Thermal and ICP annealing of defects in Ge and rate equations

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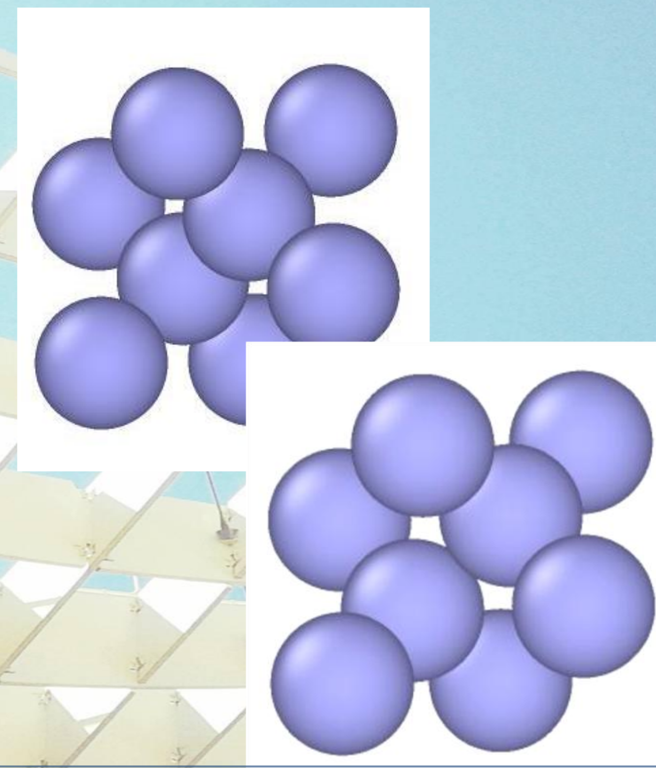
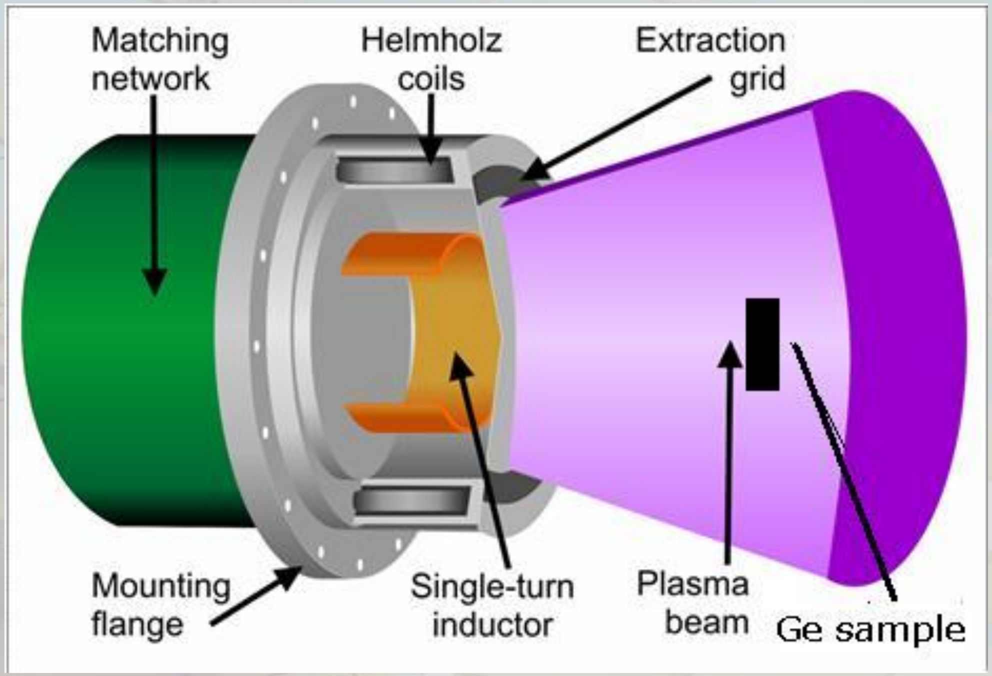


Seminar Session on Nonlinear Excitations and Waves in Solids, Pretoria, South Africa, March 31, 2017. Organized by Pavel Selyschev, Physics Department, University of Pretoria.

Experiment: plasma annealing of defects in germanium

Copra ICP Ar plasma source



Ge sample with an Au diode

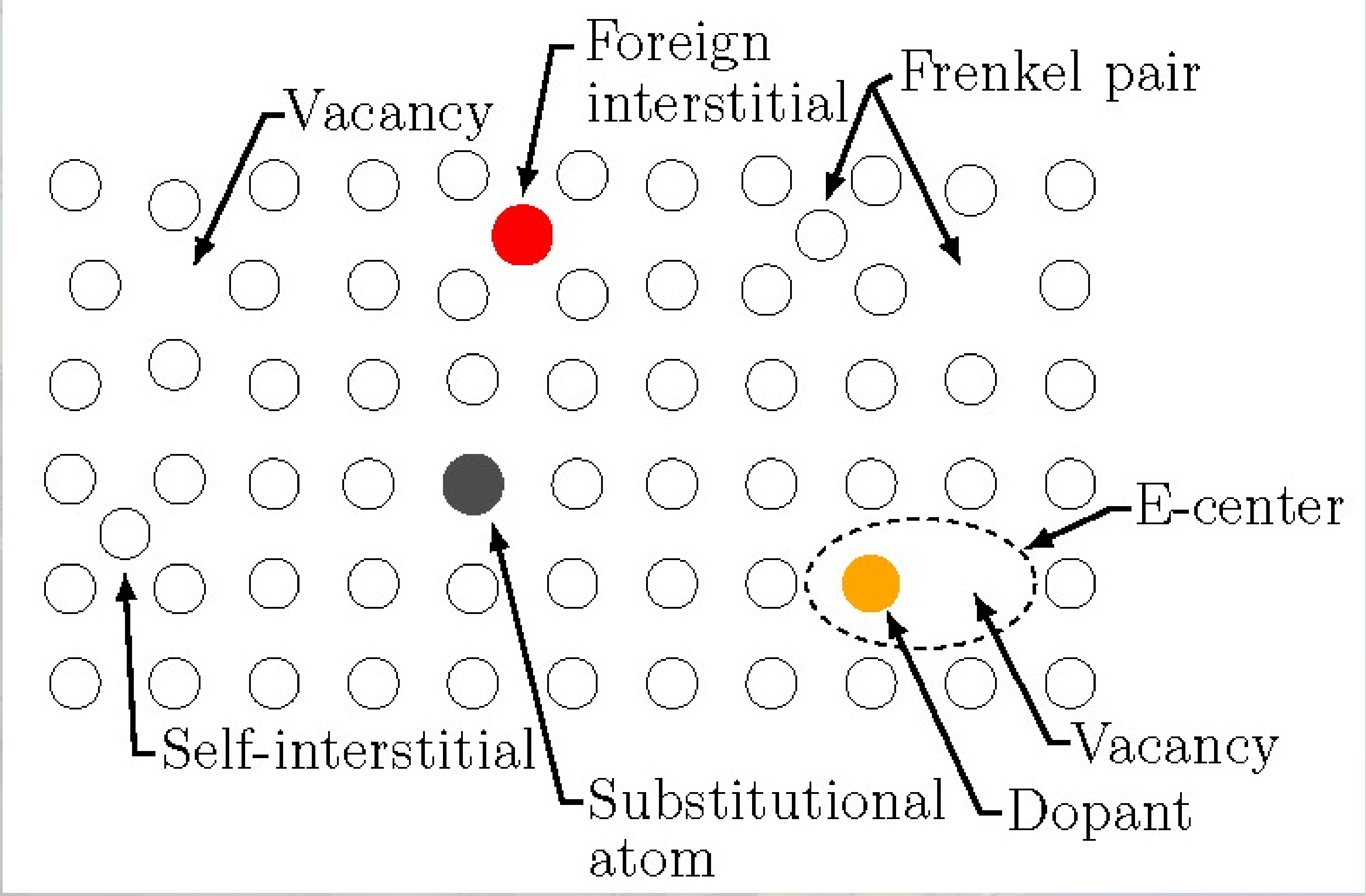
Sb-doped Ge

Defect detection by DLTS

N_{Ge}=4.42x10^{22} cm^{-3}
N_{Sb}=1.03x10^{15} cm^{-3}
N_{T}=1.07x10^{14} cm^{-3}

Defects in germanium

- Can be produced by irradiation
- Some vital, some fatal



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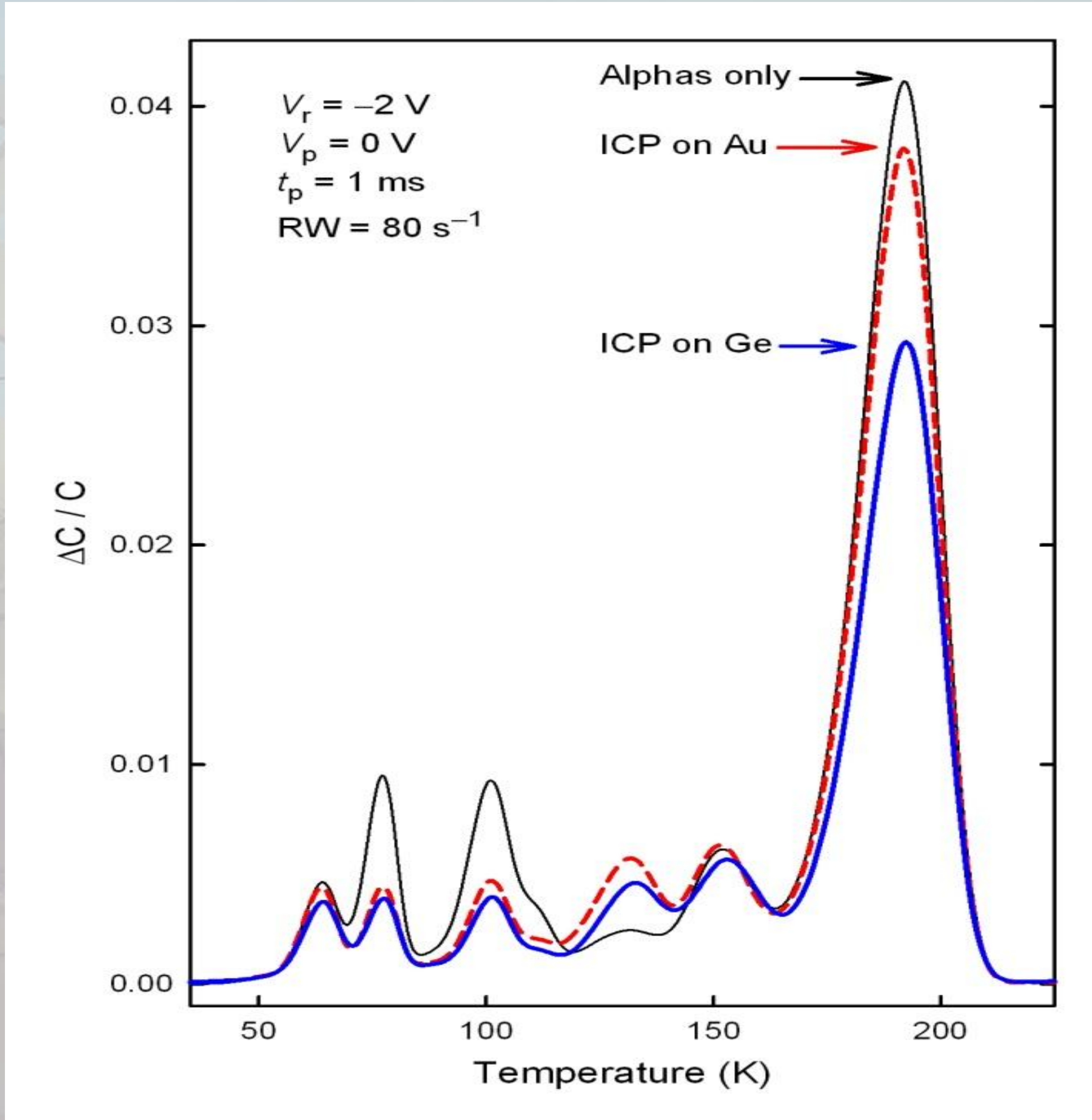
Our basic experiment: 30m, 4 eV ICP plasma annealing



Defects by alpha particles
Deep into Ge 2.6 microns

N_T=1.07x10^{14} cm^{-3}

Reduction of defects in 30% in 30 minutes

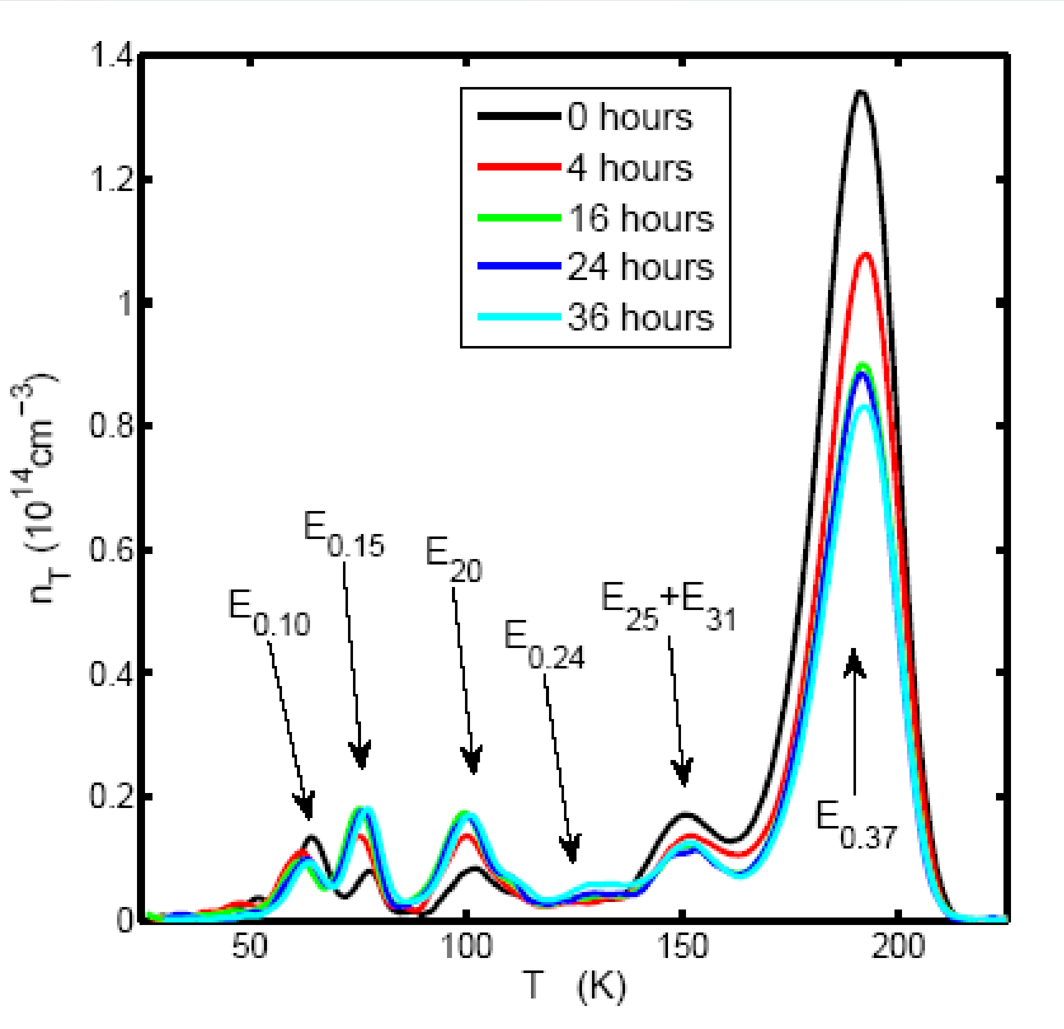
Defect detection by DLTS

8 eV ICP produce less annealing per Ar ion

If temperature increases less annealing

EXPLANATION BY ILMS?

The problem before E-center plasma annealing



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1.-There is a very rapid annealing of the E-center in the first 24 hours when it stabilizes

2.- The experiments were done after 24 hours rest at RT

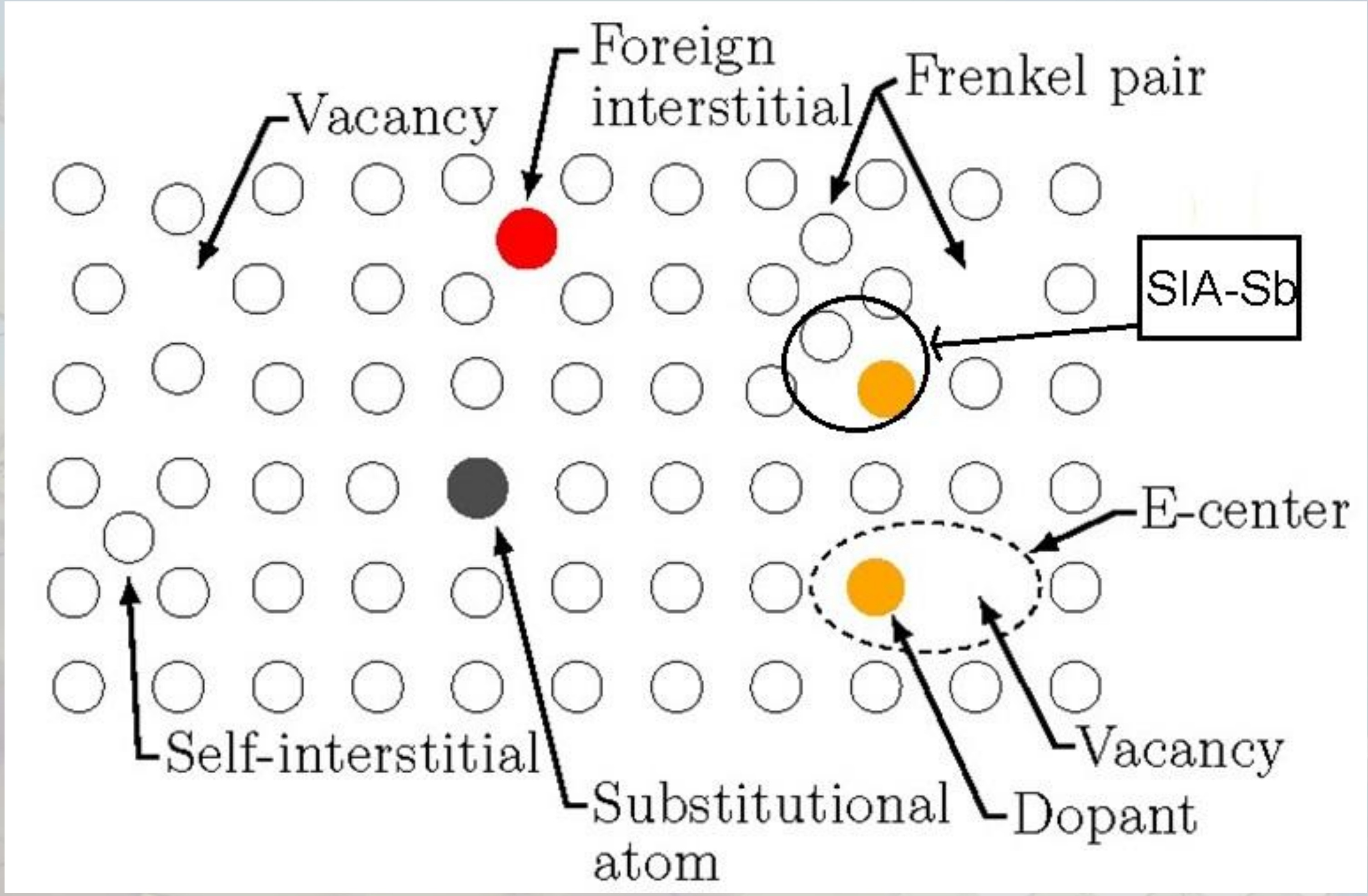
3.-There are also other defects increasing

The problem before E-center plasma annealing

Archilla, Coelho et al Physica D(2015):
In the first few hours there were a very fast kinetics which is explained by a mobile species that consumes E-centers and which is produced by an unstable source created during alpha particle irradiation [14].

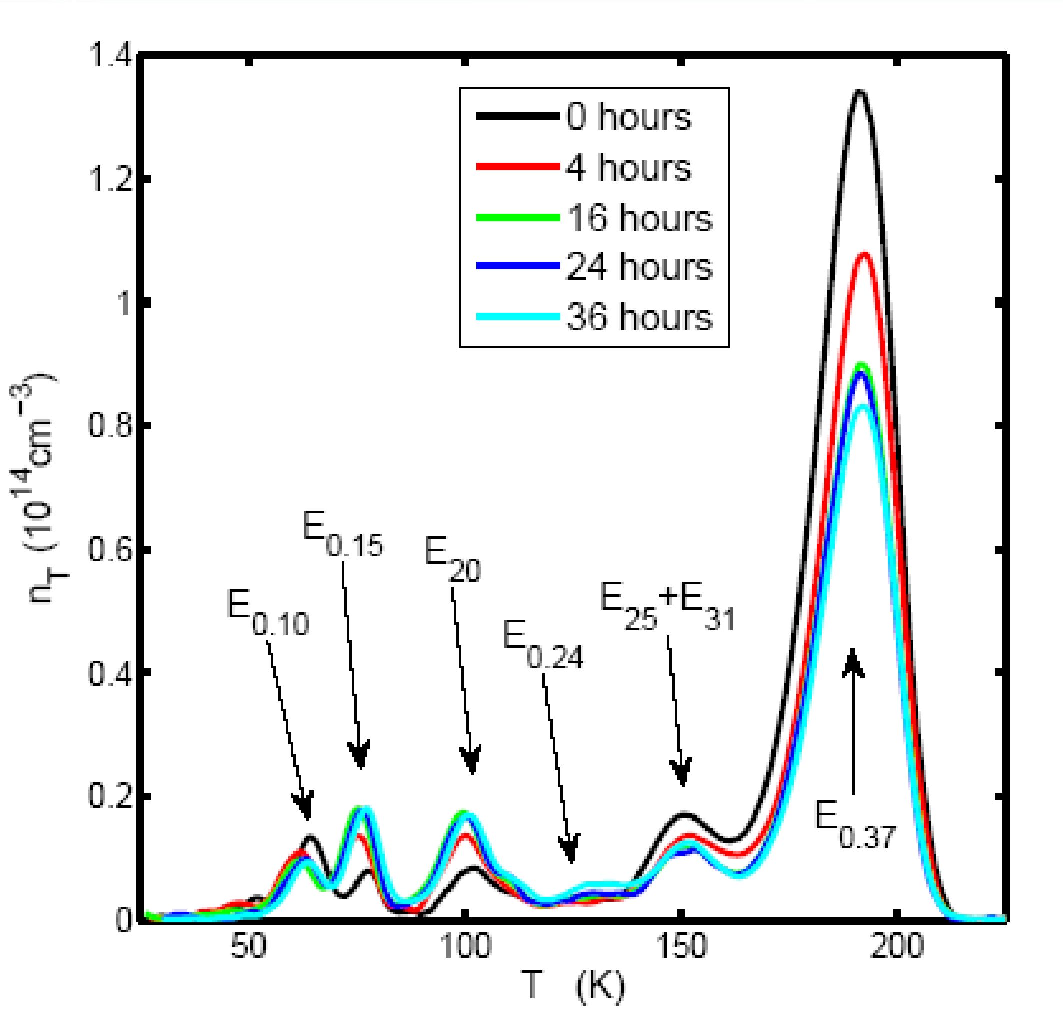
[14] J. Fage-Pedersen, A.N. Larsen, Phys. Rev. B 62 (2000) .
.. some mobile species that consumes E centers must be released at RT from an unstable source that was created during irradiation. Judging from the annealing curves, this source simultaneously causes the growth of new defects. Note that the Ge self-interstitial itself has become mobile at a much lower temperature, probably around 200 K

What can this unstable species might be?



ONE HYPOTHESIS: Cluster SIA-Sb or I-Sb

Other defects modified while RT annealing



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E10:
not identied;

E15, E20, E24:
I and Sb related;

E29:

a) associated with the divacancy V2,
b) two unidenfied defects E25 and E31.

Rate equations

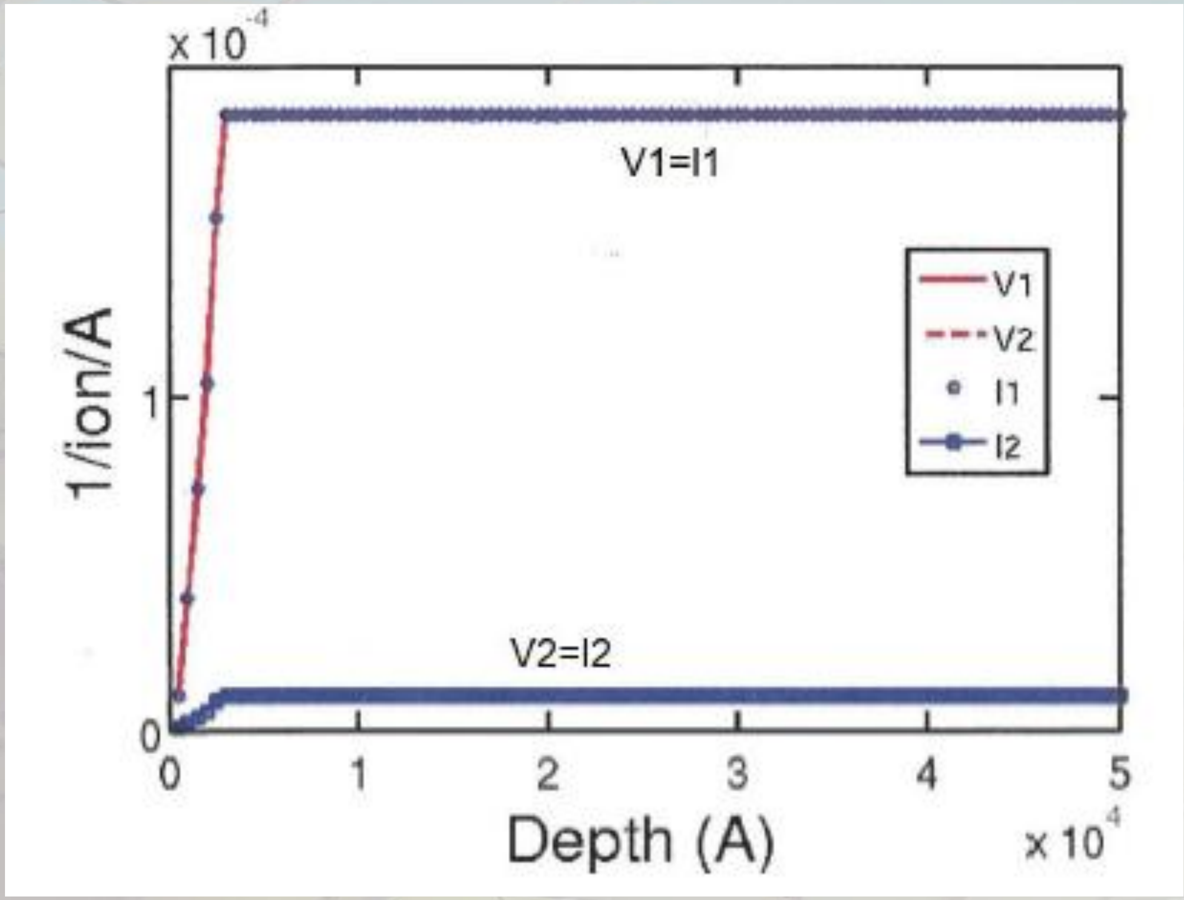
$$V + V \rightarrow V_2$$
$$V + I \rightarrow 0$$
$$V + Sb \rightarrow E\ \text{center}\,(Vac - Sb)$$
$$V + I_2 \rightarrow I$$
$$I + I \rightarrow I_2$$
$$I + Sb \rightarrow ISb\,(SIA - Sb)$$

In the simulations we have substituted the possible SIA-sb complexes for a single one formed with a single Sb and a single interstitial.

Diffusion enegies for vacancy 0.3 and I1 0.5 eV

Brailsford, A. D. and Bullough, R. (1981). The theory of sink strengths. Philos. T. R. Soc. S-A, 302(1465):87{137.

Simulations of defect evolution by rate equations
1. Alpha irradiation: TRIM calculations



1- Alphas produce V1 and I1

2.-Alphas produce also some V2 and I2

3.-Constant profile from 30 to 5000 nm

4.-Experiment gives a constant profile up to 2600 nm

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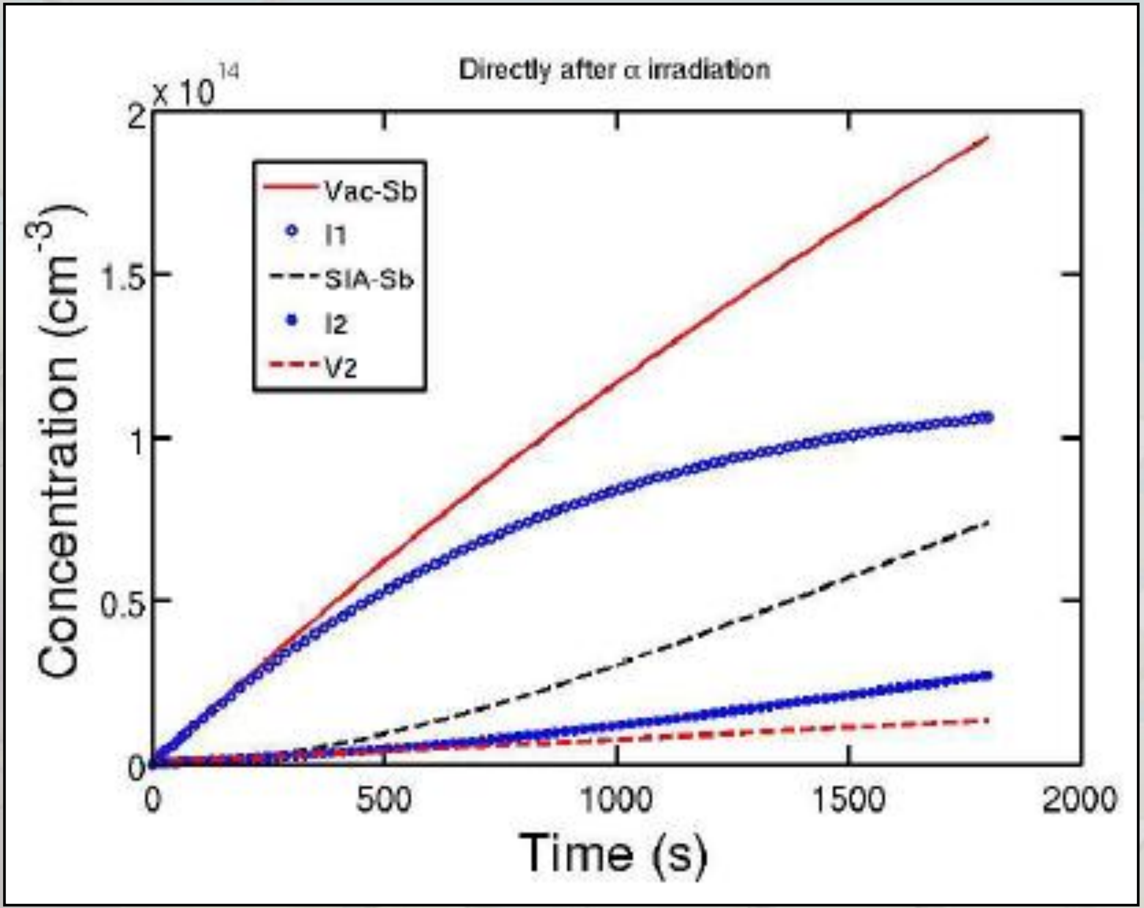
Simulations of defect evolution by rate equations
1. Alpha irradiation



1.- V1 and I1 migrate and recombine

2.-V1 combine with Sb to produce E-centers

3.- I1 combine with Sb to Produce SIA-Sb

4.-I1+I1→ I2

5.-V1+V1→ V2

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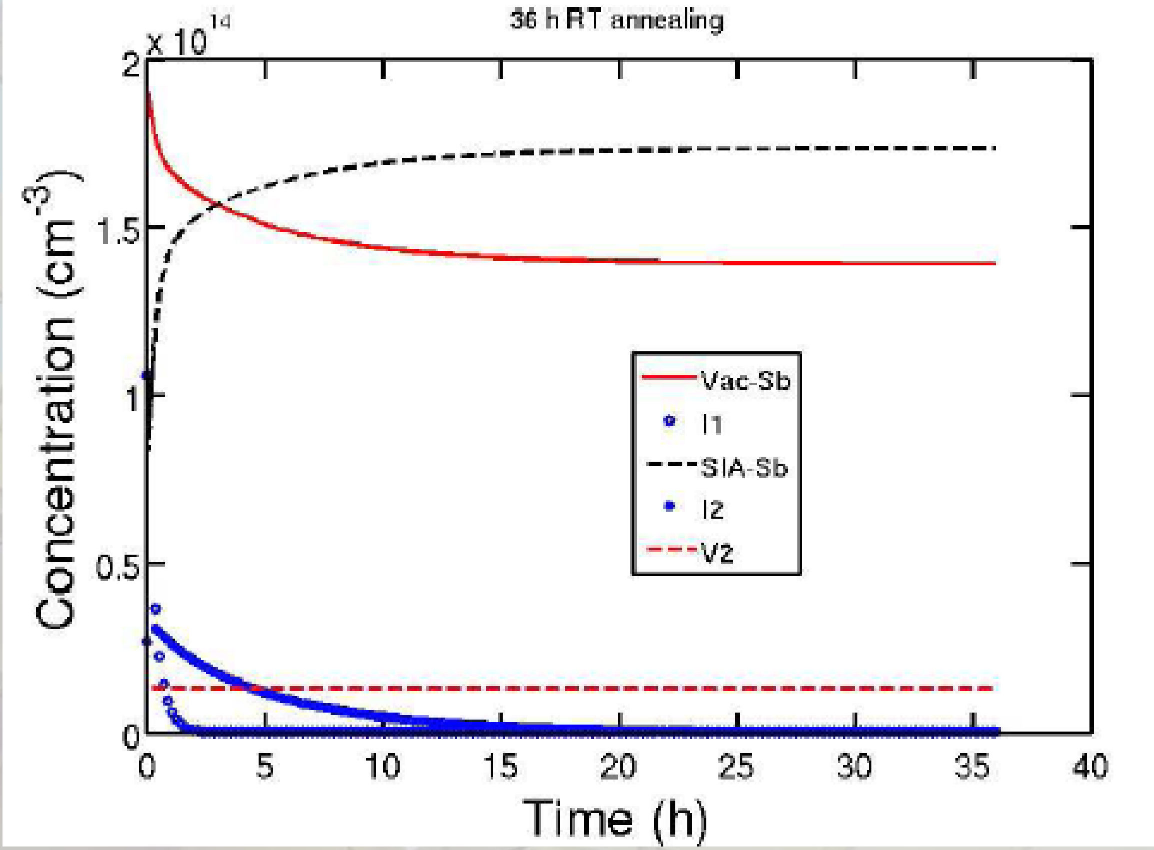
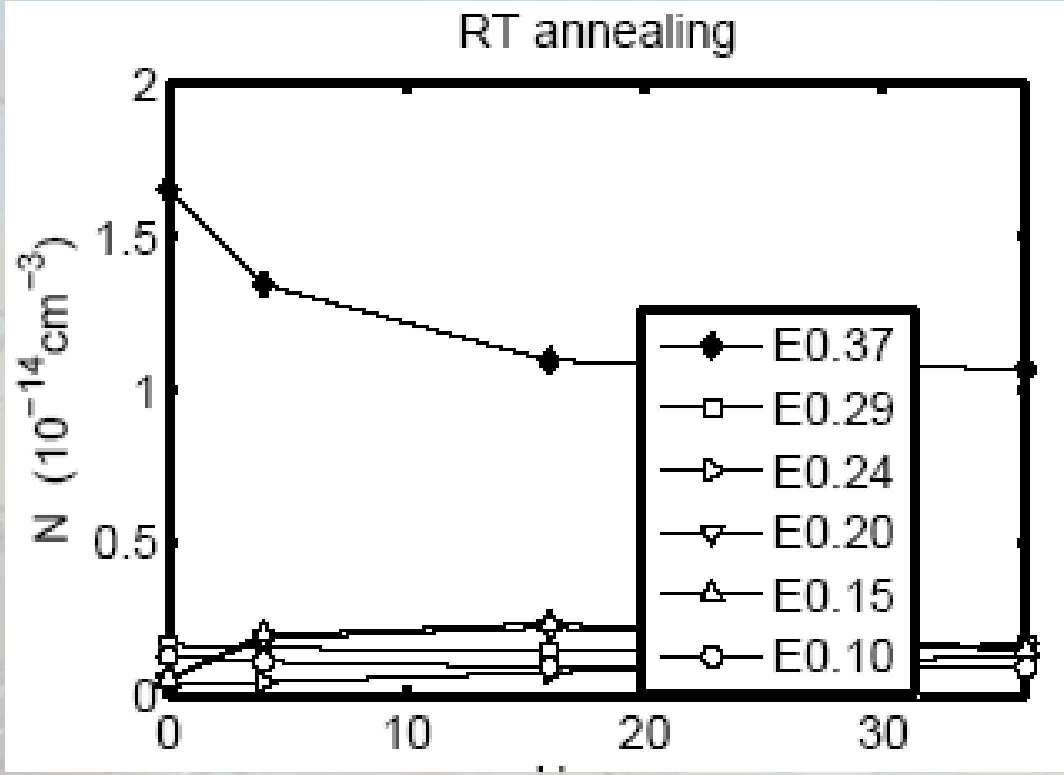
Simulation of RT annealing



1.-The production by alphas of I1, V1, I2, V2 stops
2.- I1 anneals Vac-Sb (E centers) and migrate
3.- I1 produces SIA-Sb complexes
4.- V2 stable; 5.- I2 dissociate into interstitials

Experimental RT annealing (1)



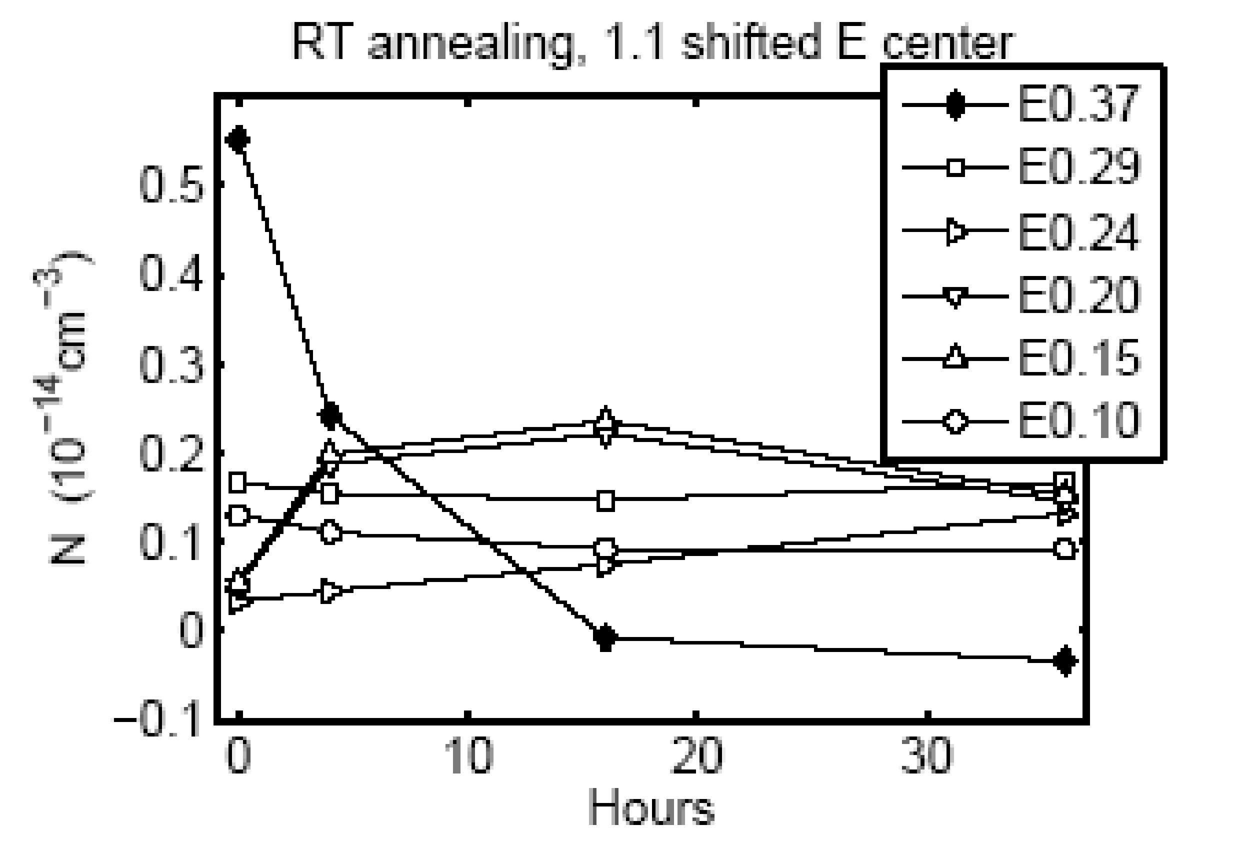
1.-The values and diminution of the E-center is larger than

2.- I1 anneals Vac-Sb (E centers) and migrate

3.- I1 produces SIA-Sb complexes

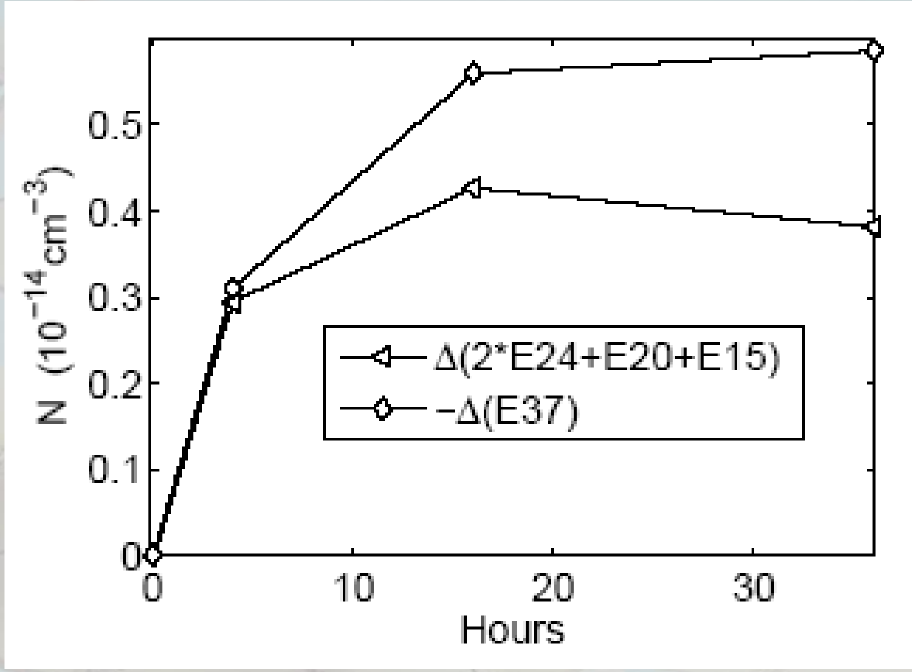
4.- V2 stable;   5.- I2 dissociate into interstitials

Experimental RT annealing (2)



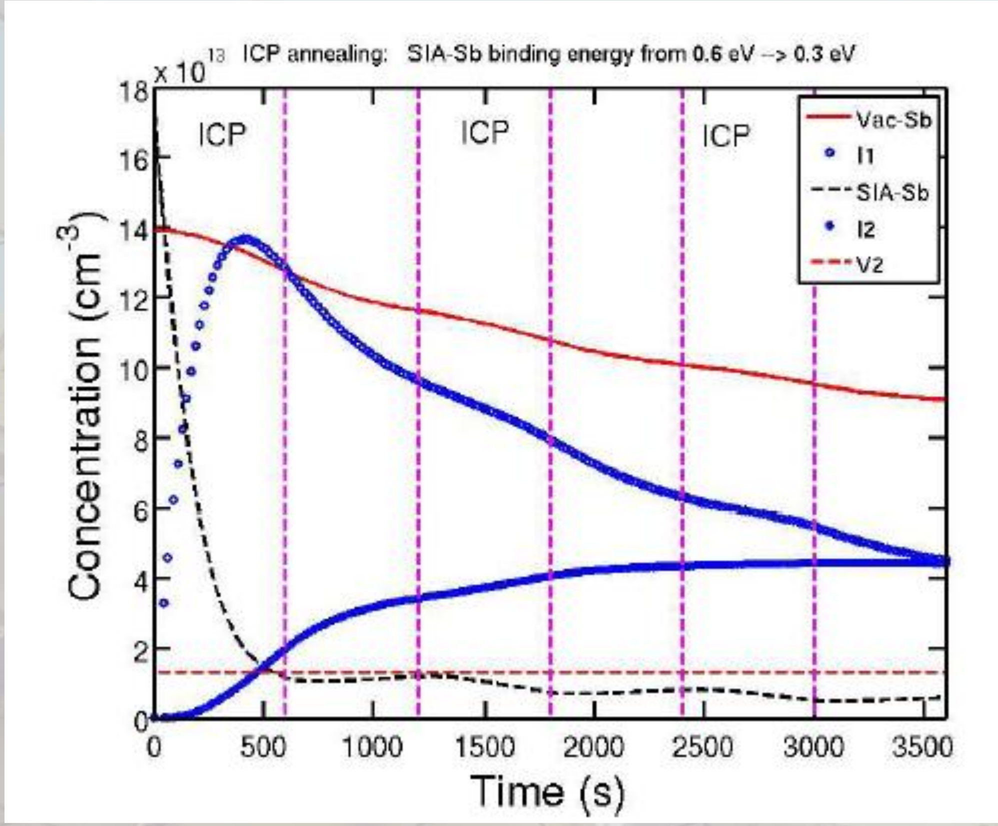
- Zoom with E center shfifted -1.1x10^{14}cm^{3}. Changes are of the same order of magnitude

Experimental RT annealing (3)



- Comparison of the decay in E0.37 with the increase 2*E24+E20+E15. These defects are often associated to Sb and interstitials [Coelho et al. 2013]. Gamma irradiation leads to a defect labeled E22, apparently with two interstitials which is idenfied as E24 [Patel et al. 2015].

ICP annealing explained as T increase? Simulations



1.-SIA-Sb release interstitials

2.- I1 anneals E-centers

3.- SIA-Sb reaches a new dissapears and the process stops

4.- I1 temporarily increase I2

One thing not explained: why an increase of the temperature produces less annealing?

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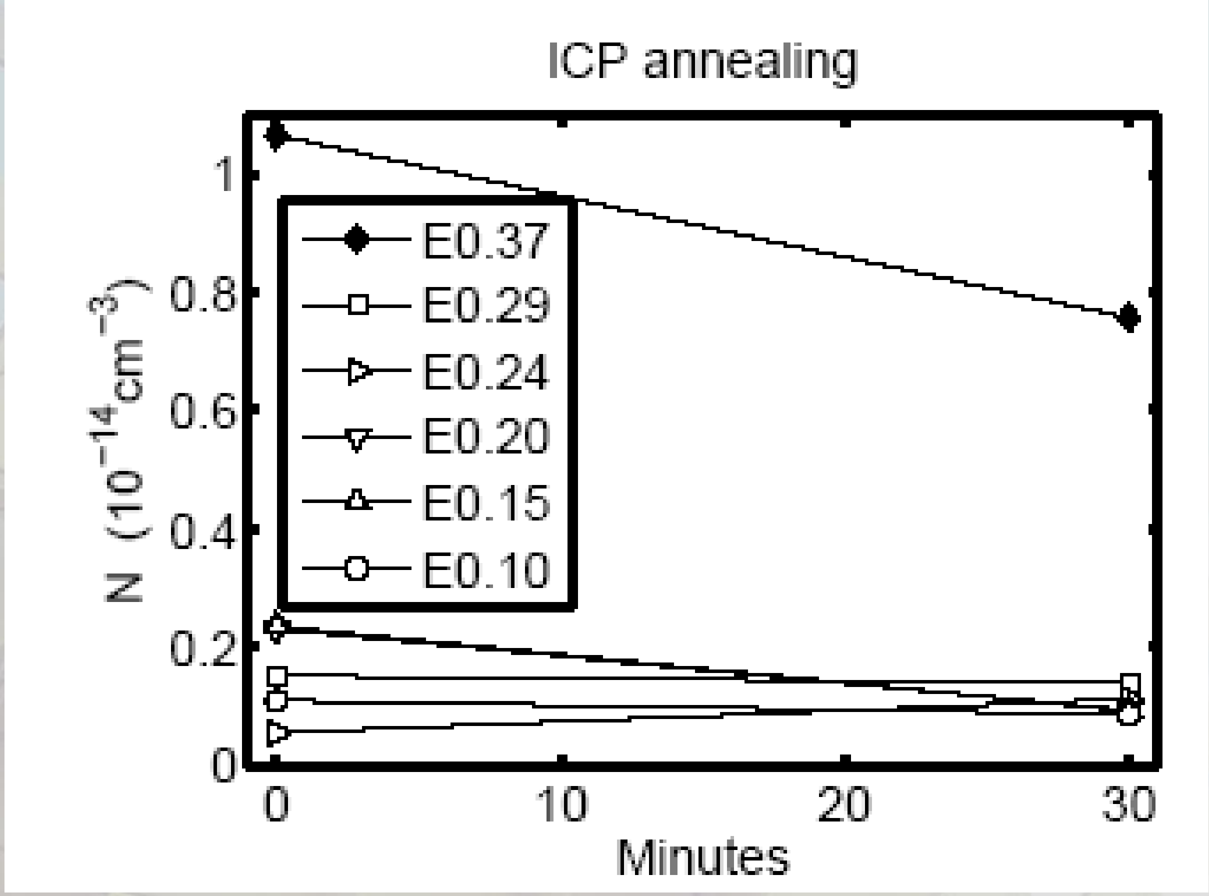
Experimental data from ICP annealing (1)



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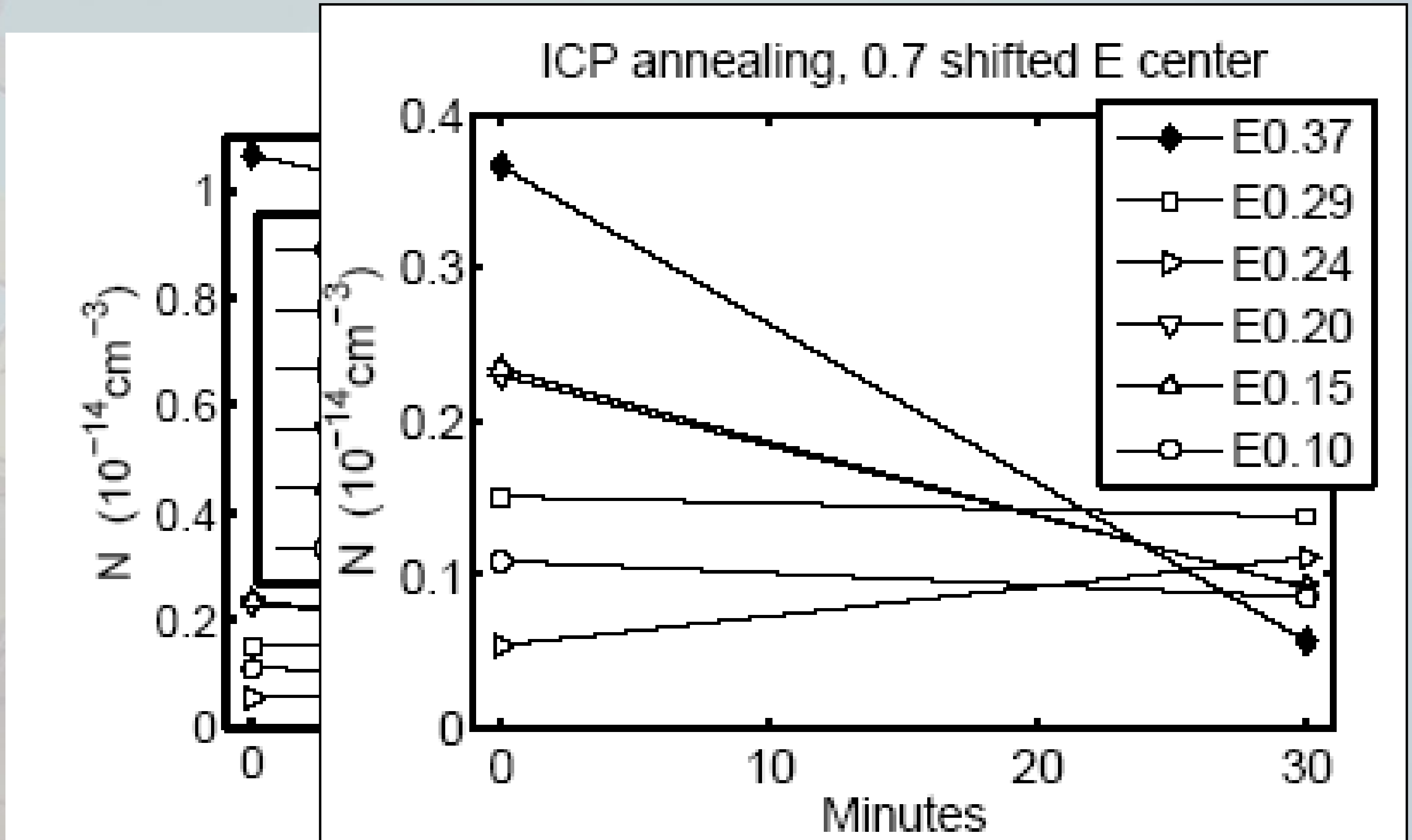
Experimental data from ICP annealing (2)



Concentration of the E center E0.37 shifted 0.7×10^{14} cm^{-3} to allow for amplification. Changes in defects are also same order of magnitude

CONCLUSIONS

1.- The effect of annealing by low energy plasma is not sufficiently explained. 4 eV ions are supposed to do nothing.

2.- Room temperature annealing seems produced by interstitials

3.- A semi-stable species SIA-Sb is very likely to be created during alpha irradiation. It is not visible by DLTS

4.- The SIA-Sb complexes are very likely to release interstitials that anneal the E-center during ICP

5- The increase of temperature during ICP is not enough to explain the experiments

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6.-More experiments are necessary to discriminate.

Some bibliography

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