PECULIARITIES OF DARK CONDUCTIVITY IN IRRADIATED SILICON

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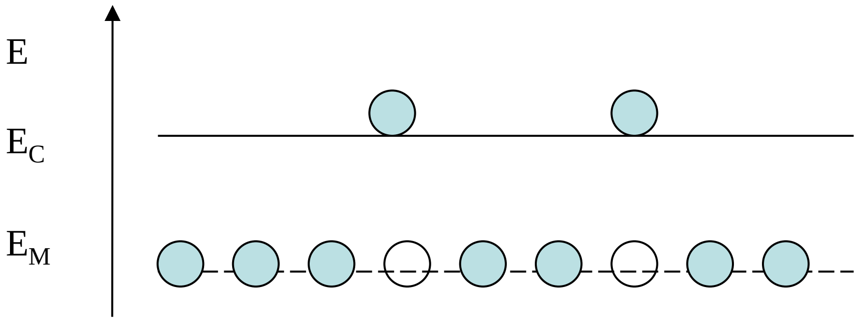
Purpose:

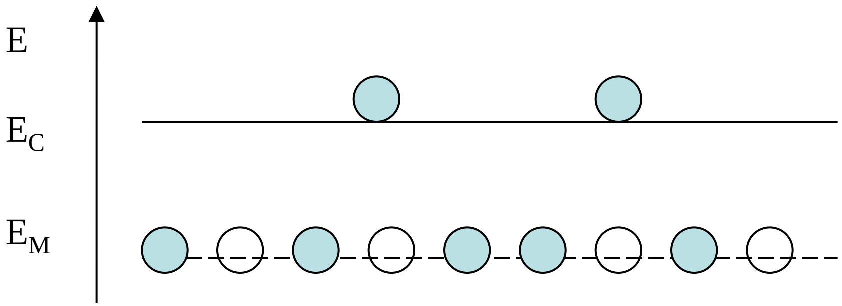
- To point out the main deep levels contributing to the dark conductivity in the irradiated silicon
- To pay attention to the problems seen in the analysis
- To propose a model that can explain the observed non-classical behavior.

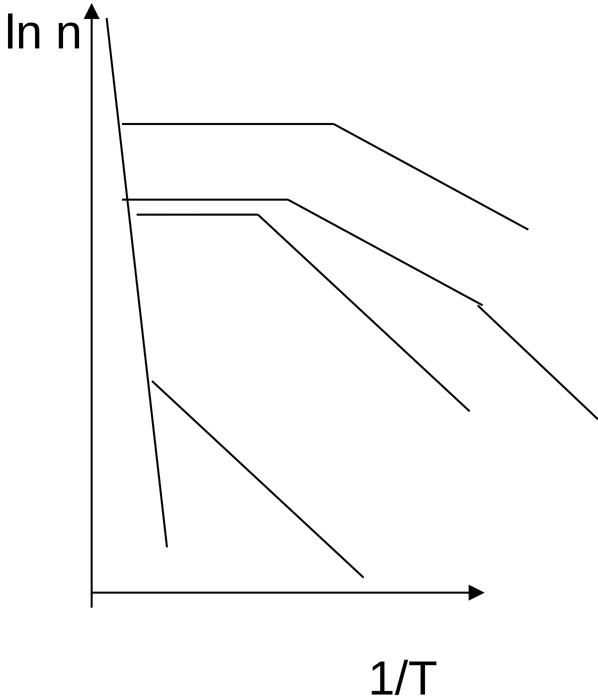
Classics:

- $n=N_M/\{1+\sqrt{[1+(4\beta N_M/N_C)\exp(\Delta E_M/kT)]}\}$.



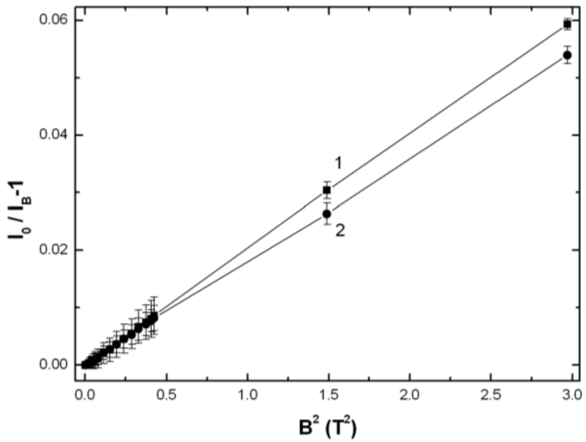
- $n=(N_M - N_K)/[1+(\beta N_K/N_C)\exp(\Delta E_M/kT)]$
  - $n=\beta N_C\,[(N_M - N_K)/N_K]\exp(-\Delta E_M/kT)\}$,

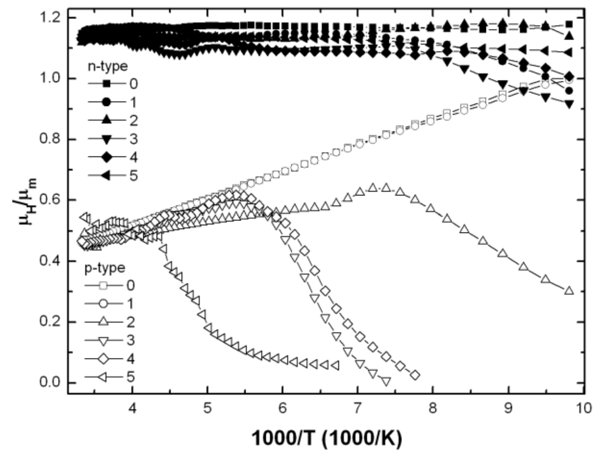




Mobility measurement results

$$\mu_H = \frac{V_H}{BV_X} \qquad \mu_M = \frac{1}{B}\sqrt{\frac{\rho_B - \rho_0}{\rho_0}}$$

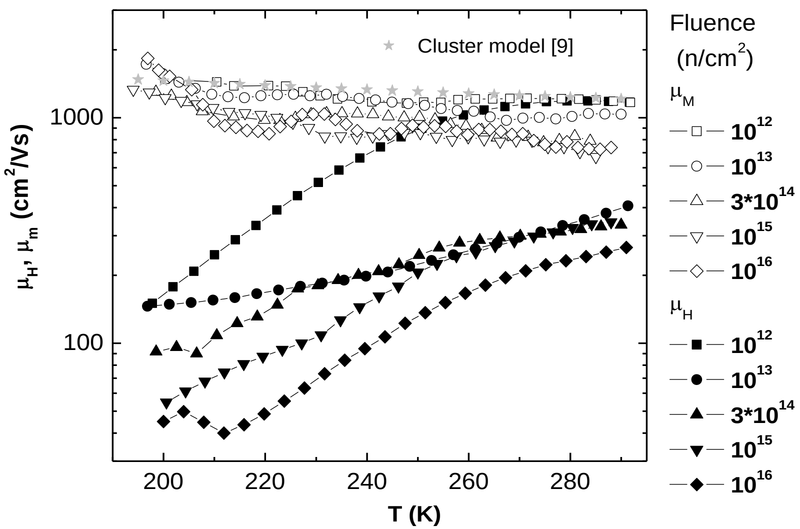


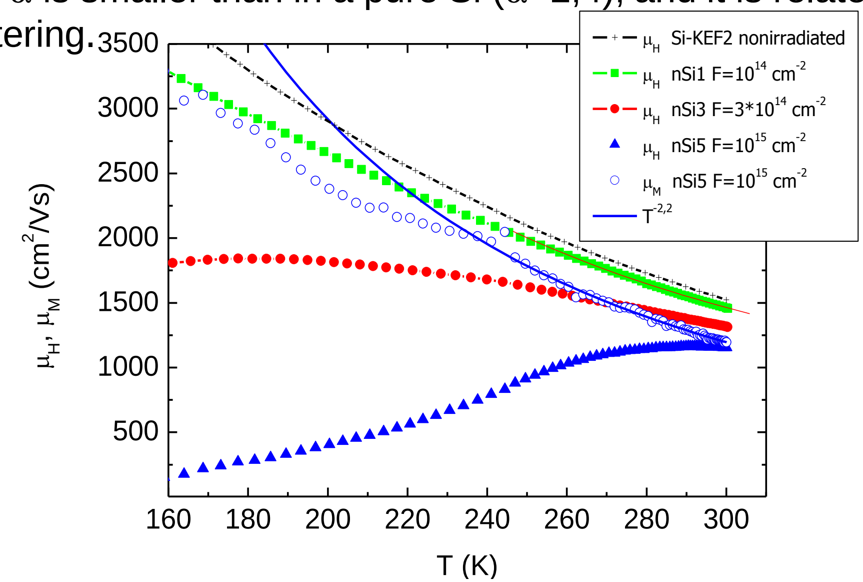


1,2,3,4,5 times10^{16} e/cm^2.

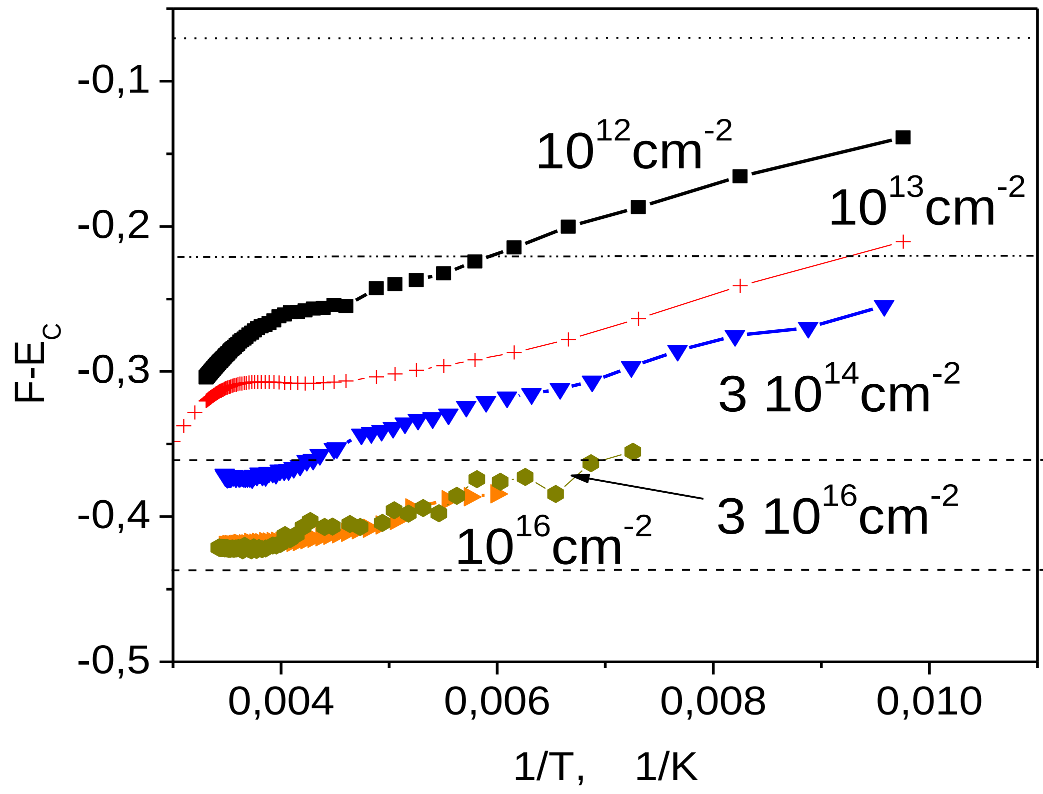
Details will be published as a joint paper with L.Makarenko group (Minsk), and it was presented at earlier meeting of RD50

At ~T_{Room} the electron μ_H and μ_M are ~ $T^{-\alpha}$, and α is smaller than in a pure Si (α=2,4), and it is related to the contribution of impurity (and the cluster) scattering.



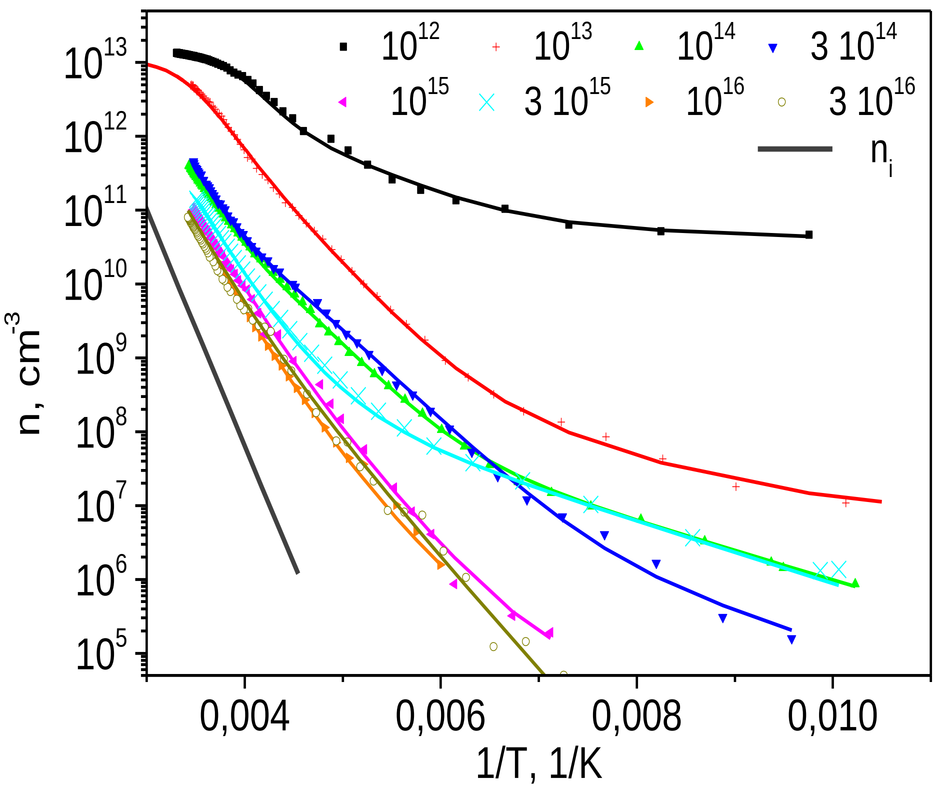


Fermi level = j(1/T) in irradiated Si



- According this dependence it is possible to think about the model that might fit to the experiment

lgN=f(1/T) in the irradiated Si



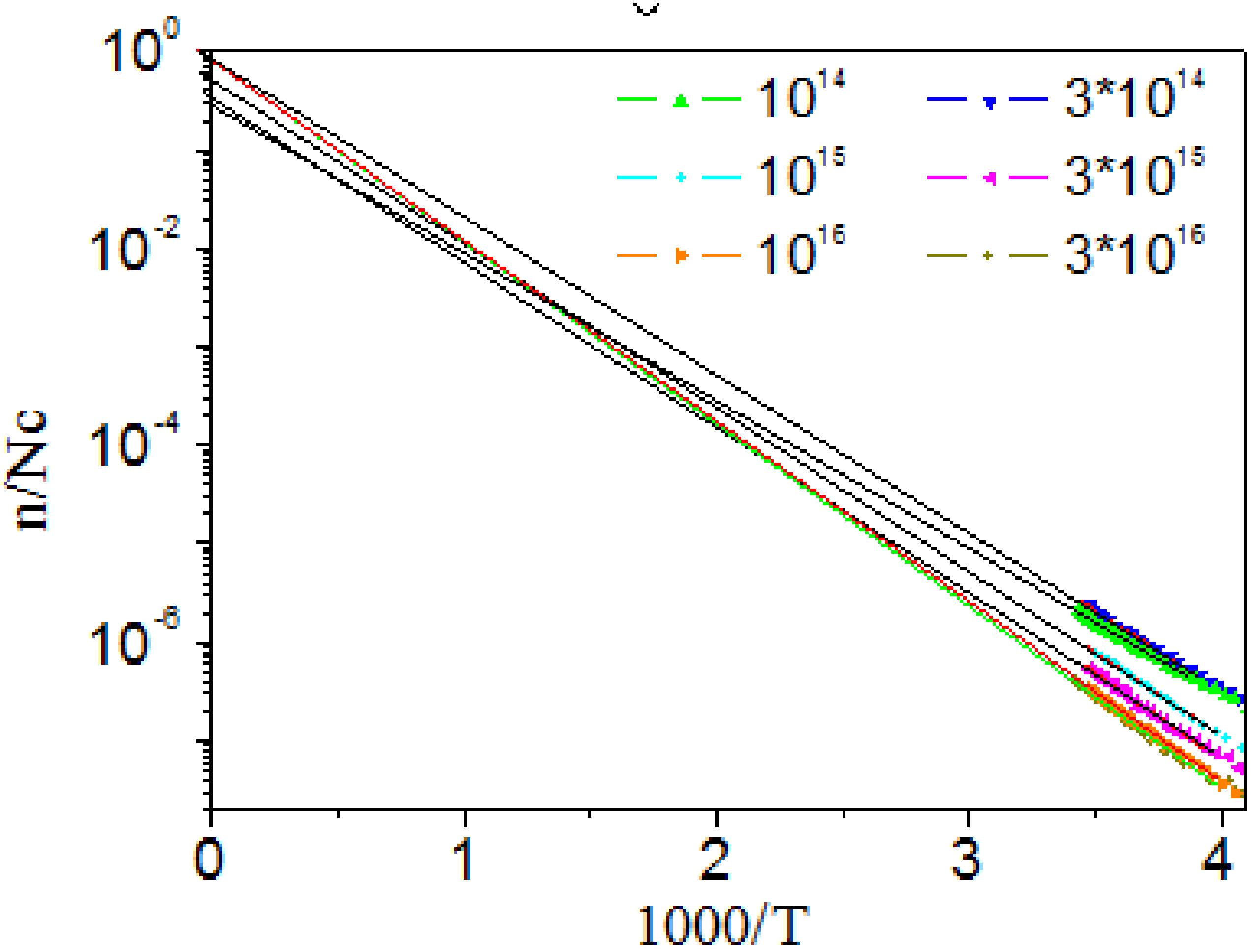
	Deep level 0,40 eV	Deep level 0,36 eV	Deep level 0,22 eV (0.23 eV)	Shallow level 70 meV	Shallow level 46 meV
Fluence 1e12 cm^{-2}					
(N_M-N_K), cm^{-3}		1.3e13	1.3e12 (8e11)	5e10	
βN_M		1.2e11	2e13 (4e12)		
Fluence 1e13 cm^{-2}					
(N_M-N_K), cm^{-3}		1.2e13 (1.2e13)	1e11 (1e11)	2e8 (2e8)	3e6 (3e6)
βN_M		8e12 (9e13)	2e13 (1e13)	2e15 (2e15)	
Fluence 1e14 cm^{-2}					
(N_M-N_K), cm^{-3}		1e14 (1e14)	1e10 (1e10)	1e8	≤ 4e5
βN_M		2.4e14 (2.4e14)	2e13 (1e13)	1e16	
Fluence 3e14 cm^{-2}					
(N_M-N_K), cm^{-3}	5e12 (6e12)		2e10 (3e10)	3e7 (3e7)	
βN_M	6e12 (2e12)		2e13 (2e13)	2e16 (2e16)	

V_2 and V_3 contribution is enough to fit the experimental data in the samples irradiated to 1e12-1e14 cm^{-2}

Level activation energy	0,44 eV	0.43 eV	0.41 eV	0.28 eV	0.27 eV	0,22 eV	70 meV
Fluence 1e15 cm^{-2}							
(N_M-N_K), cm^{-3}			3.2e12			3e10	3e8
βN_M			2e12			3.3e13	3e16
Fluence 3e15 cm^{-2}							
(N_M-N_K), cm^{-3}		5e12			3e11		2e6
βN_M		2e12			5e14		3e16
Fluence 1e16 cm^{-2}							
(N_M-N_K), cm^{-3}	4e12			2e13			3e6
βN_M	2e12			4e16			3e16
Fluence 3e16 cm^{-2}							
(N_M-N_K), cm^{-3}	4.2e12			3e11			
βN_M	2e12			3.3e14			

The main problem: why activation energy depends on the irradiation fluence???

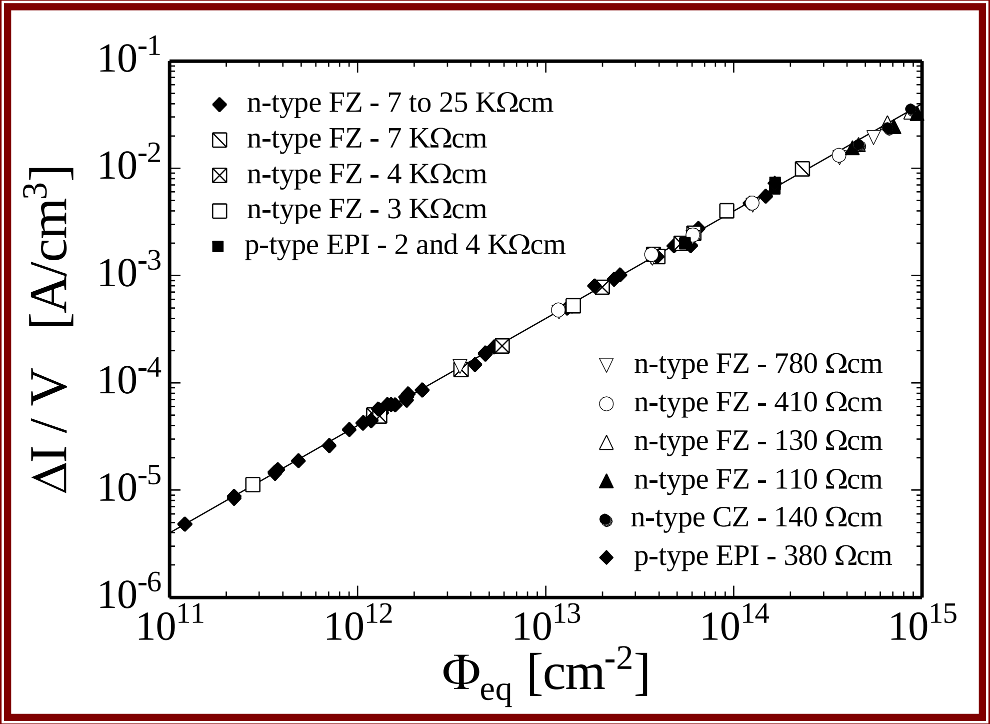
lgN=f(1/T) in the irradiated Si

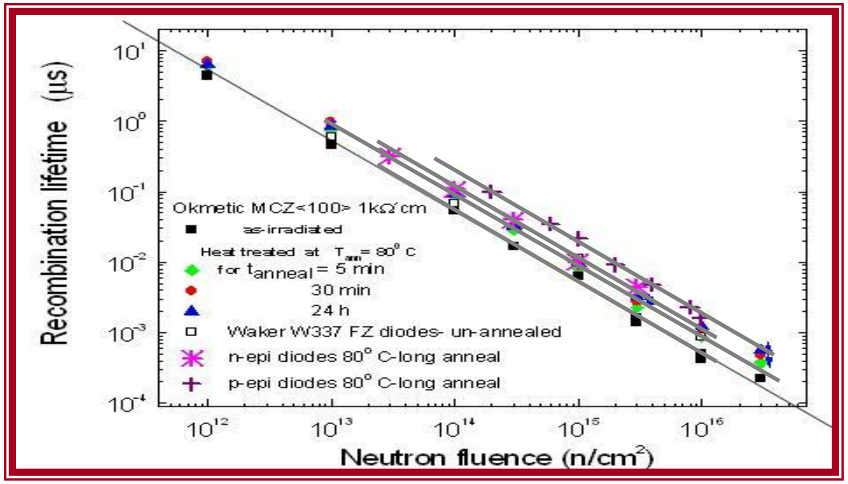


A fan type dependencies.

Earlier investigations show: the increase of irradiation fluence does not introduce evident nonlinearity:

The reverse current [Lindstrom G., Moll M., Fretwurst E. Radiation hardness of silicon detectors - a challenge from high-energy physics. NIMA 426, 1999, 1-13 p.] and free carrier lifetime [E. Gaubas, T. Čeponis, A. Uleckas, J. Vaitkus. Anneal dependent variations of recombination and generation lifetime in neutron irradiated MCZ Si. NIMA 612, 2010, 563-565 p.] linearly depend on the fluence in a wide range of fluence.





$$\frac{1}{\tau} = \gamma P_R = aF$$

A summary of non-classics:

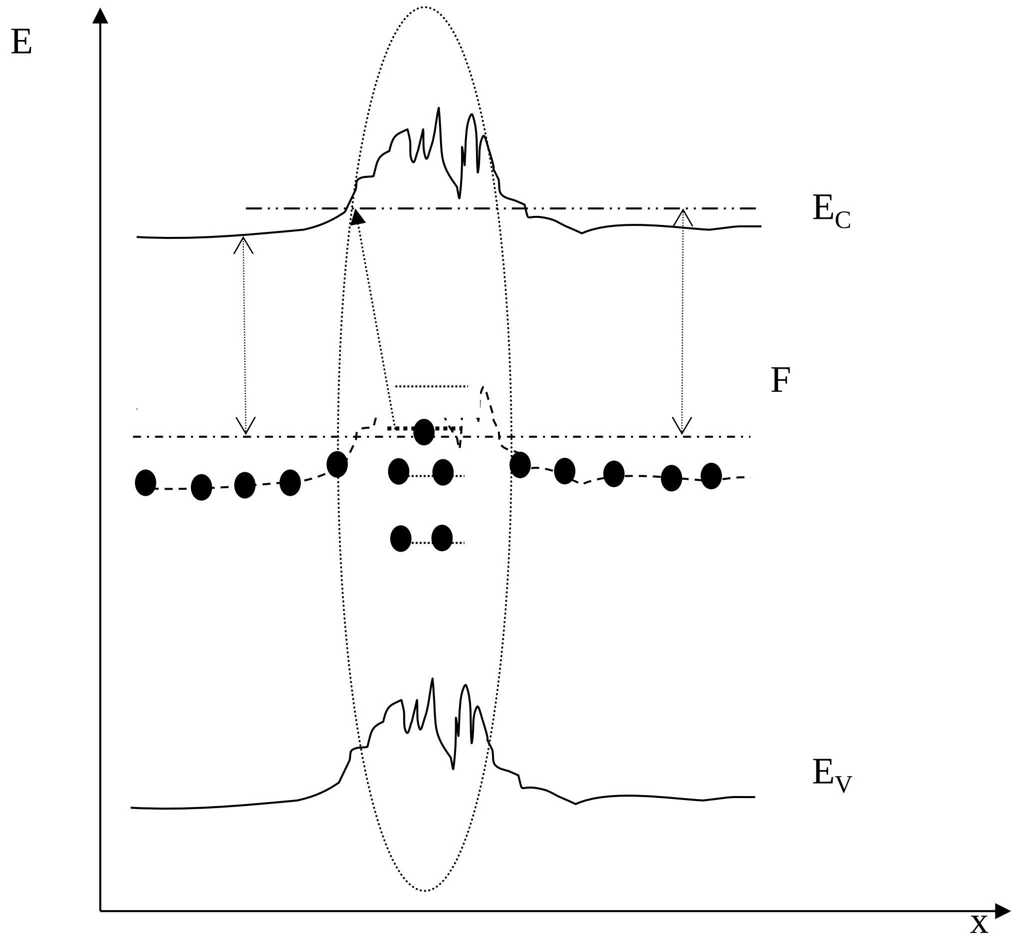
- The deepest level responsible for the dark conductivity is partly filled by electrons;
- The activation energy depends on the compensation of conductivity (that directly related to the fluence).

A summary of predicted cluster properties:

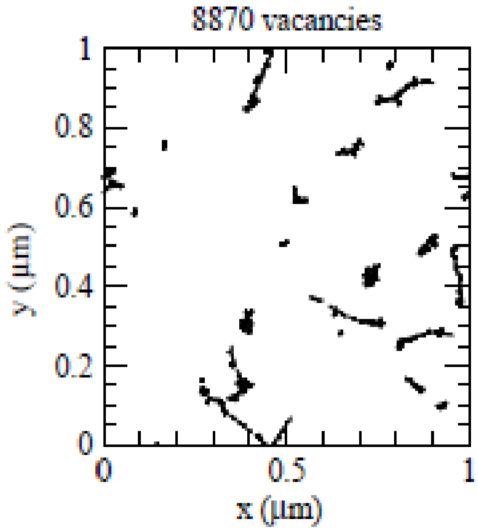
- The cluster has a randomized structure including various complexes of vacancies;
- The crystal structure around the cluster is random and it can introduce the disordered region properties.

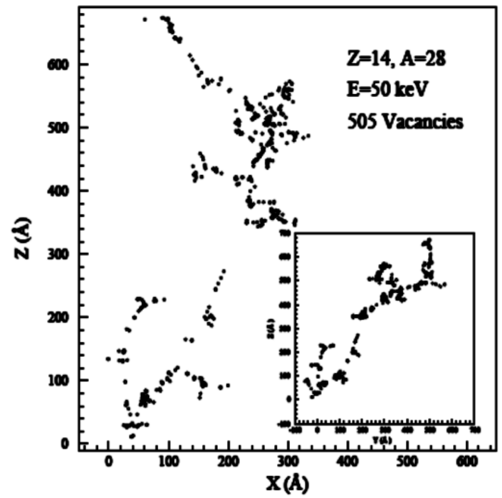
A model of cluster following from the dark conductivity measurement:

- The cluster barrier causes a partly filling the centers inside the cluster or at its boundary.
- The compensation increase *(an increase of deep acceptor concentration)* the Debye length therefore causes the increase of the energy required to excite the electron from the deep level.



Modeling of defect generation





Vacancies generated by 1 MeV neutronais.
Fluence: 10^{14} cm^{-2} . [M.Huhtinen. NIMA 491 (2002) 194–215]

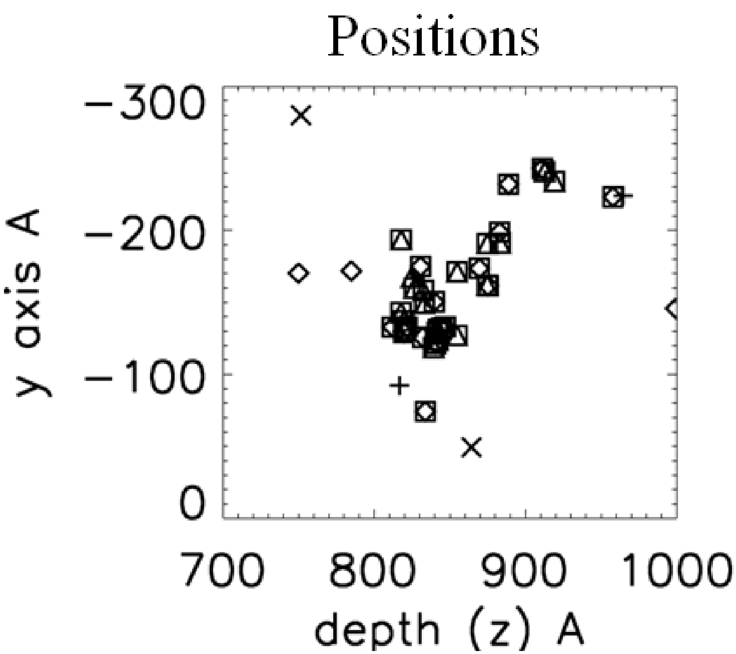
General points: TRIM calculation. A 50 keV ion creates a cluster about 100 nm length in a time of 20 fs. (one vibrational period). The energy deposited gives a high temperature (up to ~1000 K). If [O] = 10^{18} cm^{-3}, may have 1 O atom in the cluster.

Following the WODEAN (Bucharest) 1.

After random walk (Time nano- to milli-seconds)

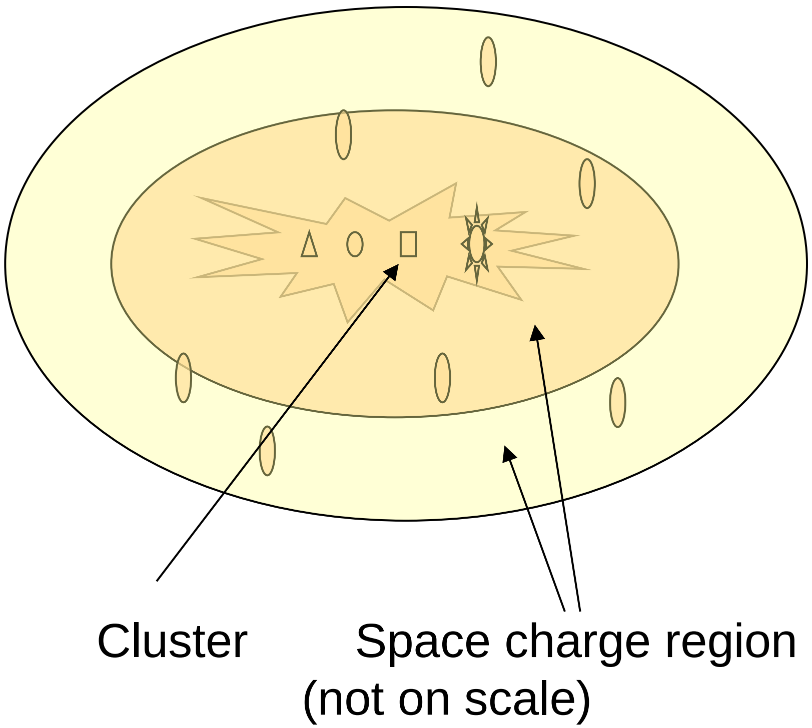
I (X)   V (+) I_2 (◆) V_2 (Δ)

I-clusters (◆) and V-clusters (Δ) in squares



Reconstruction of the cluster in a cube.
G.Davies, RD50 WODEAN conference, Bucharest:

Approximation:



Conclusions:

- The main impurities responsible for the dark conductivity are similar to bi- and tri- Si vacancies (V_2 and V_3).
- At T near to room T the conductivity is caused by the deep levels in the cluster or its environment, and they are partly filled in the highly irradiated Si.
- The increase of the free carrier activation energy in the highly irradiated samples allows to propose the quenching of thermal generation of free carriers due to the compensation of conductivity.
- The proton irradiation could allow to test the model. *(Who like to collaborate?)*

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THANK YOU FOR YOUR ATTENTION!