is given by the relation

$$\sigma=\sigma_{\infty} \exp(-\Delta E/KT)$$

where ΔE is an energy barrier which should be overcome by the capturing carrier. At temperatures below T_{Debye} the capture cross-sections are temperature-independent.

c) <u>The cascade model</u>. This model pressuposes a number of closely sited excited states to facilitate the phonon emission. As it turns out the temperature dependence of σ follows a power-law (18,19) of the form $\sim T^{-n}$, $1<n<4$.

Fig.3 displays the temperature dependence of the capture cross section of the $H_4(0.37)$ peak. However, the data for the fast process fit with a relation $\sigma=\sigma \exp(\Delta E/KT)$ where $\Delta E = 0.034eV$. This does not mean that we should rule out multiphonon emission. It has been argued (17) that in the case of a defect which attracts the carriers a local increase of the carrier concetration could account for the increase in the capture cross-section.

Our data could also be fitted (fig.4) with a power-law $\sigma \sim T^{-2.02}$

The Auger model can definitely be excluded for the interpretation of our results since the free carrier concentrations in our material is less than $10^{16}cm^{-3}$. However, a final decision about which of the other two mechanisms i.e the multiphonon emission process or the cascade process is behind the dissipation of energy in the fast process of $H_4(0.37)$ level cannot be made.

As far as the identity of the $H_4(0.37)$ defect state, a comment could be made. At first, the two participants of the DLTS peak con-

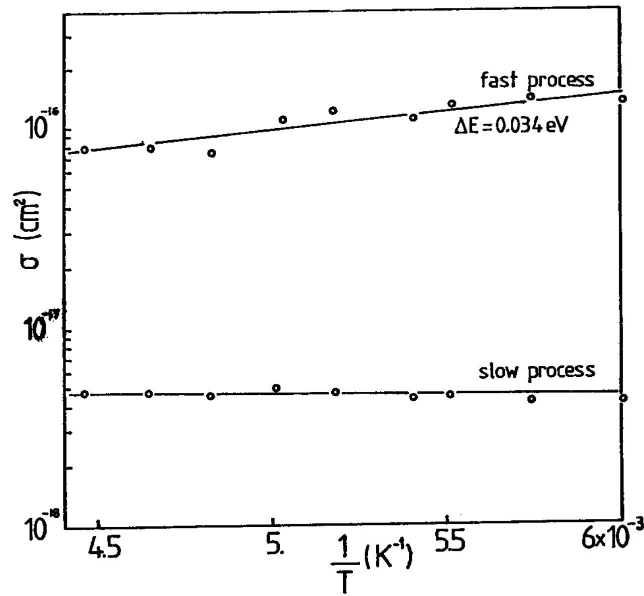

Fig.3. Temperature dependence of the capture cross-sections of the two contributors of the $H_4(0.37)$ level assuming multiphonon emission process.

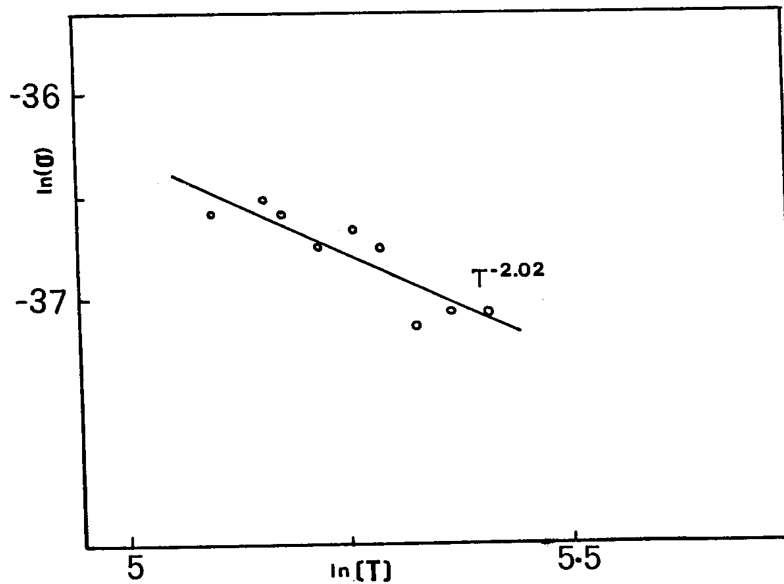

Fig.4. Temperature dependence of the capture cross-section of the fast process of the $H_4(0.37)$ level assuming cascade process

tribute simultaneously in its emergence in the spectra. The fact that they have similar activation energies, within the resolution limits of our equipment, if it is not mere coincidence, indicates that they have similar chemical structures. However, the difference in the determined values of the capture cross-sections and the different exhibited temperature dependences point out to different physical structures of the two centers. In view of the fact that C_i-O_i is possibly the one partner contributing in the creation of the H_4(0.37) peak we might speculate that another kind of C-O pairs is the second partner. Optical studies have already shown (19) the existence of various kinds of C-O pairs.

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