Electrically active defects in semiconductors induced by radiation

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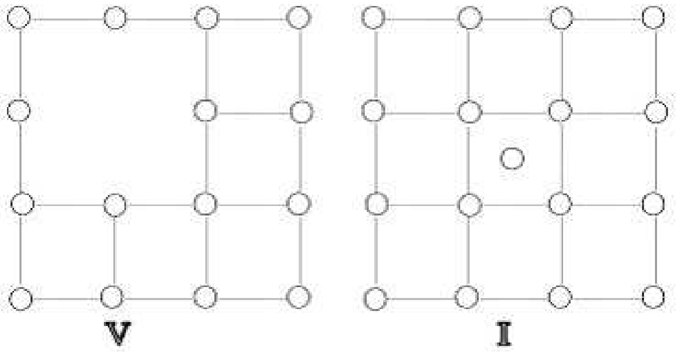
Outline

- Radiation damage
- Capacitance transient techniques
- Experimental results: radiation induced defects in n-type Si and Ge
- Conclusion

Radiation damage

Primary damage is the displacement of a lattice atom to create an interstitial and a vacancy. These can:

- Recombine … no damage
- React with impurities in the silicon eg VO or displace atoms eg B_i which are mobile and will react with other impurities or defects … these are likely to have electrical activity
- The intrinsic defects may react with each other eg V_2 to generate electrically active centres or possibly inert defects.



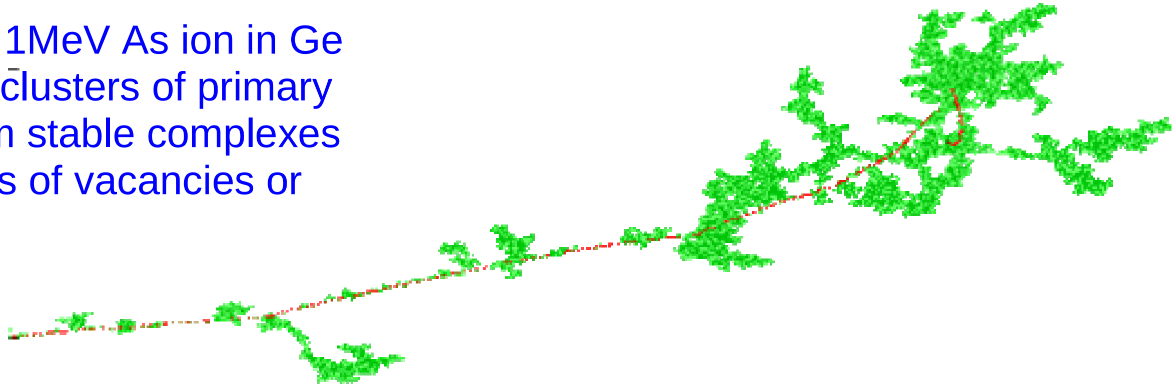
Effects of particle type

At low levels of irradiation with electrons or gamma rays almost all the lattice damage is in the form of simple point defects which can be studied by many techniques and are relatively well understood in Si.

Damage from energetic particles or heavy ions is much more complex, difficult to study and with many unknowns in terms of electrical activity and reaction energetics.

Main theme of our research in the last few years has been damage using fast neutron irradiation (at TRIGA Ljubljana) to help us to understand ion damage.

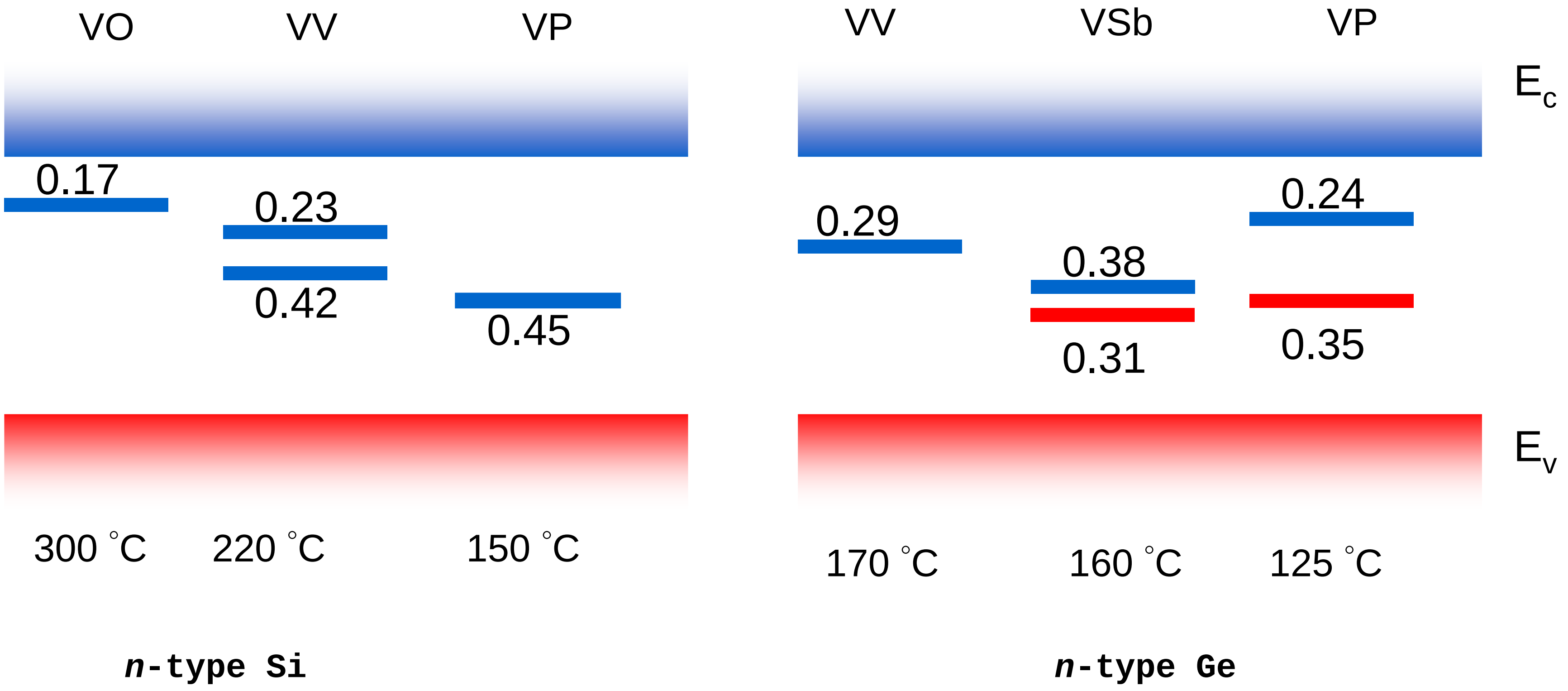
This SRIM simulation of a 1MeV As ion in Ge shows high concentration clusters of primary defects which react to form stable complexes eg V_2 , V_3 or larger clusters of vacancies or interstitials eg extrinsic stacking faults.



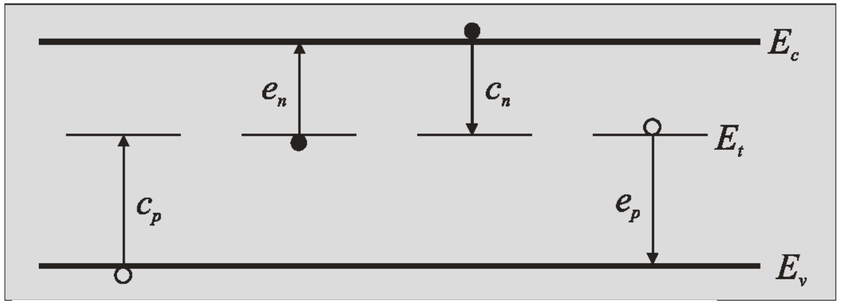
Factors affecting the defect species created by particle irradiation or implantation

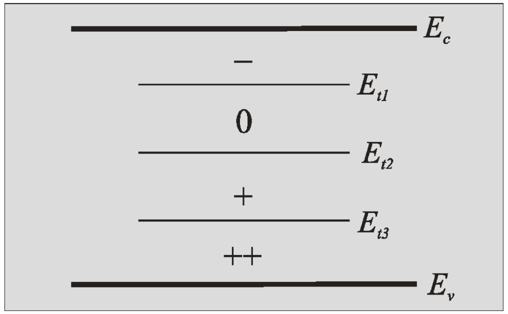
- Type and concentration of impurities
- Particle species
- Particle energy
- Particle dose (fluence)
- Particles dose rate (flux)
- Temperature

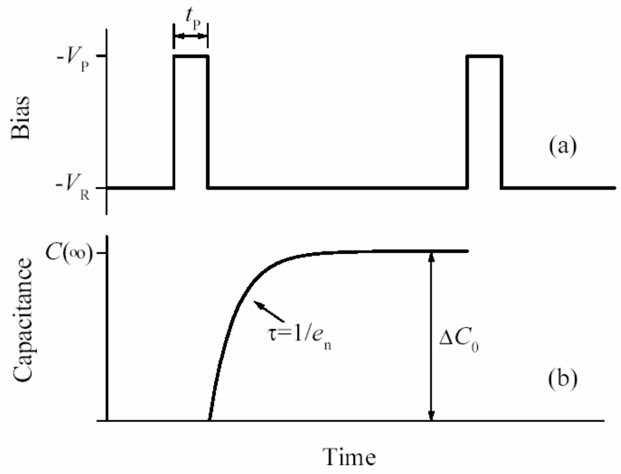
Electrically active defects in nSi and nGe

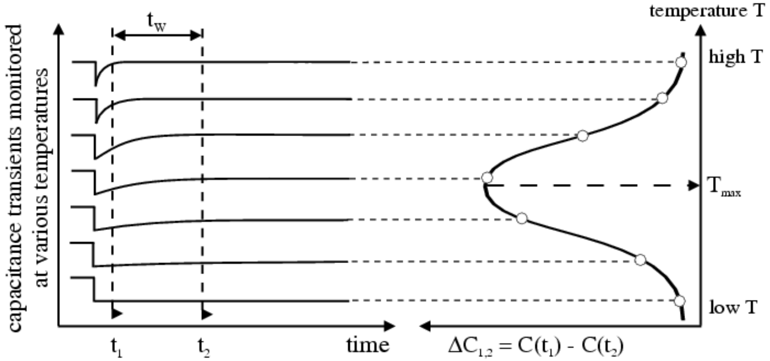


Deep level transient spectroscopy (DLTS)



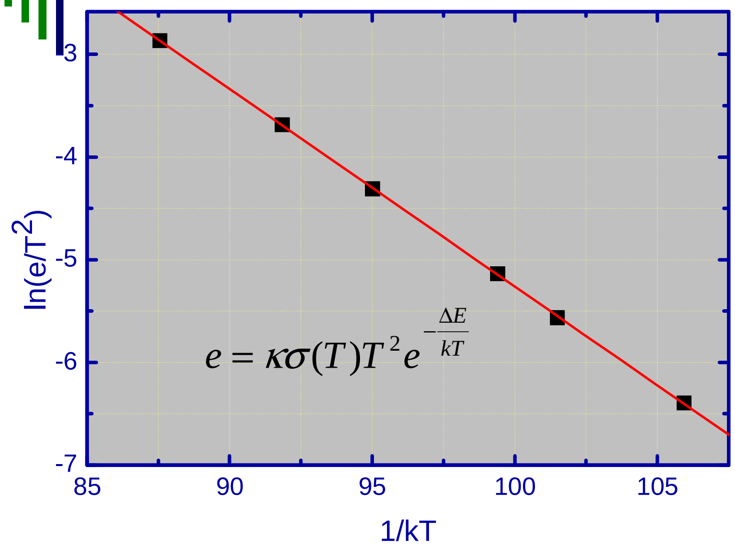


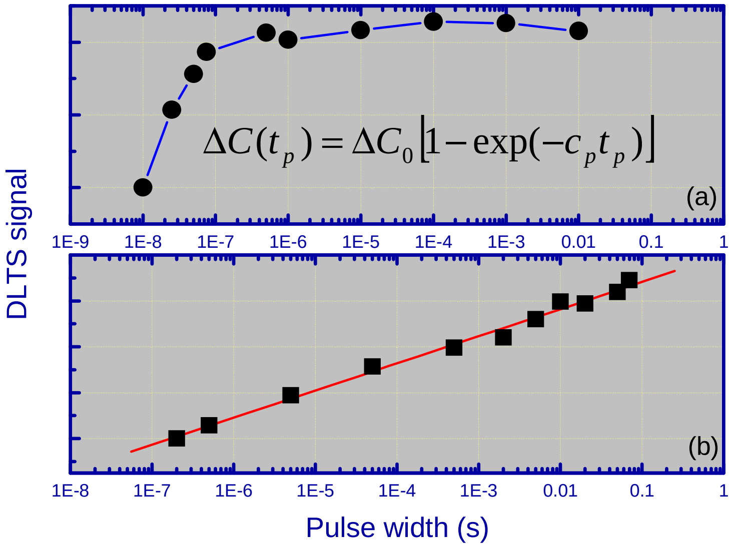




At typical doping levels of **10^{14}-10^{16} cm^{-3}** sensitivity of the technique is **10^{9}-10^{11} cm^{-3}**

DLTS analysis

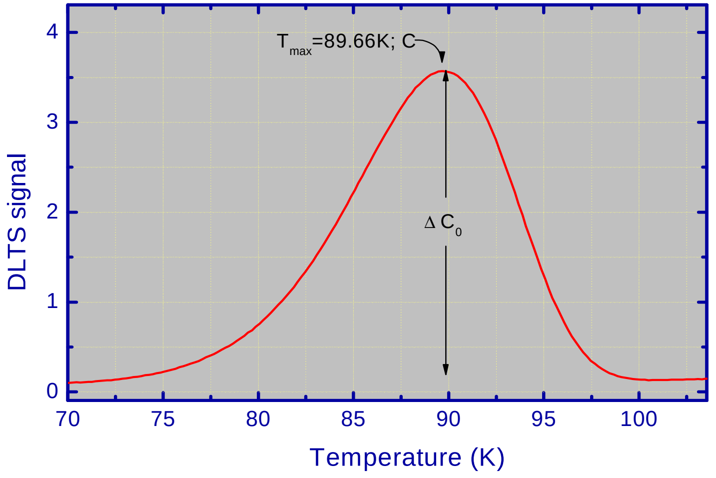




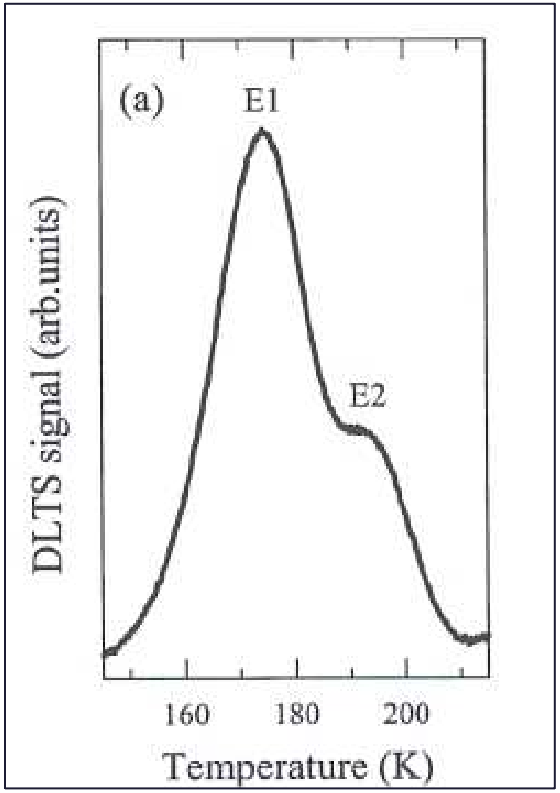
$$N_T = 2 \cdot \frac{\Delta C_0}{C} \cdot N_D$$

$$f(W) = (W_0 - \lambda_0)^2 - (W_1 - \lambda_1)^2 / W_0^2$$

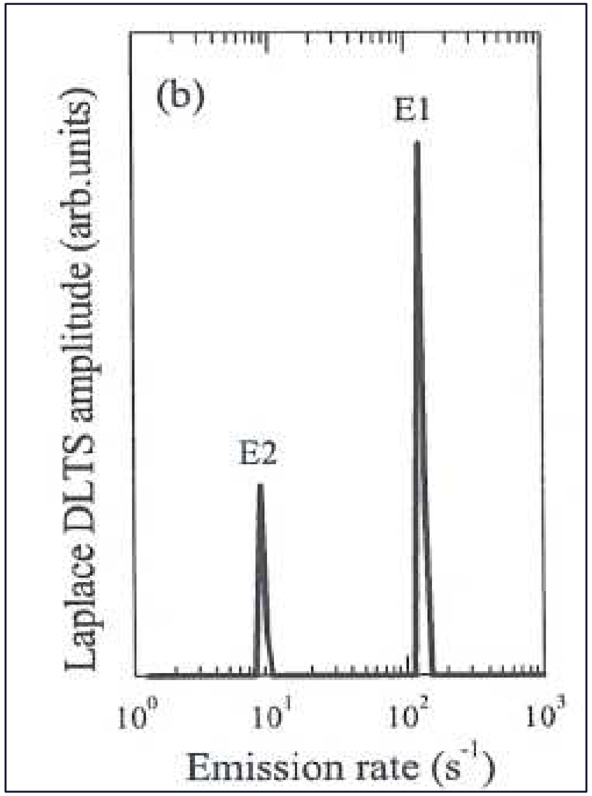
$$N_T = 2 \cdot \frac{\Delta C_0}{C} \cdot N_D \cdot \frac{1}{f(W)}$$



High-resolution Laplace DLTS



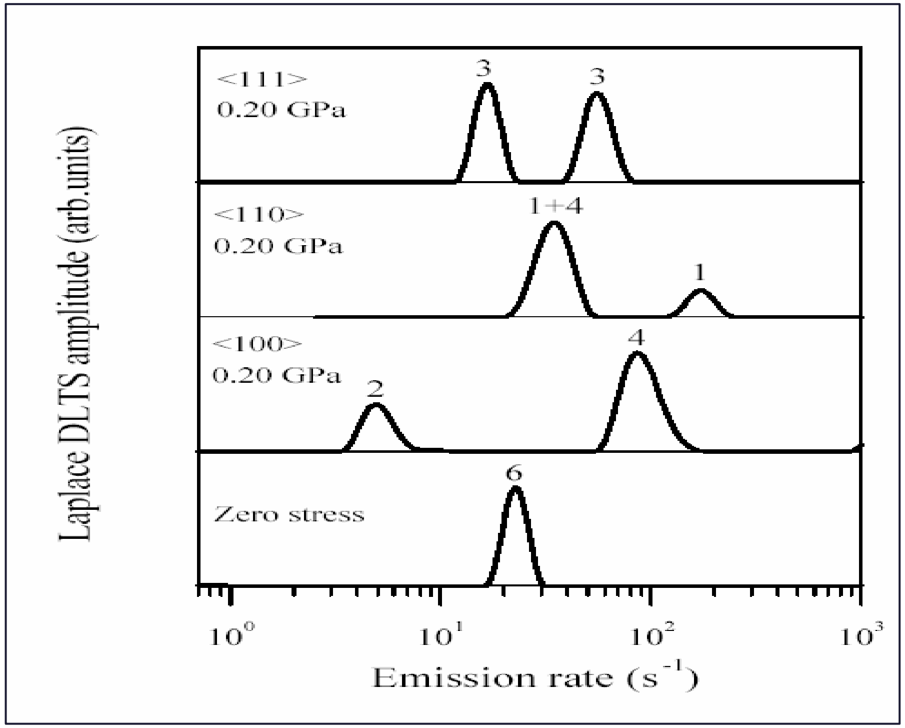
[DLTS]



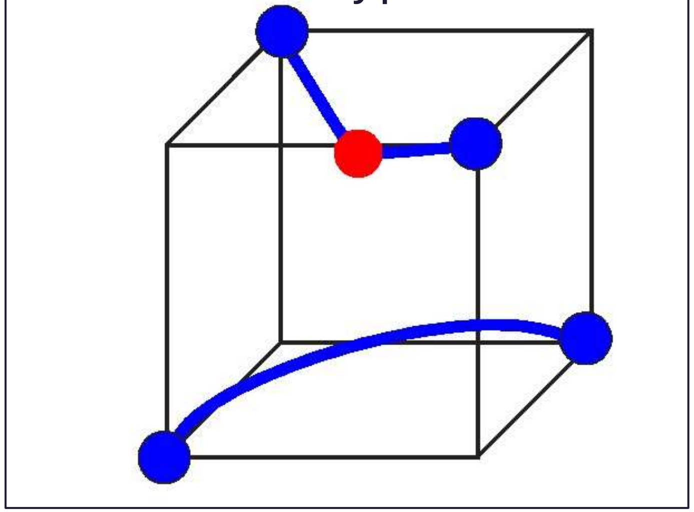
[Laplace DLTS @ 170K]

Uniaxial stress Laplace DLTS

The symmetry of a defect centre is obtained from the intensity ratio of the split DLTS lines under uniaxial stress applied along the three major crystallographic directions, <100>, <110> and <111>.

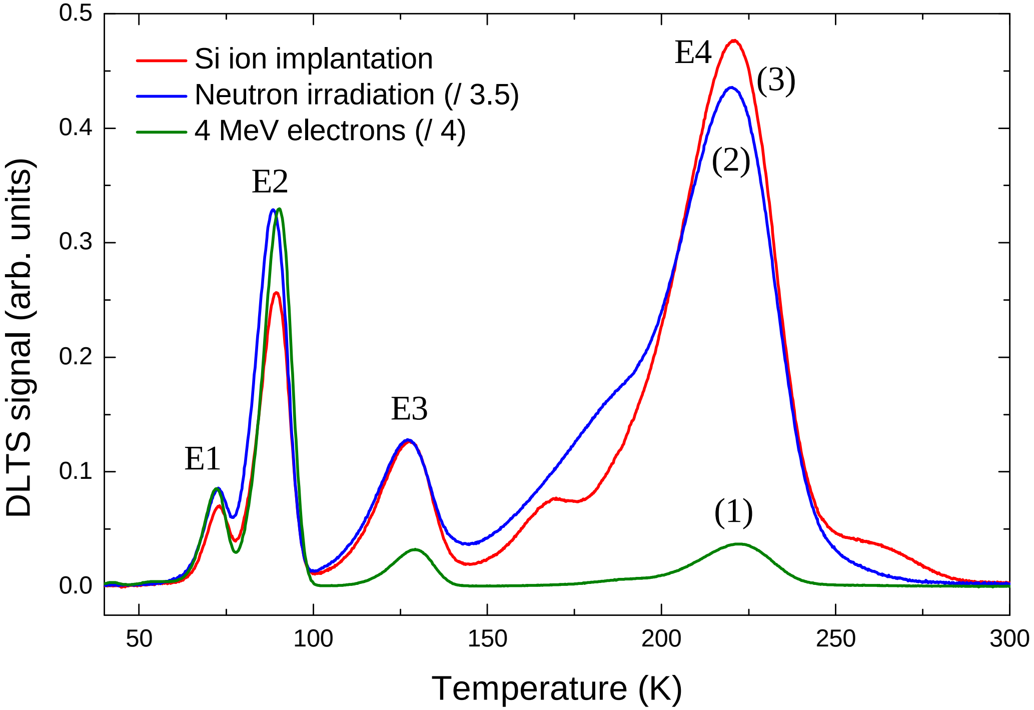


VO in n-type CZ:Si



The splitting pattern establishes the orthorhombic-I symmetry of the VO complex.

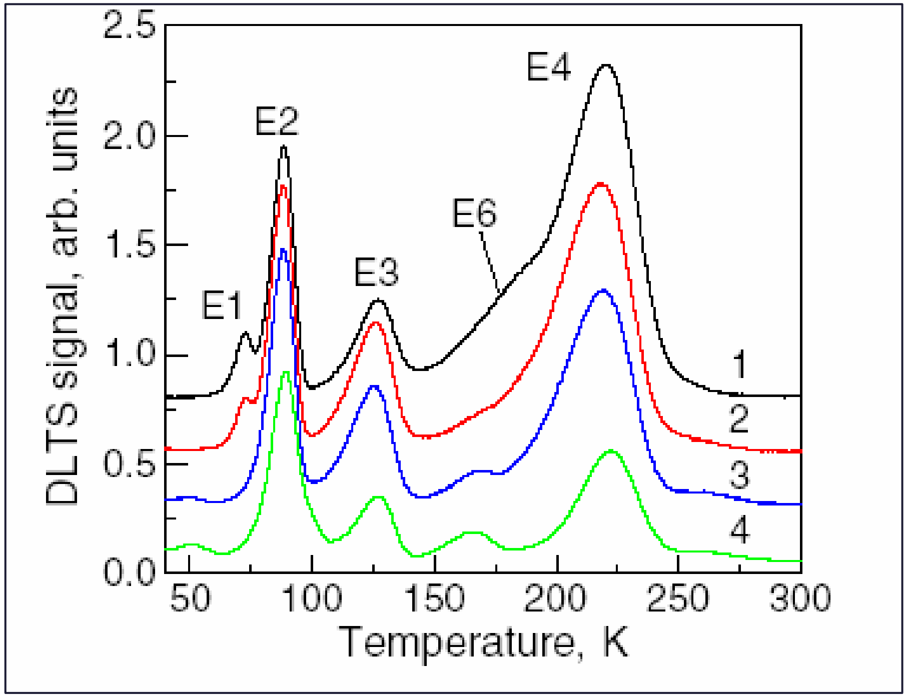
Irradiatated *n*-type CZ Si



(1) 4 MeV electrons (F = 1×10^{15} cm^{-2})
(2) 1 MeV neutrons (F = 2×10^{14} cm^{-2})
(3) 800 keV Si ions (F = 1×10^{9} cm^{-2})

[J. Phys.: Condens. Matter 17 (2005) S2229]

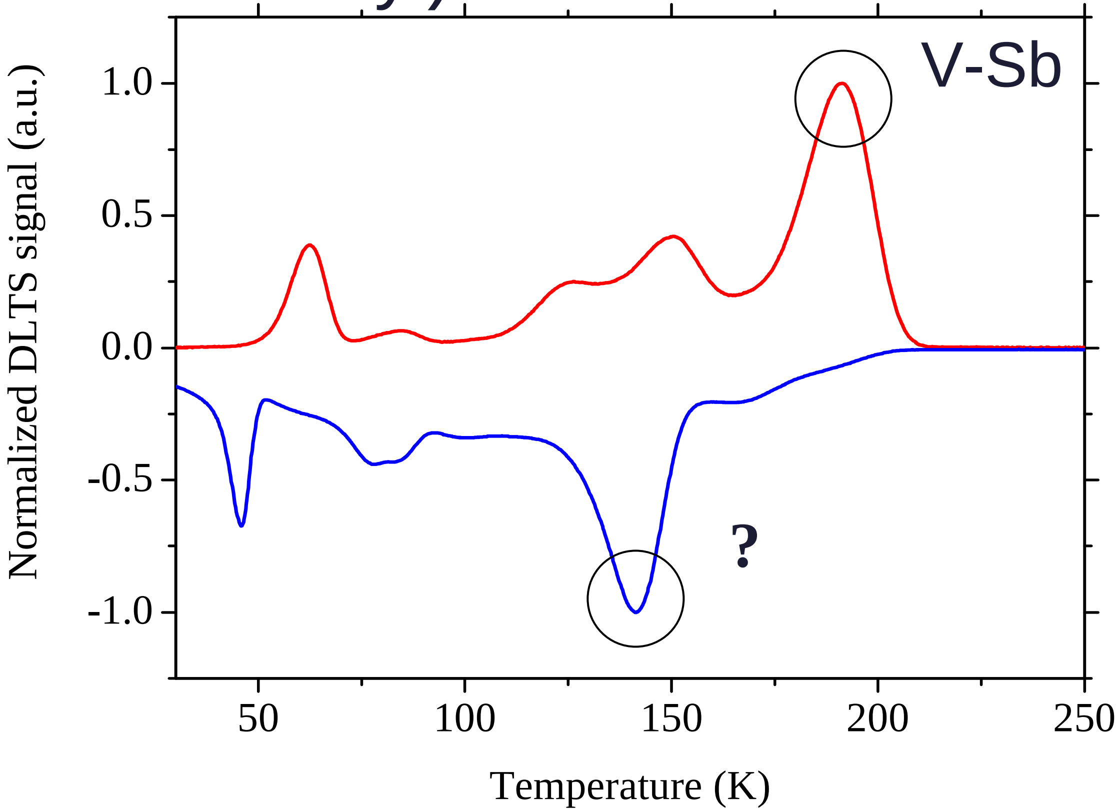
Si:n^0 sample → annealing study



(1) as irradiated
(2) 100 °C
(3) 150 °C
(4) 200 °C

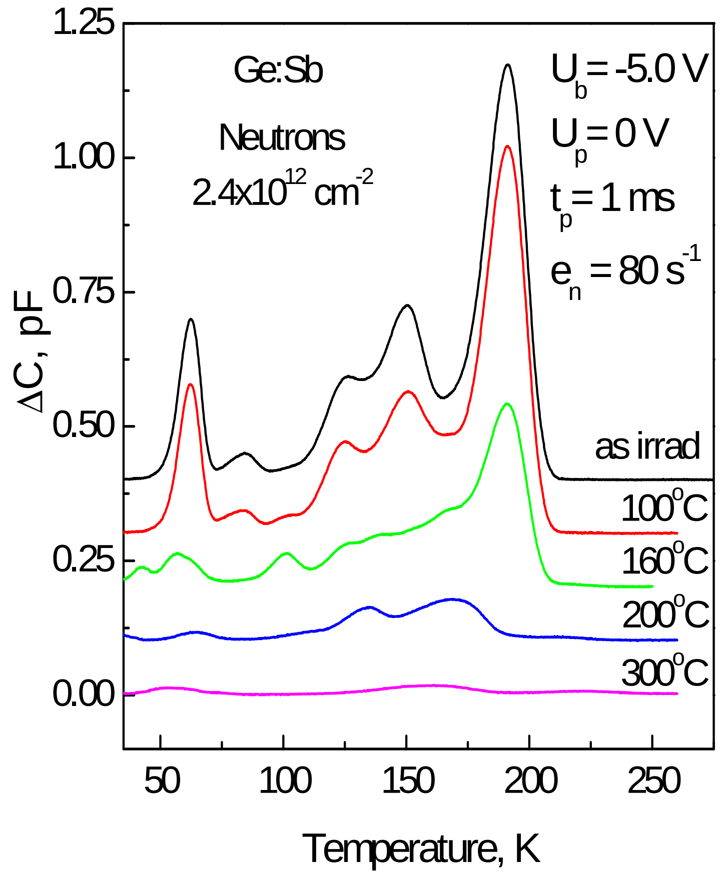
VV(=/-) ⬆ **VV(-/0)** ⬇ **(T < 200 °C)**

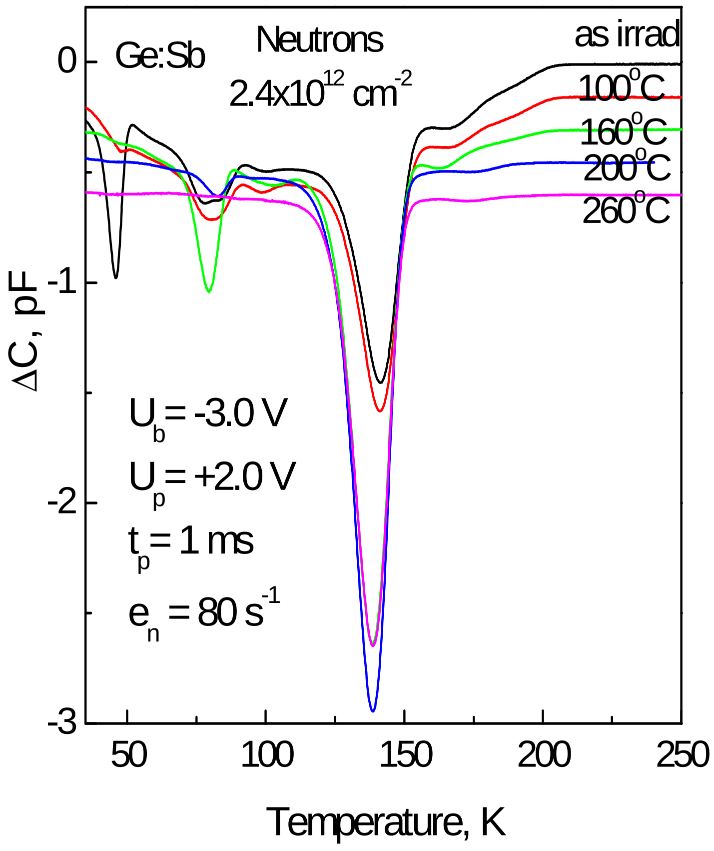
Majority (electron) and minority (hole) carrier traps in n**Ge** (low resistivity)



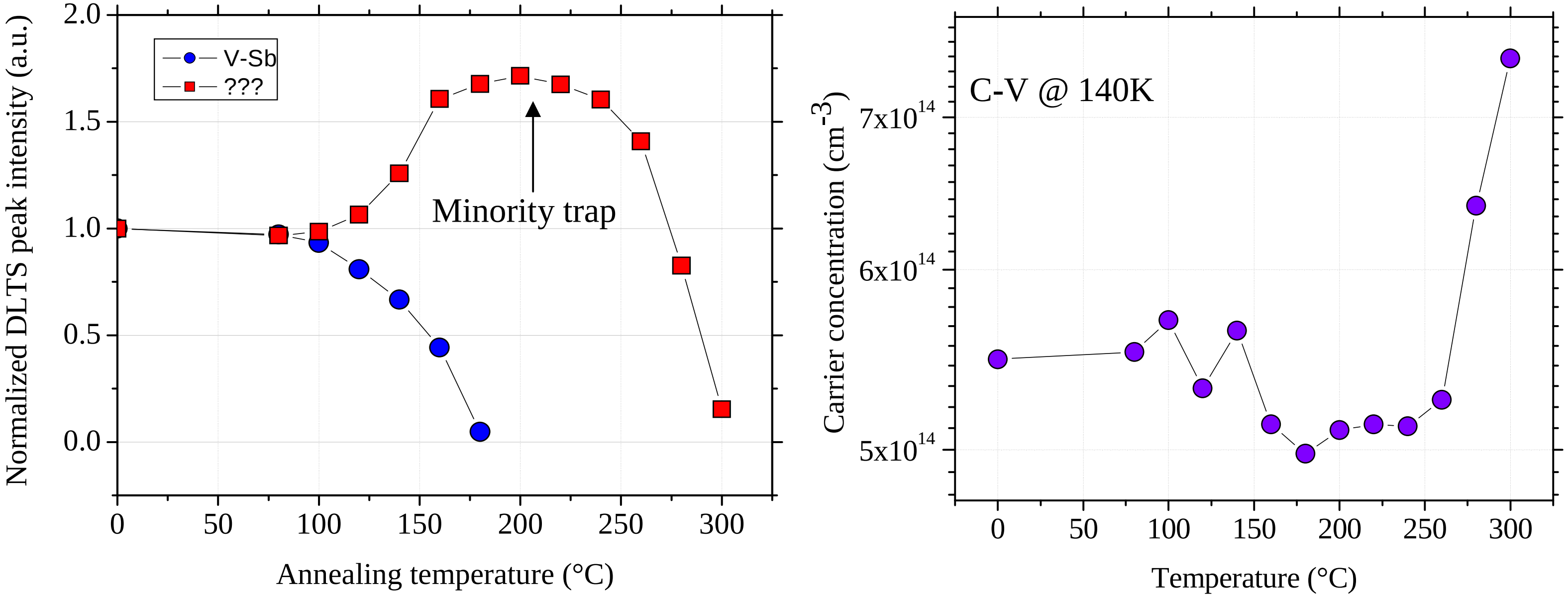
[Materials Science in Semiconductor Processing 9 (2006) 606]

Annealing study





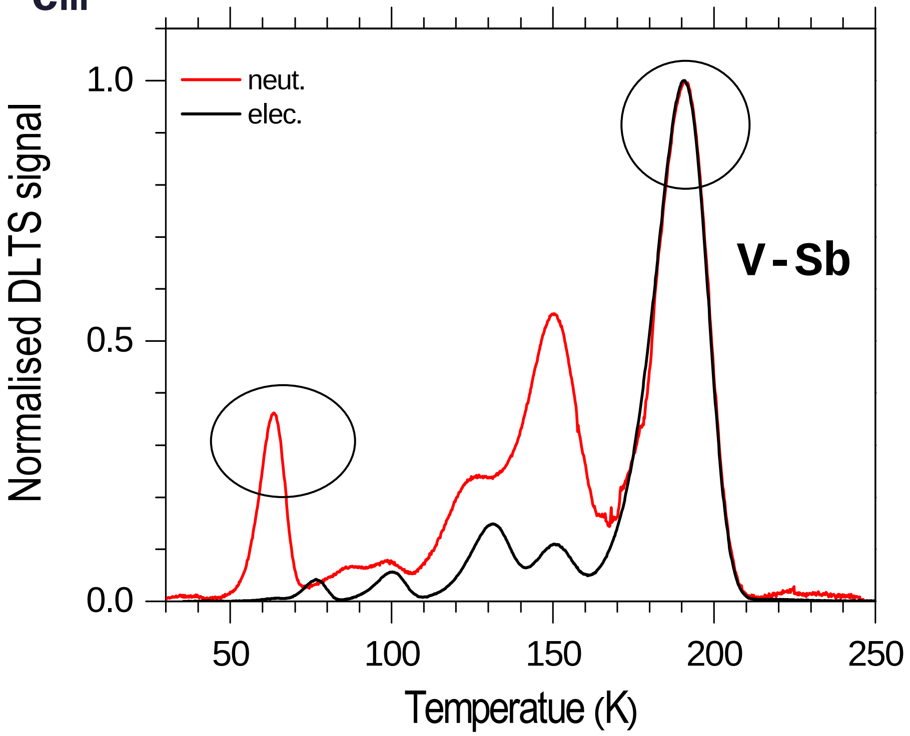
Annealing study + C-V



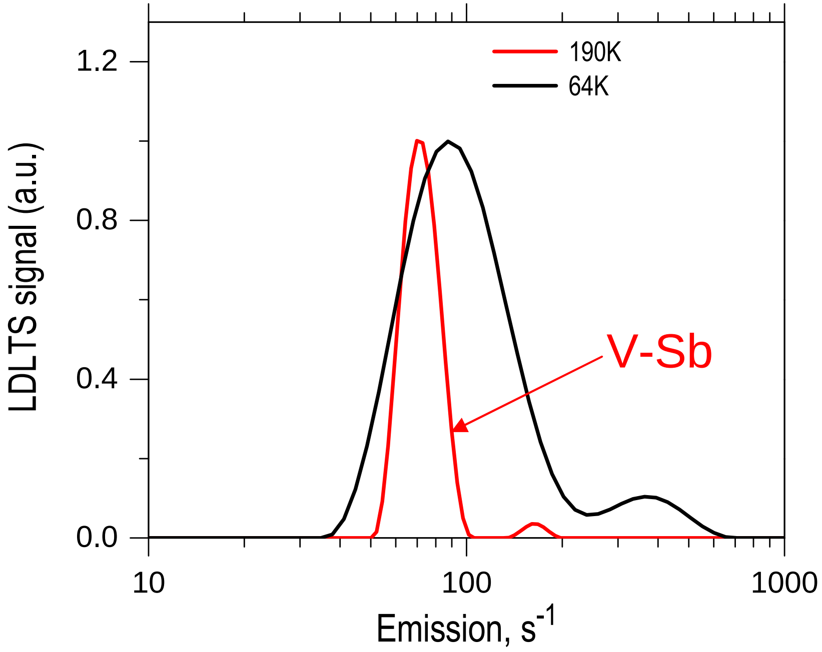
V-Sb + Sb → VSb_2

Uniaxial stress LDLTS measurements

- CZ *n*-type (100) Ge:Sb 5Ωcm
- Dose: **$5\cdot10^{11}$ cm^{-2}**

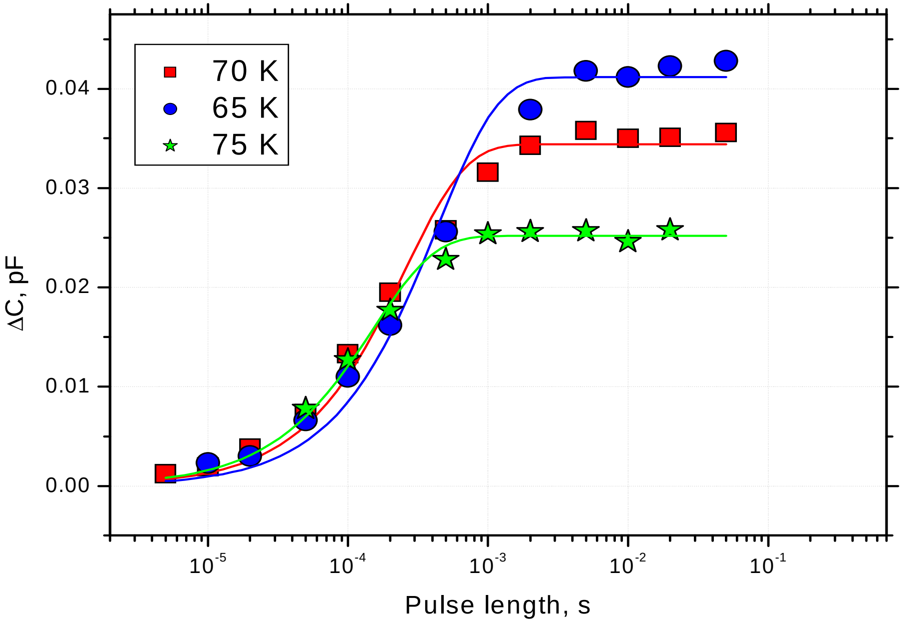


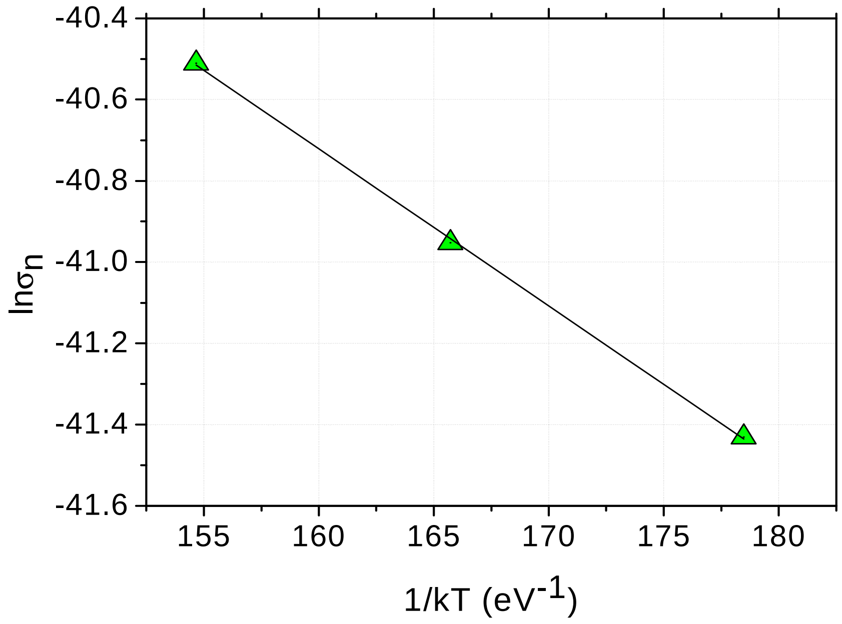
Point-like defects and clusters as seen by Laplace DLTS



[Solid State Phenomena 131-133 (2008) 125]

Vacancy clusters – 0.10 eV





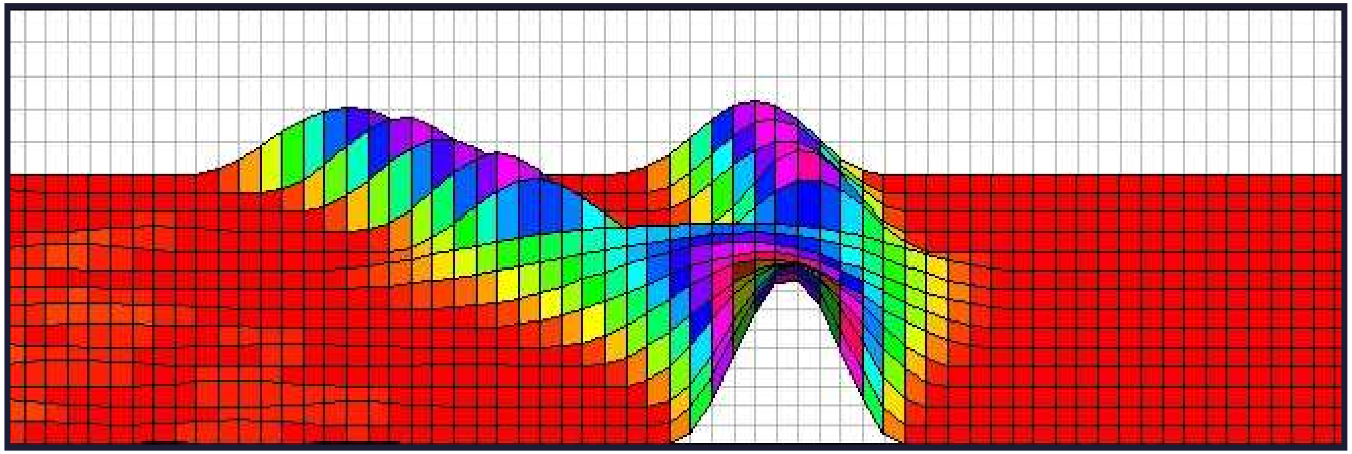
$$\sigma_n(T)=\sigma_{n0}\exp(-\Delta E_{n\sigma}/kT)$$

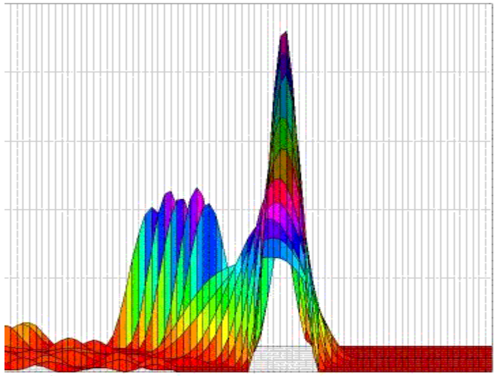
$$\Delta E_{n\sigma} = 0.04 \text{ eV}; \ \sigma_{n0} = 1 \times 10^{-17} \text{ cm}^2$$

Akceptor-like defekt → **Vacancy clusters**!!!

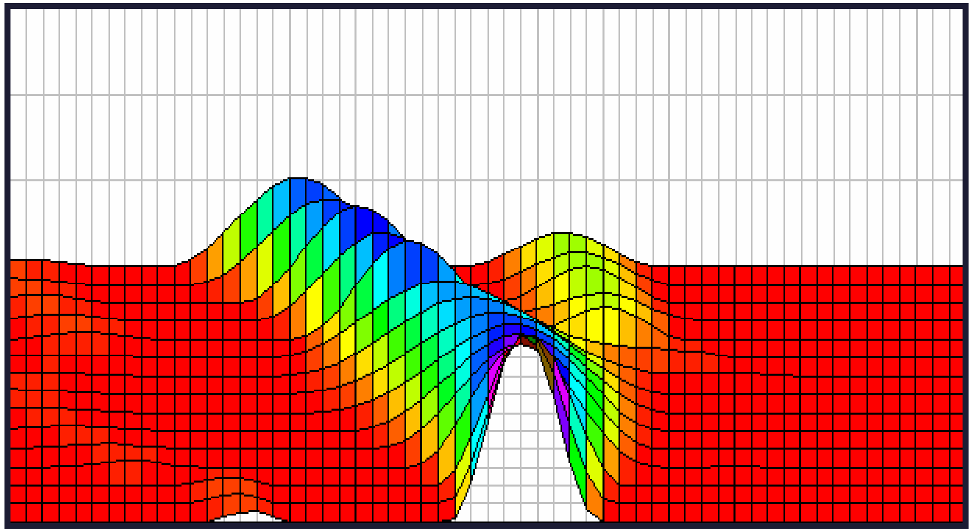
[Vacuum 84 (2010) 32]

V-SB → <110>

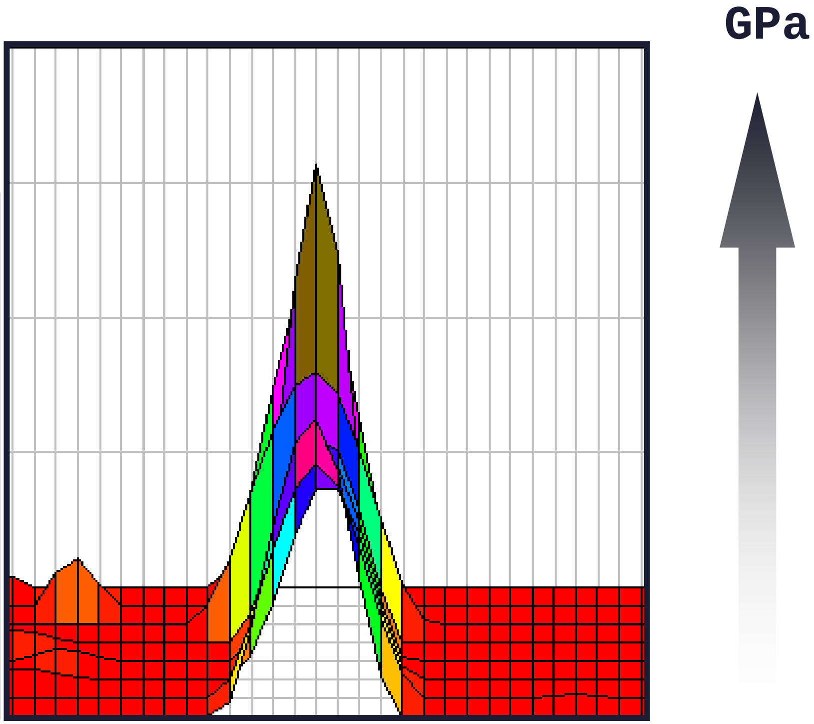




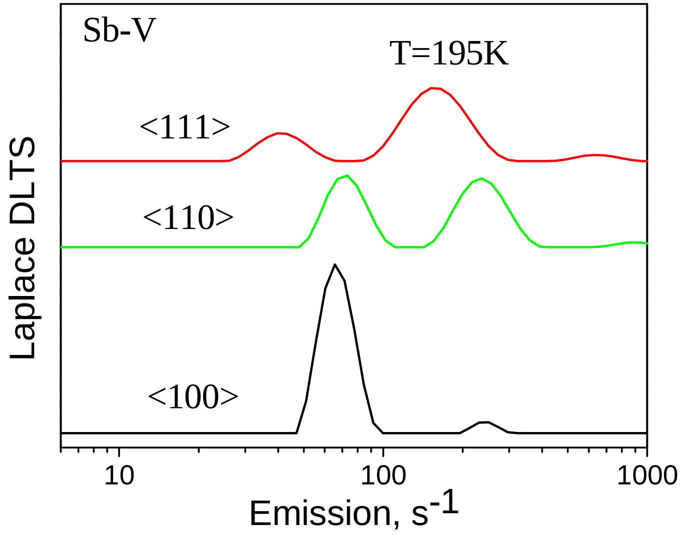
V-SB → <111>

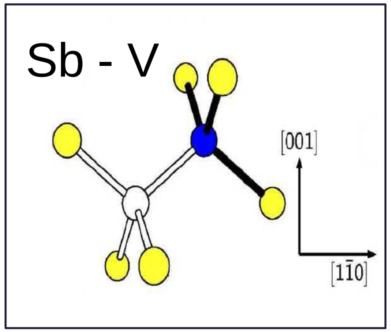


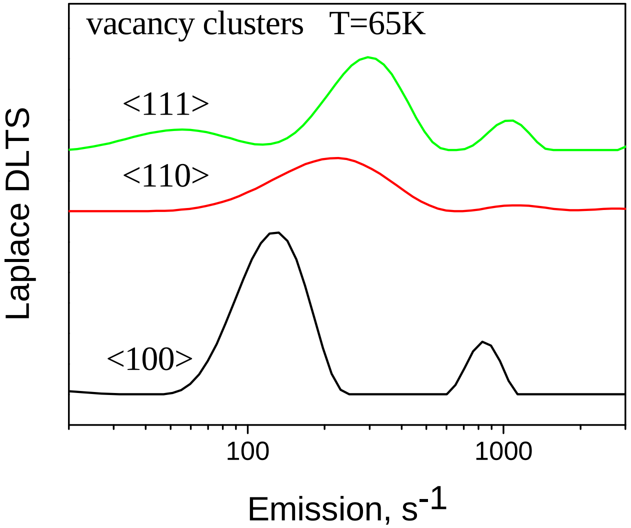
V-SB → <100>



	<100>	**<110>**	**<111>**
C_{3v} – *trigonal*	**NS**	**1:1**	**1:3**
C_{1h} - *monoclinic*	**1:2**	**1:2:2:1**	**1:2:1**







- Sb-V pair → C_{3v}
- Vacancy clusters → C_{1h} ???

Conclusions

- Annealing study of n-type Si irradiated with fast neutrons clearly shows that the concentration of the double negative charge state of the divacancy increases with annealing temperature as vacancies and/or divacancies are released from cluster related defect, the E4 defect.

- Formation of the minority carrier trap in n-type Sb-doped germanim: Sb-V + Sb → Sb_2-V

- Low dose of fast neutrons has introduced the point-like defects and small vacancy clusters

- Trigonal symmetry of the Sb-V pair

- Branko Pivac (IRB)
- Milko Jakšić (IRB)
- Radojko Jačimović (IJŠ)
- Željko Pastuović (Australian Nuclear Science and Technology Organisation)
- Anthony R. Peaker (Uni. of Manchester)
- Vladimir P. Markevich (Uni. of Manchester)