On-line DLTS and Laplace-DLTS investigations of defects in low-temperature electron irradiated boron-doped Si

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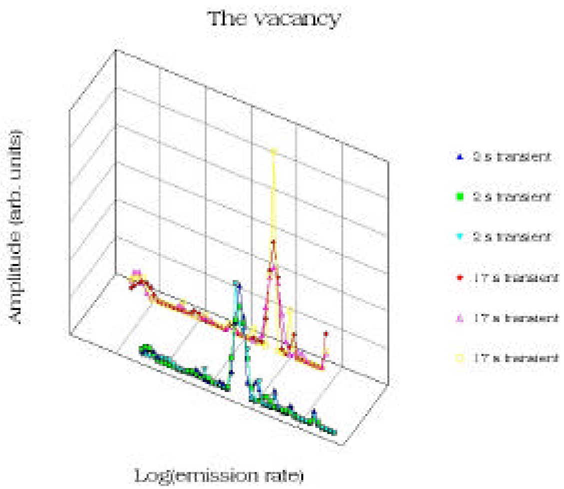
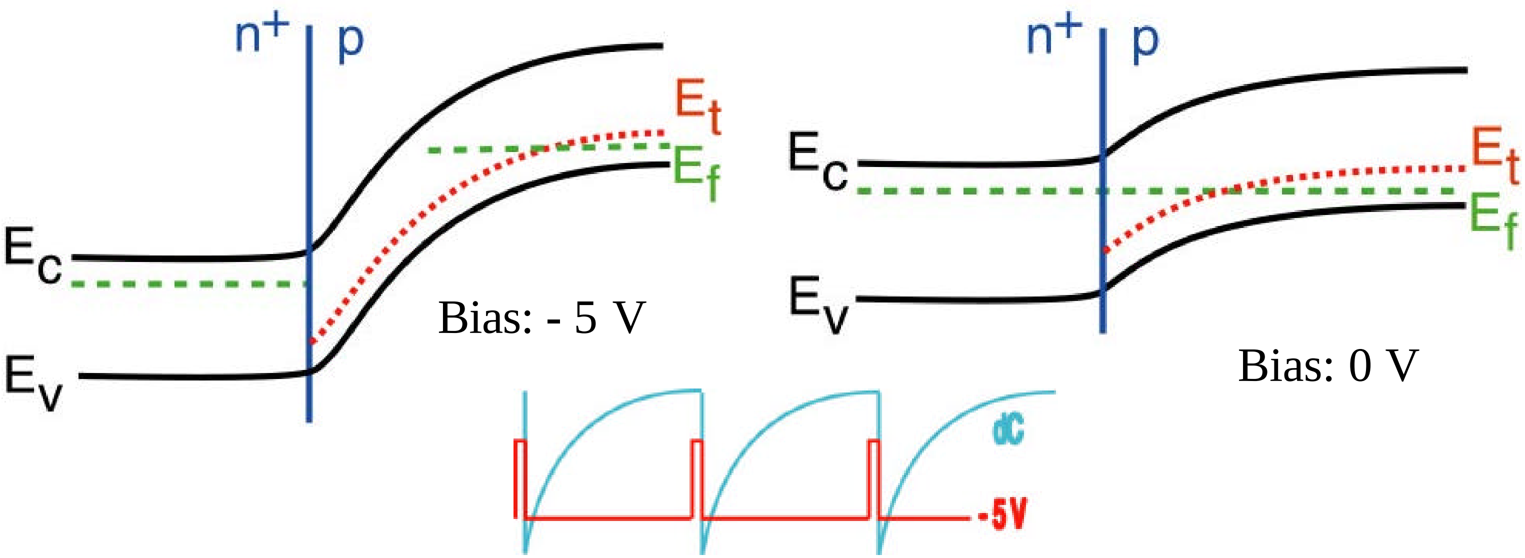
- DLTS and Laplace-DLTS
- Creation of defects
- New low-temperature defect
- Annealing of the vacancy
- Bistable V-B_s
- Room temperature (V_2)



Deep Level Transient Spectroscopy in p-type Si.



DLTS measure the transient capacitance coming from the emission of holes from the defect states. Each trap will give a maximum signal at one specific temperature dependent on the emission rate:

$$e_p = T^2 g s_{na} e^{-\frac{E_{na}}{kT}}$$

Laplace-DLTS uses the same principle but only records the transient at one temperature. Noise is reduced by recording the transient 500-2000 times. The involved emission rates can be extracted by making an inverse Laplace transformation of the transient.

Creating the defects.

Material: B-doped epitaxial CVD-grown Si.

Low oxygen and carbon contamination.

Mesa diodes made by capping with n^+ toplayer.

Irradiation: 2 MeV electrons at 20-40 K.

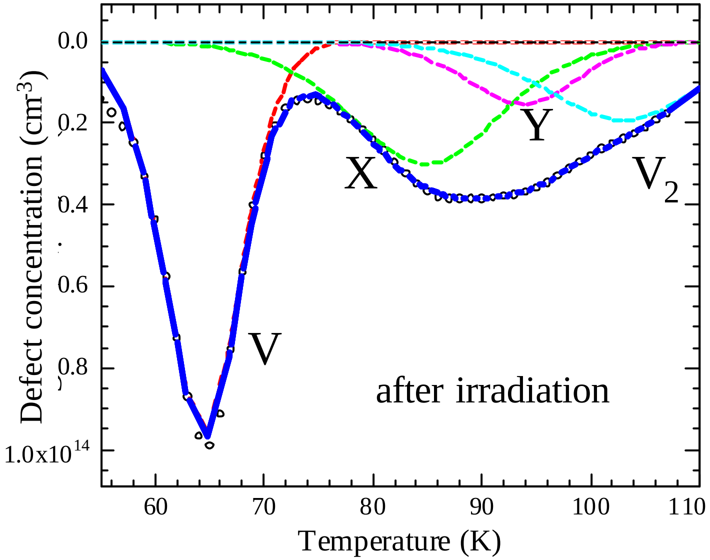
Measurement: Pulsing from - 5 V to - 1 V with 50-200 μs pulse width.

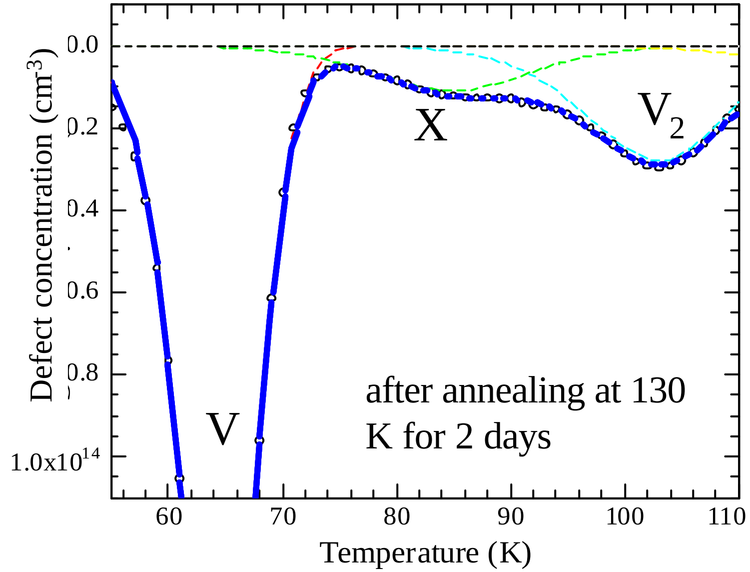
Irradiations	dose 1	dose 2	dose 3
[B]= 2×10^{15} cm^{-3}	1.3×10^{15} cm^{-2}	2.6×10^{15} cm^{-2}	3.7×10^{15} cm^{-2}
[B]= 8×10^{15} cm^{-3}	3.0×10^{15} cm^{-2}	4.9×10^{15} cm^{-2}	10.5×10^{15} cm^{-2}

Little damage from electrons → only simple defects of V, I, and B.

Dose dependence.

Defects V, X, Y, and V_2 after irradiation.



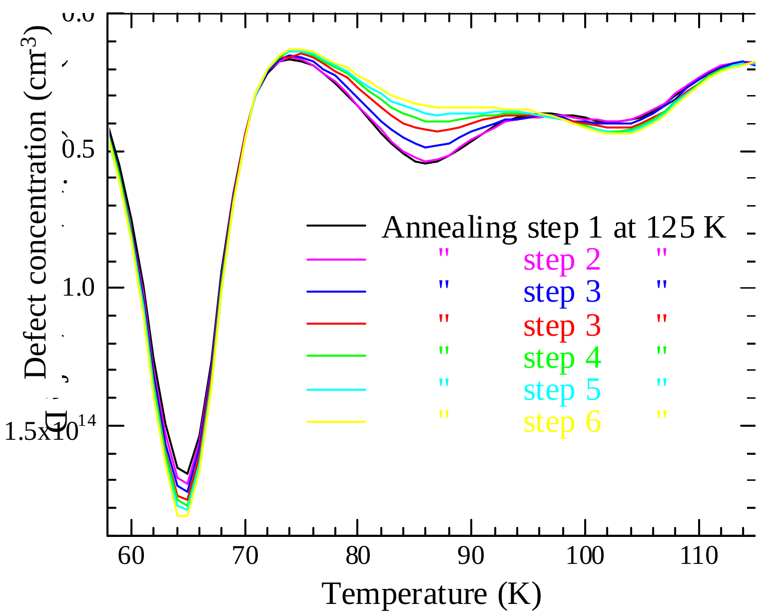


V: [V] $\propto$ ϕ (dose).

Y: Very unstable: dissappears after applying (large) forward bias to diode or keeping the sample at 130 K.

X: [V]/[X] constant: 5 ± 1. [X] independent of boron concentration. Starts to anneal at 125 K.

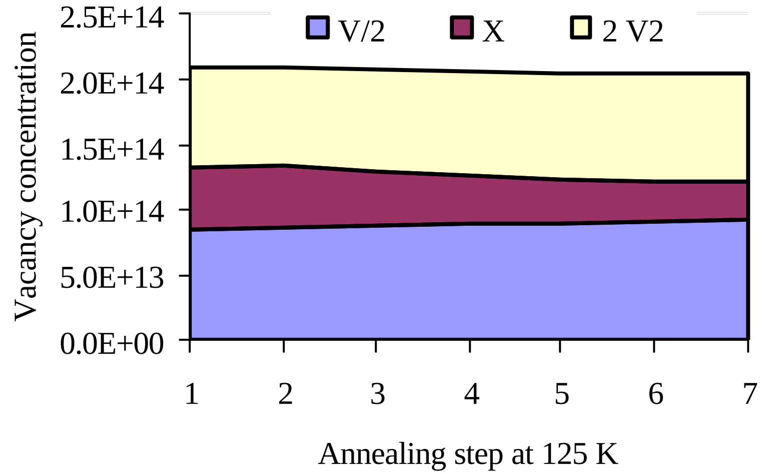
Annealing of X.



Note:

[V] from V-trap = 1/2 × signal (neg. U)

[V] from V_2-trap = 2 × signal



Observation: Annealing of one X releases one V.

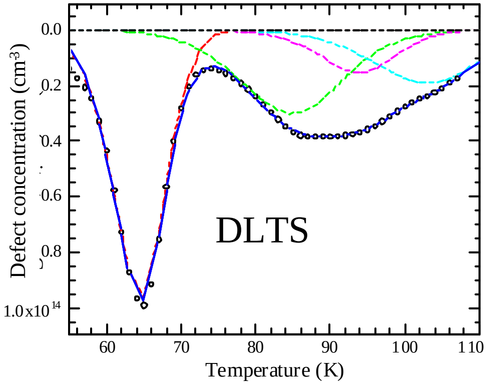
From before: X does not involve B.

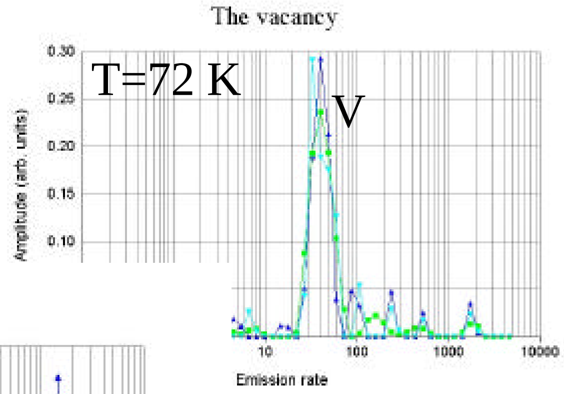
→ Suggestion: X = V-I ? - No! Recombination barrier is lower than dissociation barrier [Tang *et al.*, PRB **55**, 14279 (1997)].

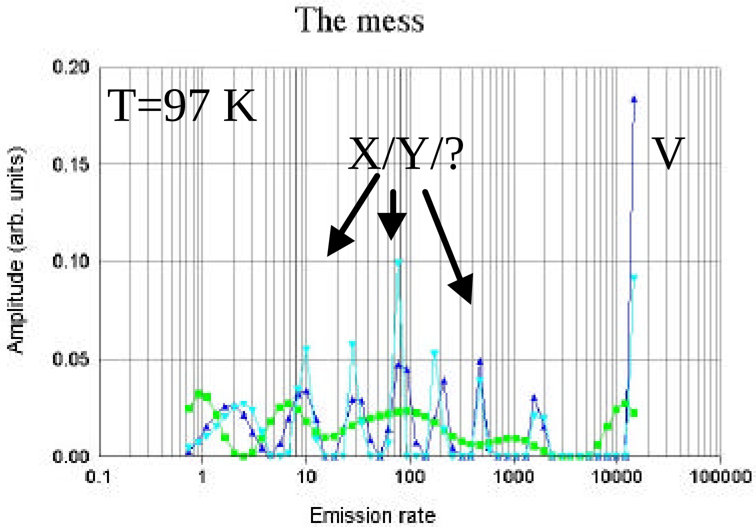
→ Inspiration: [Antonelli *et al.*, PRL **81**, 2088 (1998)] vacancy in alternative configuration with ~0.1 eV higher energy. Corresponds to our observations.

→ Peculiarity: X anneals → [V_2] increase ⇔ diffusion!
(not just a simple change in configuration)

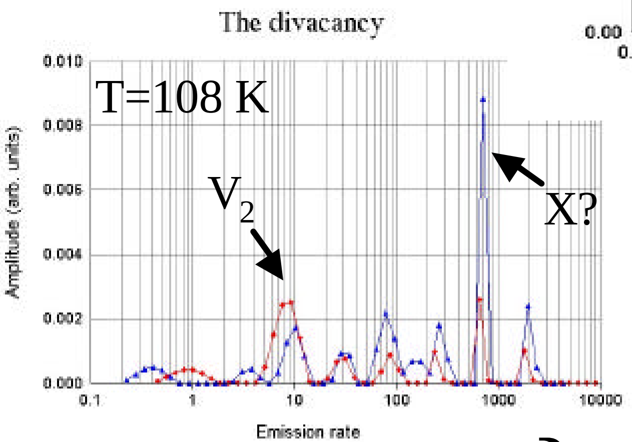
Laplace-DLTS used on “mess”.







(The inverse Laplace transformations are performed in three different mathematical ways not always leading to the same answers.)



V_2 and V dominate the spectra in different temperature ranges.

There are TOO MANY peaks to make reliable Arrhenius plot.

Blue: after irradiation.

Red: after 130 K anneal.

} V_2 grows, X (and others) drop.

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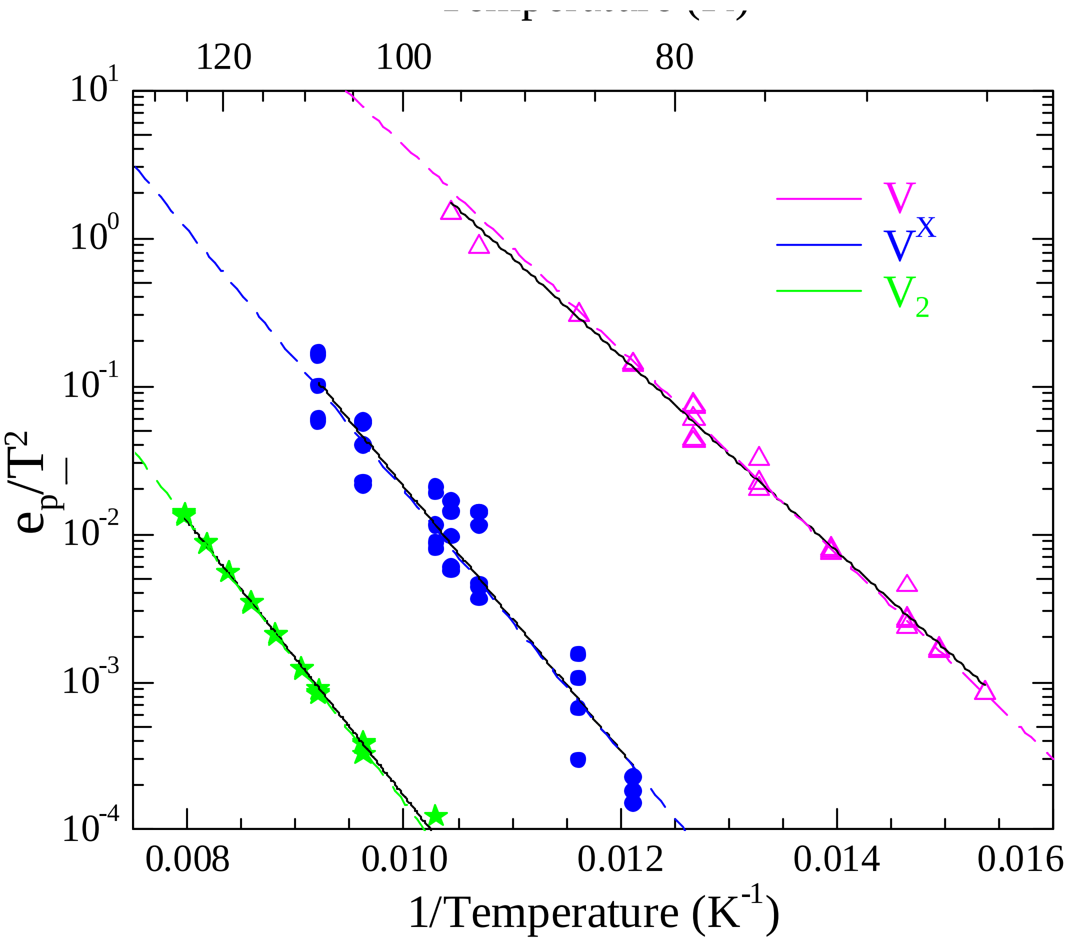
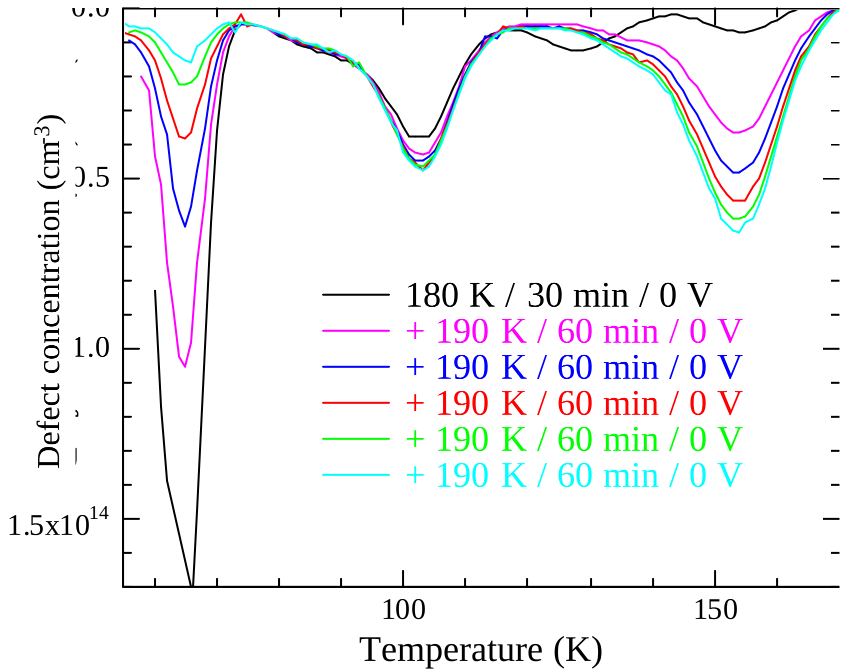
Arrhenius plots from Laplace-DLTS.

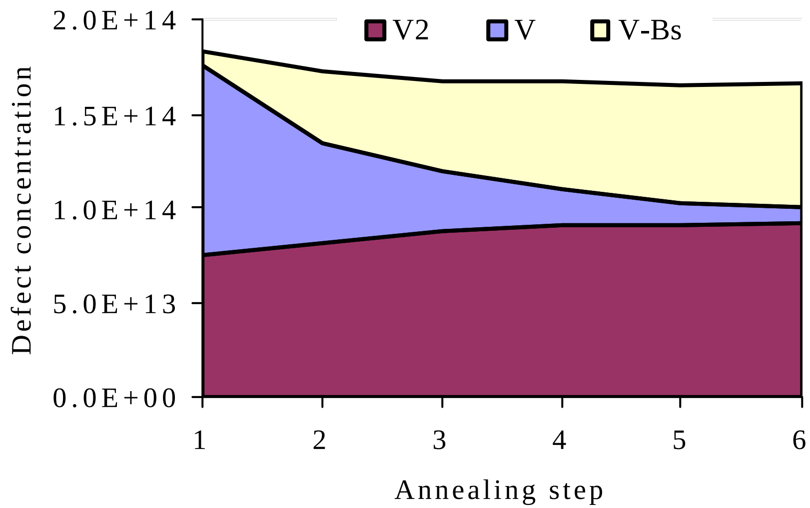


defect	DLTS (E_{na}, σ_{na})	Laplace DLTS (E_{na}, σ_{na})
V	137 ± 5 meV 1.71×10^{-14} cm^{-2}	131 ± 2 meV $(7.06\pm2.1)\times10^{-14}$ cm^{-2}
X	175 ± 10 meV 6.50×10^{-15} cm^{-2}	177 ± 9 meV $(8.75\pm9.8)\times10^{-15}$ cm^{-2}
V_2	189 ± 3 meV 2.59×10^{-16} cm^{-2}	183 ± 2 meV $(1.58\pm0.4)\times10^{-16}$ cm^{-2}

$$e_p = T^2 g s_{na} e^{-\frac{E_{na}}{kT}}$$

Annealing of V.





V becomes mobile at 190 K and is captured by B_s to form V-B_s.

The V-B_s signal is very clear since there is no C_i-O_i.

Notice: Only small V_2 increase!

Applying reverse bias during the annealing slows down/stops the annealing process $\rightarrow$ charge states are important!

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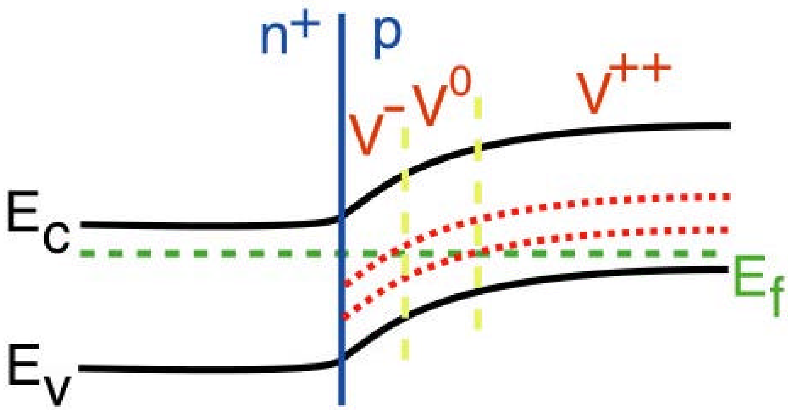
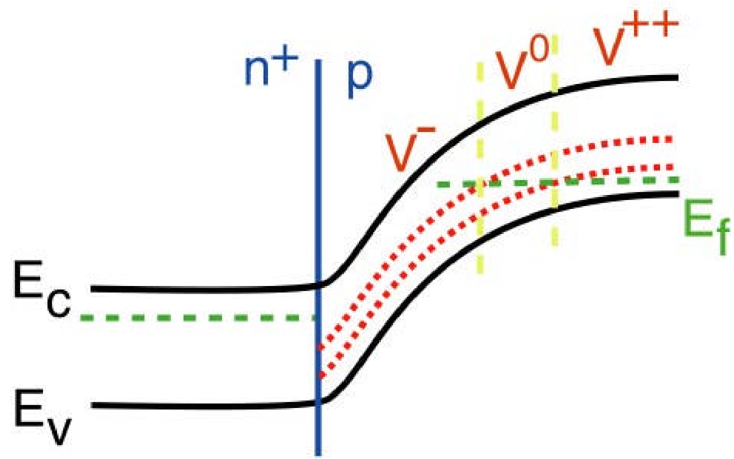
Annealing of V.





<u>Without bias</u> vs. <u>With - 5 V</u>

$[V^{-}] < [V^{-}]$

$[V^{0}] \cong [V^{0}]$

$[V^{++}] > [V^{++}]$

Encourages reaction: $V^{++} + B_s^{-} \rightarrow V\text{-}B_s$

Restrains reaction: $V^{-} + B_s^{-} \rightarrow V\text{-}B_s$

The overall vacancy concentration drops during the transfer:
a) $V + B_i \rightarrow B_s$
b) $V + Si_i \rightarrow Ø$ (Si_i becomes mobile in n^+ toplayer at 140-175 K).

Bi-stable V-B$_s$.

<u>2 configurations of V-B$_s$.</u>

Without bias: A is prefered (has two charge states).

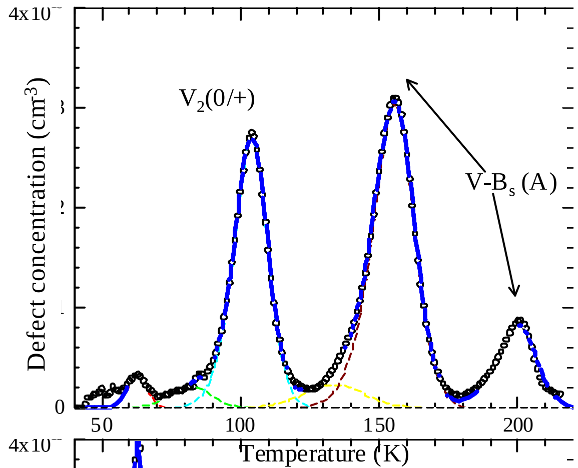
With - 5 V: B is prefered.

Londos [PRB 34, 1310 (1986)] shows that P(150) and P(200) are two charge states of the same configuration.

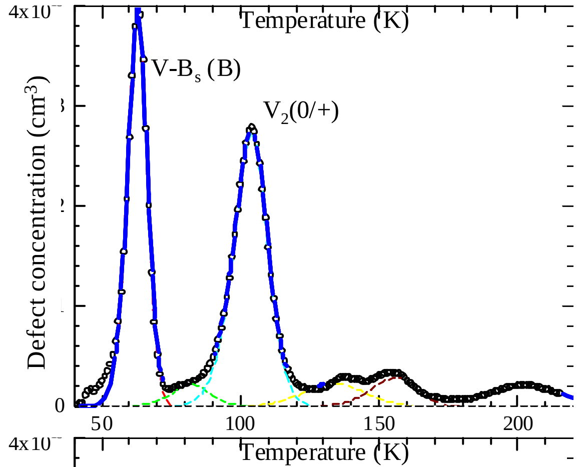
Chantre [PRB 32, 3687 (1985)] shows that they belong to different configurations!

We prove Londos right but Chantres work remains puzzling.

Sample kept at 220 K for 30 min at 0 V.

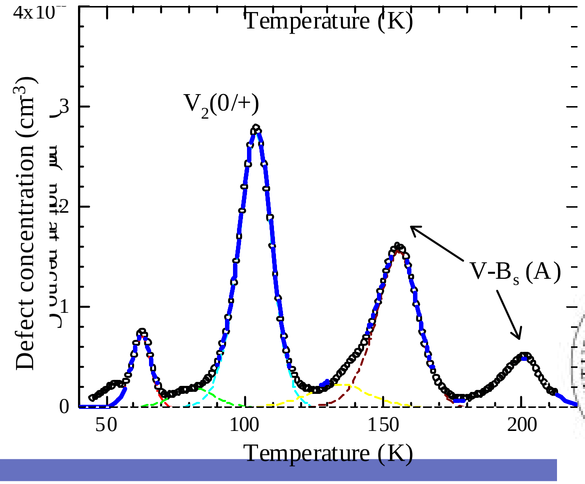


215 K/15 m/- 5 V.



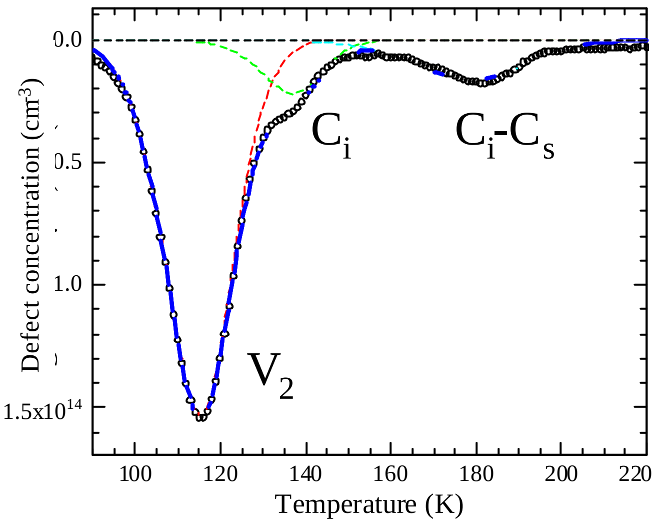
Arrhenius:
V-B$_s$(B)[0.105 eV; 8.09×10^{-16} cm^{-2}]

215 K/15 m/0 V.

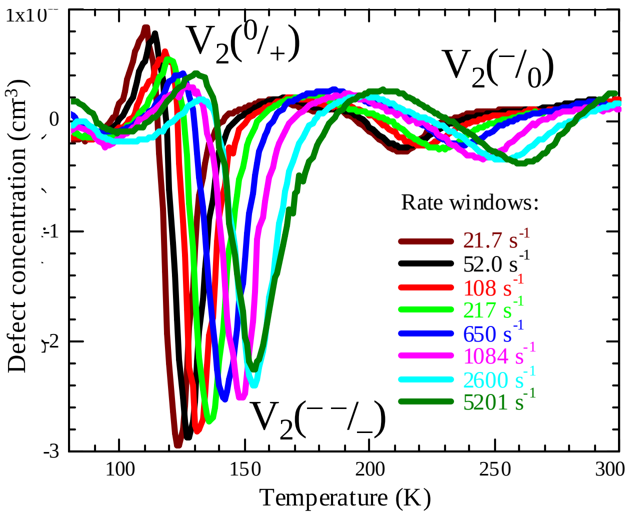


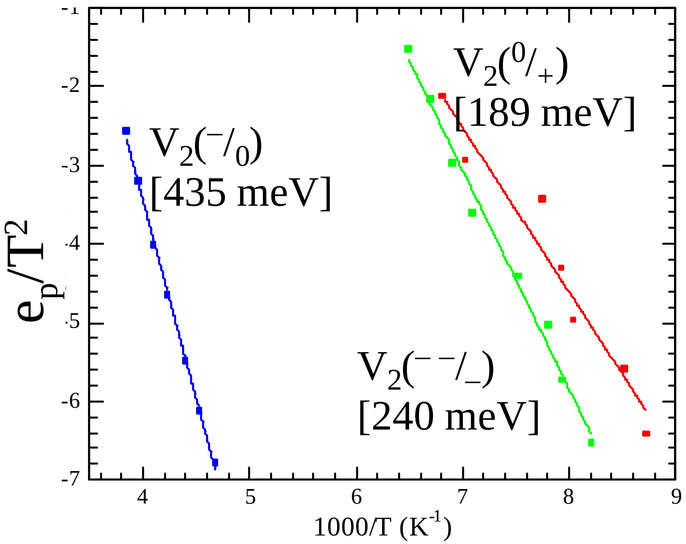
Room temperature.

After room temperature annealing V_2 dominates. No B_i-B_s is seen.



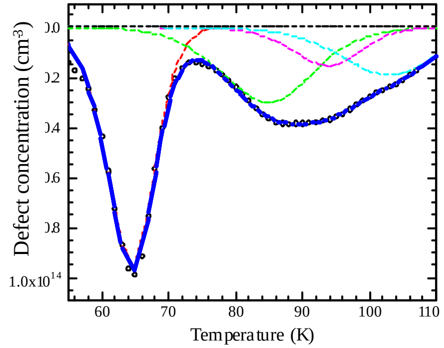
Pulsing from - 5 V to + 1 V → minority (electron) traps of V_2.



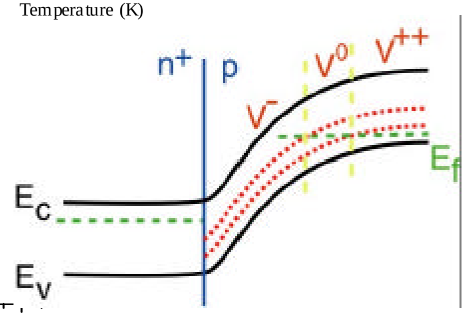


Summary.

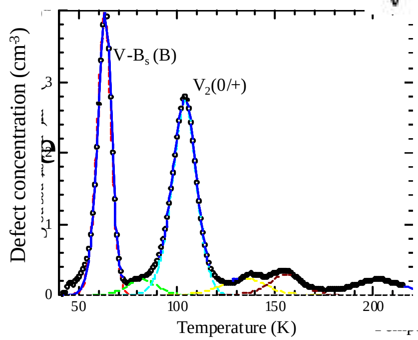
- New defect discovered after electron irradiation; a vacancy in a new configuration?



- Annealing of V depends on its charge state due to Coulombic interactions with B_s^{-}.



- Bi-stable V-B_s defect explored, low temperat configuration measured.



- Laplace-DLTS confirm DLTS-peaks and can measure the emission rates more precisely.