DLTS Study of quenching induced defects in Germanium

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Introduction

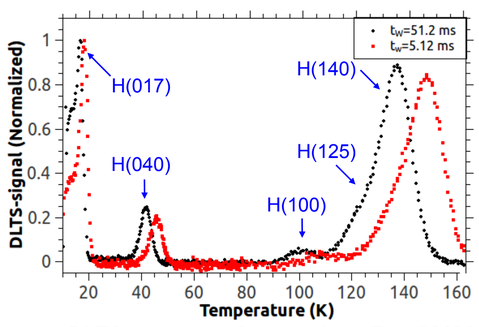
Due to its high mobility for electrons and holes, Ge is regaining importance as active layer in semiconductor technology. Its basic defect properties are less studied than those of Si. Quenching experiments in principle allow to determine the activation energy and diffusion constant of vacancies in Ge. In this context it is important to identify the defects formed upon quenching. We report a Deep Level Transient Spectroscopy (DLTS) characterization of quenched Ge samples. Three prominent DLTS peaks are observed after quench. One of them can be annealed out at 280°C. For the remaining two peaks a detailed comparison is made with literature data for substitutional Cu, since it is difficult to avoid this impurity when quenching Ge.

DLTS

Experimental

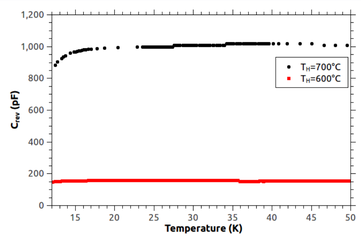
P-type germanium (6 ×10¹⁴/cm³) was used. Samples (10×10×2 mm³) were put in a pre-**heated** tube furnace (temperature T_H) during 60 minutes, after which they were **quenched** in silicon oil at room temperature (25°C).
Some quenched samples were additionally **annealed** in the same oven at 280°C during 60 minutes. The samples where etched ($HF+H_2NO_3$) and prepared for DLTS measurements by evaporating In to form Schottky junctions. Ohmic contacts were prepared using In-Ga eutectic and In foil. Capacitance transients are measured after a pulse from (V_R) -1V to (V_P) -0.2V
A pulse duration of 10 ms was used and the DLTS time window is noted by t_W.

Typical DLTS spectrum

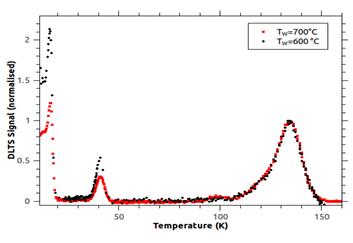


DLTS spectrum of germanium (T_H = 700°C) at two different window times.

Influence of quenching Temperature



Reverse Capacitance (C_{rev}) of two quenched samples.



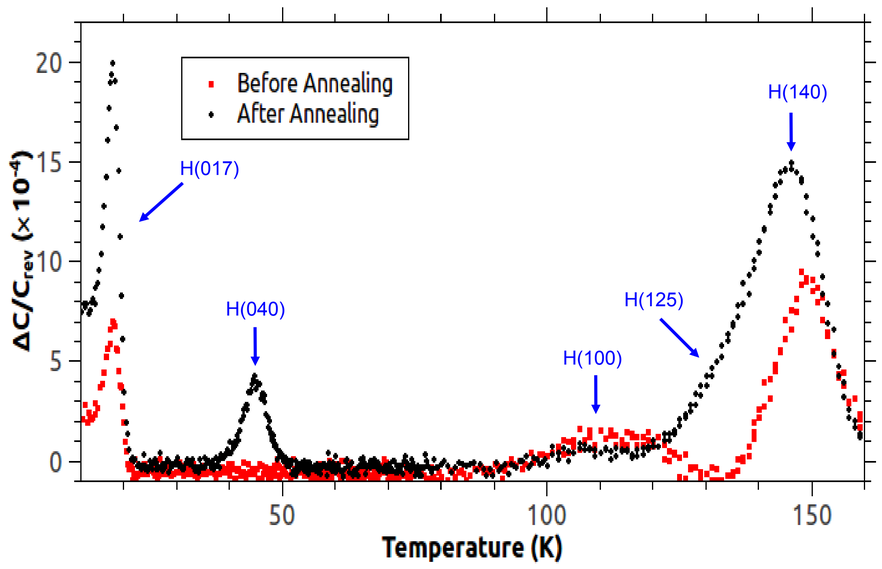
DLTS spectrum of two quenched samples. (T_W = 51.2 ms)

Van der Pauw measurements:

p(700°C) = 6.42 ×10¹⁴/cm³

p(600°C) = 6.04 ×10¹⁴/cm³

Effect of annealing

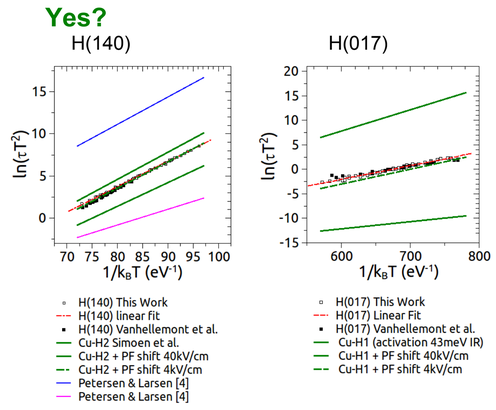


DLTS spectrum of sample quenched from 600°C before and after annealing at 280°C. (T_W=5.12 ms)

Annealing reduces the amplitude of the H(017) peak by 62% and the H(140) peak by 36%.The H(040) peak has totally disappeared after annealing, while the H(100) peak increased slightly.

Substitutional Copper?

Yes?



Arrhenius diagrams for H(017) and H(140) in comparison with Cu_s and irradiation induced defects in germanium [4].

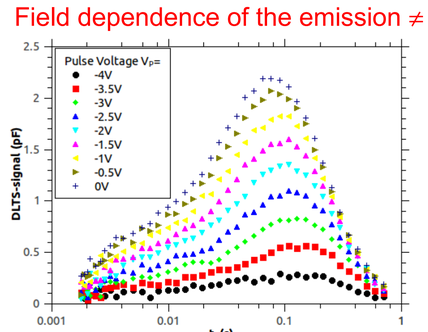
No agreement between the irradiation induced defects [4] and the quenched in defects was observed.
If one assumes a Poole Frenkel (PF) shift of 4kV/cm on the copper emission, as observed by Simoen et al.[5], a remarkable similarity with the H(140) and H(017) Arrhenius diagrams is obtained. For the H(017) the activation energy in absence of an electric field was set to the IR absorption energy.

$$p = C_R \cdot \frac{E}{\pi . e . r^2}$$

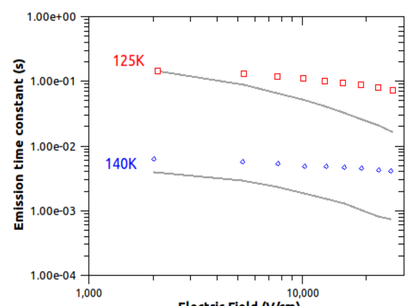
An average 4kV/cm shift corresponds with a free hole concentration of p = 2 ×10¹⁴/cm³, which is in fair agreement with the 6 ×10¹⁴/cm³ observed by resistivity measurements.

No?

Field dependence of the emission ≠ $Cu_s^{-/2-}$

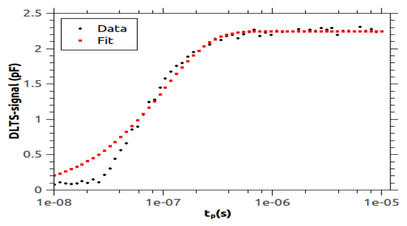


Field enhanced emission observed for H140 at T = 140K, pulsed from V_R=-5V.



Field enhanced emission observed at 125K and 140K for H(140) compared with the modeled PF-effect (lines) based on emission measured by E. Simoen et al. [5] and PF shift observed by Pearton et al. [6].

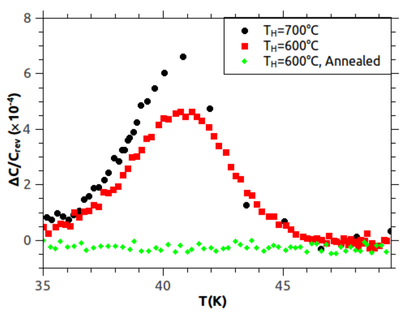
Capture cross-section ≠ $Cu_s^{-/2-}$



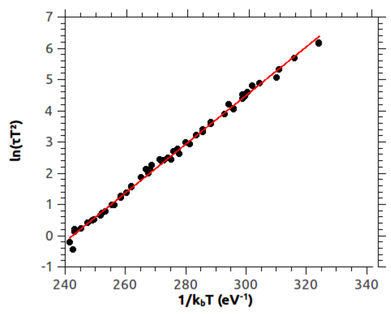
σ < σ($Cu_s^{-/2-}$) observed by E. Simoen et al. [5]

DLTS signal as a function of filling pulse duration and fit using the method of Lauwaert et al. [7] derived a capture cross section of σ = 4 × 10⁻¹⁶cm²
Literature: σ($Cu_s^{-/2-}$) = 1.8 ×10⁻¹³cm² [5]

H(040) peak



DLTS-spectrum of H(040). (t_W= 51.2 ms)



Arrhenius plot of H(040).

$E = E_V + 79$ meV
$K_T = 1.8 \times 10^8$ K⁻²s⁻¹

The annealing behavior of H(040) suggest an assignment to an intrinsic vacancy related defect.

Conclusions

The three most prominent deep levels in the lower half of the band gap of quenched p-type germanium have been characterized using DLTS. At first glance the similarities of the H(017) and H(140) levels with those of substitutional copper are striking. A detailed analysis of the properties of H(140) using isothermal DLTS reveals, however, remarkable differences. The field enhanced emission, which does not obey the Poole Frenkel law, and the capture cross section, which strongly deviates from the one observed for Cu, suggest that other assignments (e.g. vacancy related centres) may have to be considered.

References

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[2] J. Vanhellemont et al. PHYS B **404,** 4529 (2009)
[3] S. Brotzmann et al. JAP **103**, 033508 (2008)
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[5] E. Simoen et al. SST **1**, 53 (1986)
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[7] J. Lauwaert et al. RSI **79**, 093902 (2008)