Photoconductivity spectra as a tool for Si material stability control?

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Silicon

- Everybody here knows:
  - During irradiation:
    - by hadrons and high energy electrons clusters are created, detectors degrade.
    - By gamma rays and charged particles – vacancies and interstitials appears. They also contribute to degradation of devices.
  - The mixed irradiation differs from any one type irradiation:
    - i.e., different defects participated in the reactions.
- Question(s):
  - How cluster and pint defect system changes during the detector age?
  - Is it different in different type of Si
  - HOW TO compare Si material?
    - How different peculiarities reflects in the detector degradation procedure?

In this talk I like to look for answer on one of those questions:

- –HOW to compare different types of Si material?
- –Does the growth method is critical, or something else is important

Summary:

It is proposed:

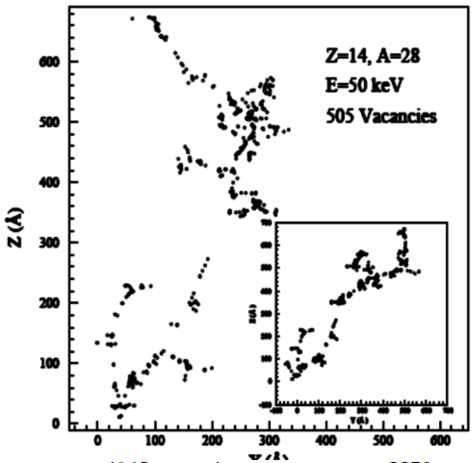
to use the photoresponse spectra measurement at low temperature for the initial characterization of material,

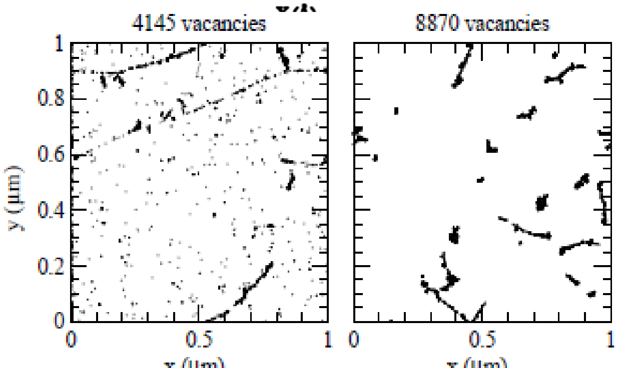
to recognize an existence of deep levels characterized by strong electron-phonon interaction

to characterize the traps responsible for a long memory of nonequilibrium carriers generation.

Processes related to defect generation in Si.

One cluster – complicated shape nanosize defect (<100 nm)





[M.Huhtinen. NIMA 491 (2002) 194–215]

The vacancies and interstitials are rather mobile even at room T, therefore this multivacancy and interstitials complex is not stable, and transforms to the different vacancies and interstitials clusters, also part of V_{Si} and I_{Si} recombines.
G.Davies, at CERN RD50 WODEAN Workshop.

It could be proposed: no impurities present in the cluster because if [O] = 10^{18} cm^{-3}, it may be only one oxygen atom in the cluster,

but Si(O) is more radiation hard than only Si !!!,

Important problems:

Do the clusters and their environment change during the detector work?

What could be a nature of these processes?

Therefore:

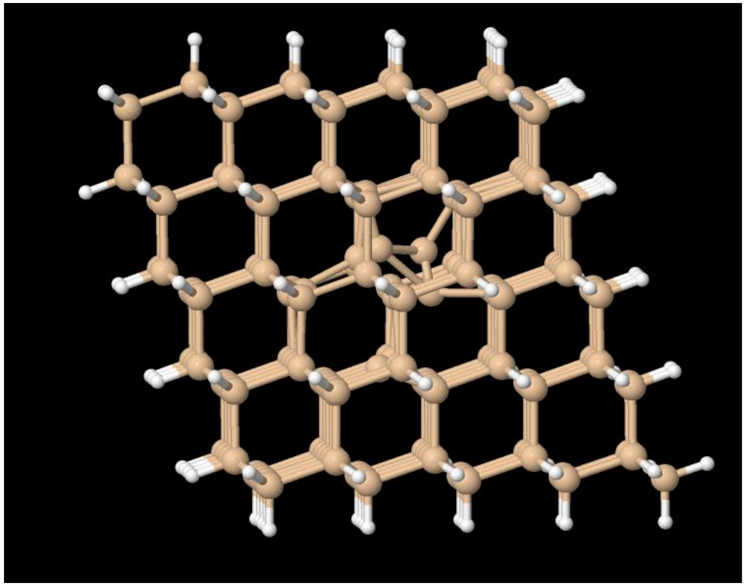
probably it is important to develop the means to recognize which Si is more stable, or has a feature – to self-anneal the defects.

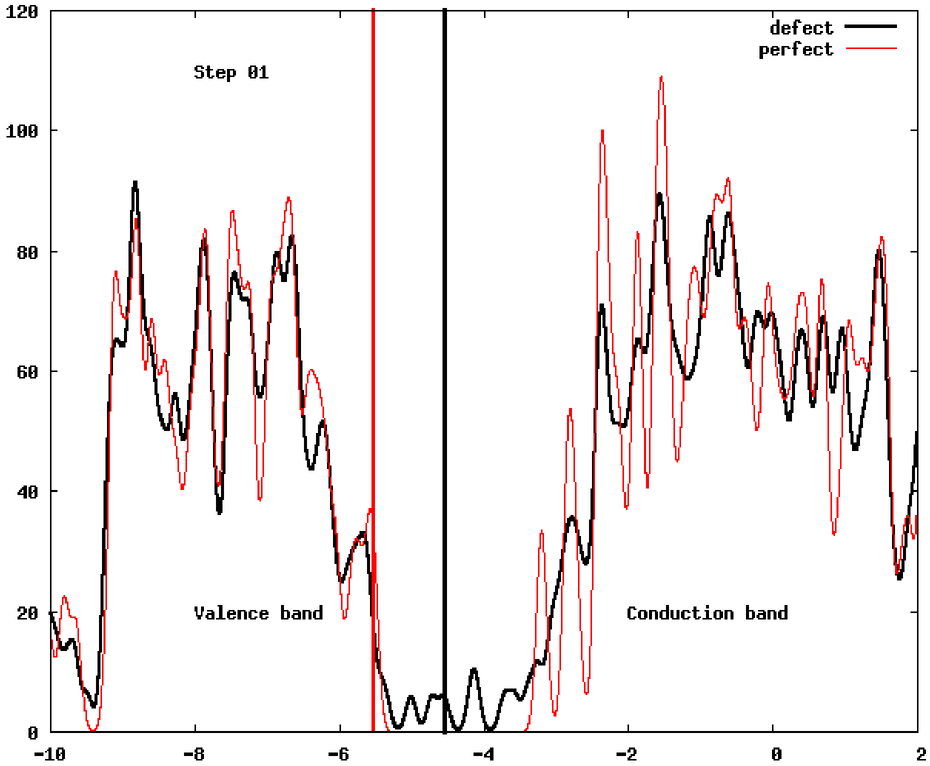
What is a nature of parameters' time dependence?

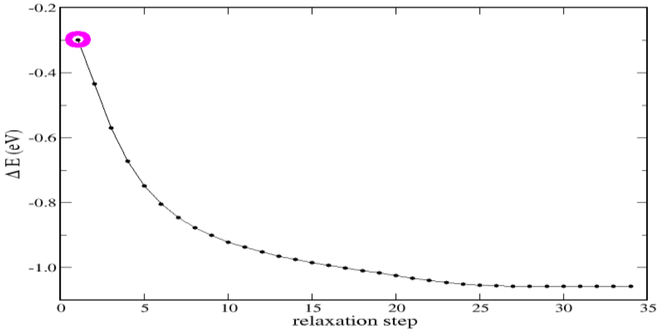
- Vacancies and interstitials mobility *(it is well known processes)*
- Defect reactions – complex formation
- Cluster transforms due to V & I annihilation, V_2, V_3 and etc. formation.
  - Why do they change? It requests energy.
  - The energy comes from a sample temperature, but, also, from the free carrier capture.

The relaxation of structure:
(this slide is from previous RD50 Workshop. Simulated by E.Zasinas)

The relaxation of the density of states



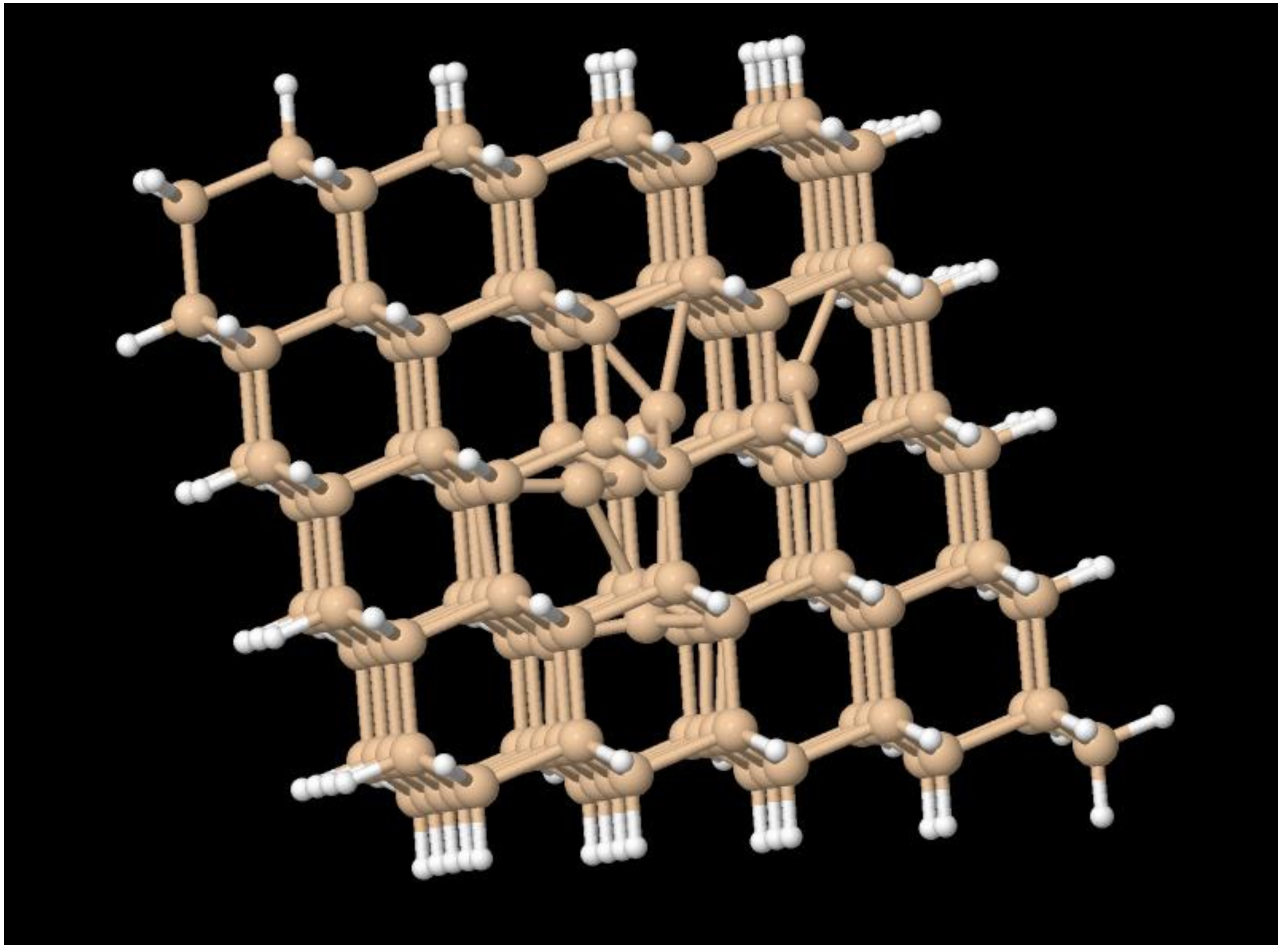




What energy source does it stimulate?

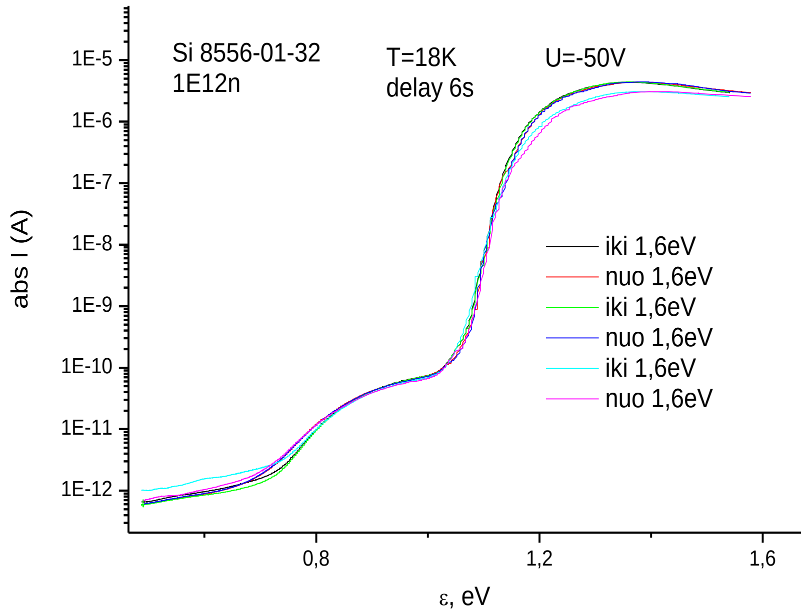
Relaxation of the system energy.

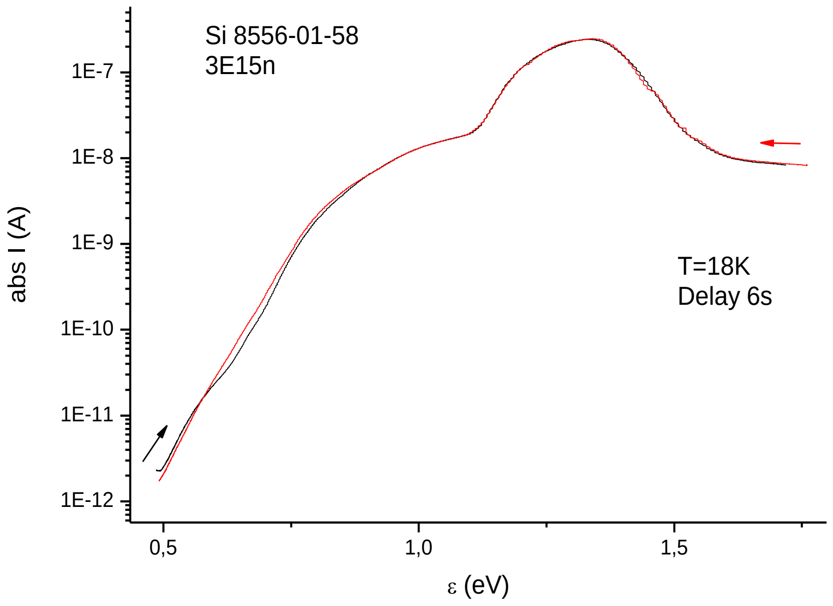
An example: the randomized cluster relaxed to the perfect structure.



If now to turn to the photoconductivity:

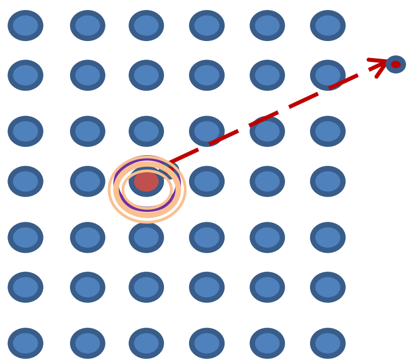
PC spectra as from the manual
Si (MCZ)

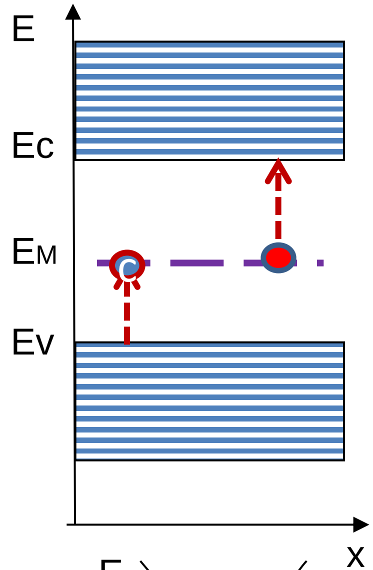


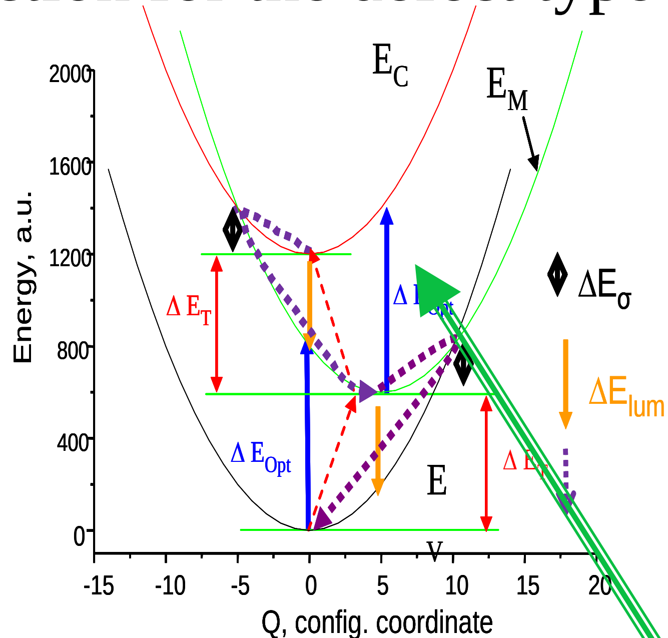


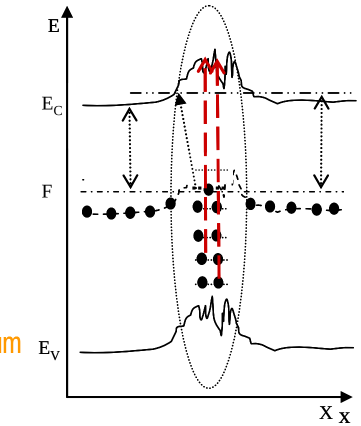
Photon capture cross-section for the defect type recognition.

No electron-phonon interaction

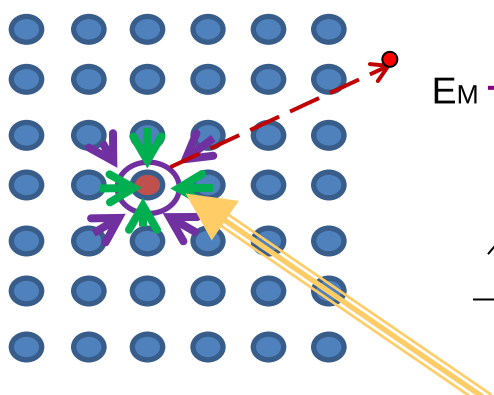


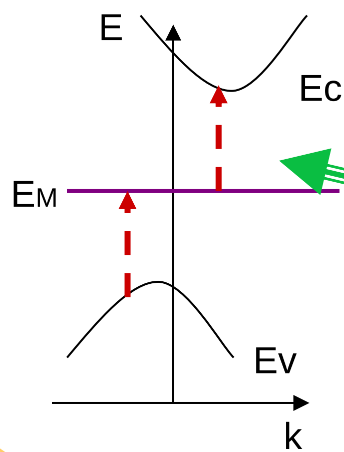


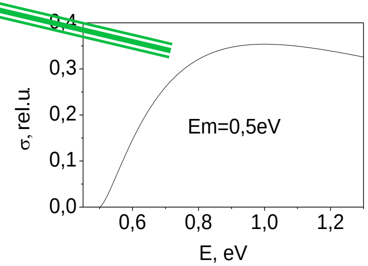




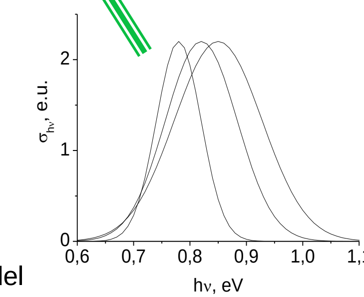
The spectral dependence of photon capture cross-section $\sigma_{h\nu}$ are different for these centres.







Lukovsky model



Gaussian model

Electron-phonon interaction

Lattice relaxation and reconstruction

If the electron-phonon interaction is strong, the cluster can be changed due to free carrier recombination.

It is important to control if the clusters are different in different Si wafers !!!

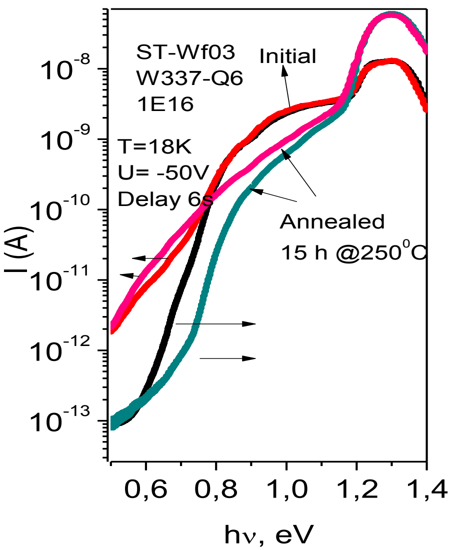
How to use this method in practice?

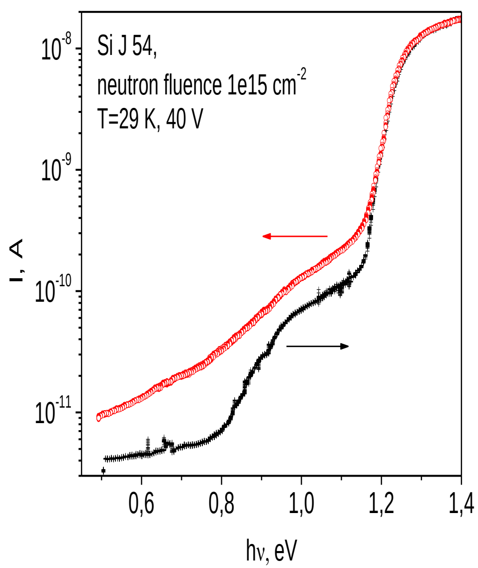
It is easy in a case of the simple semiconductor case.

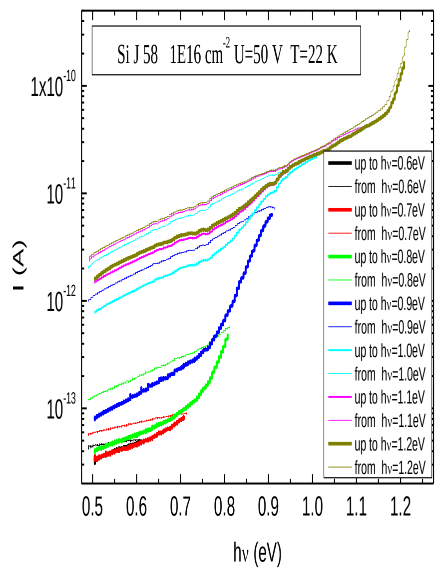
In case of semiconductor with the clusters there are the barriers that may separate the non-equilibrium electrons and holes.

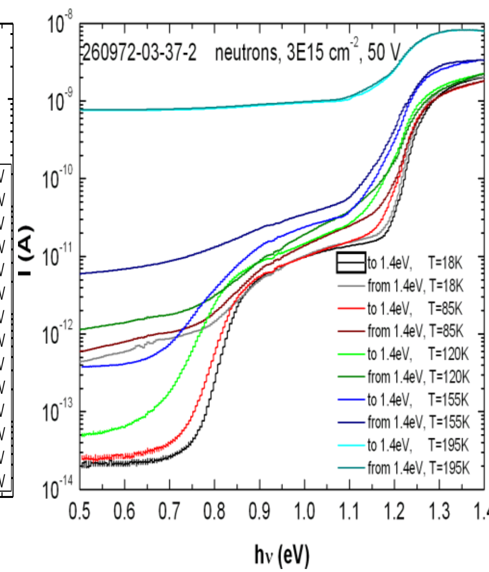
It causes the accumulation of signal (& a long relaxation time)

Examples:









FZ MCZ

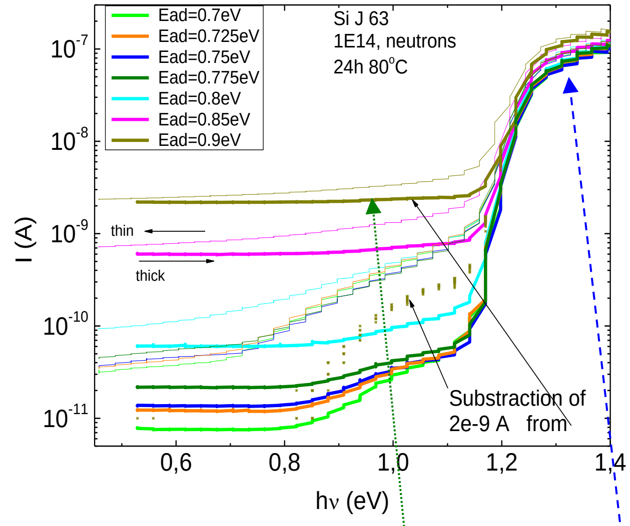
The dependence of photoresponse on the photon energy during the measurement increasing **(black)** and decreasing **(red)** the photon energy

MCZ Epi

The dependence of photoresponse on the photon energy during the repeated measurement *(and @ different T – right).*

An attempt to avoid the signal accumulation:

- If the accumulation of a signal in the sample observed, it is impossible a direct fitting of spectral dependence of photoresponse to the models.
- If the accumulation is caused by traps, the additional light has to fill them and effect should disappear.

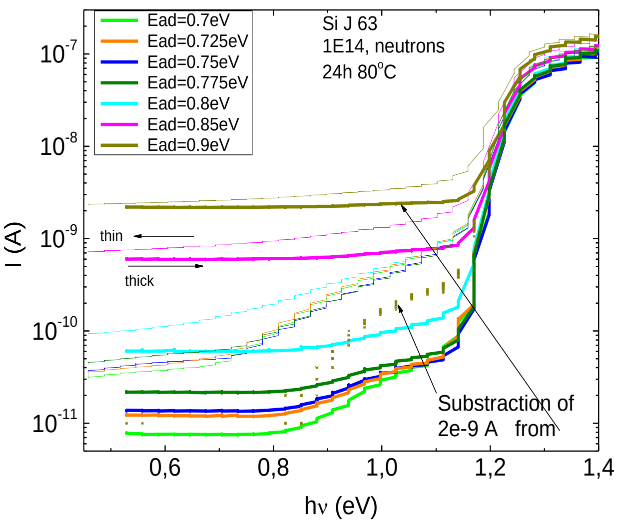


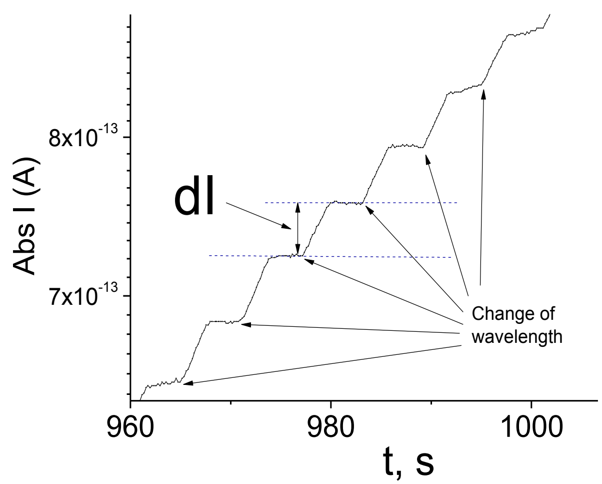
The additional excitation changes the deep level contribution and free carrier lifetime, but not reduce the accumulation effect.

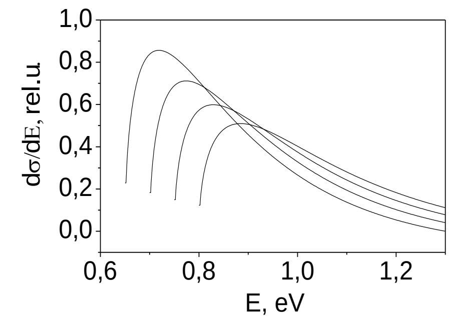
The additional excitation did not exclude the accumulation, i.e., it is not related to the trap influence.

The method to avoid the signal accumulation:

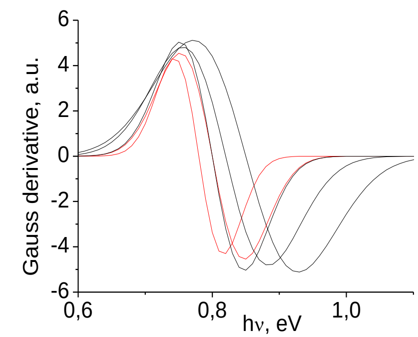
It is proposed to analyze a spectral dependence of a change of the photoresponse if the photon energy is increased by a small value.







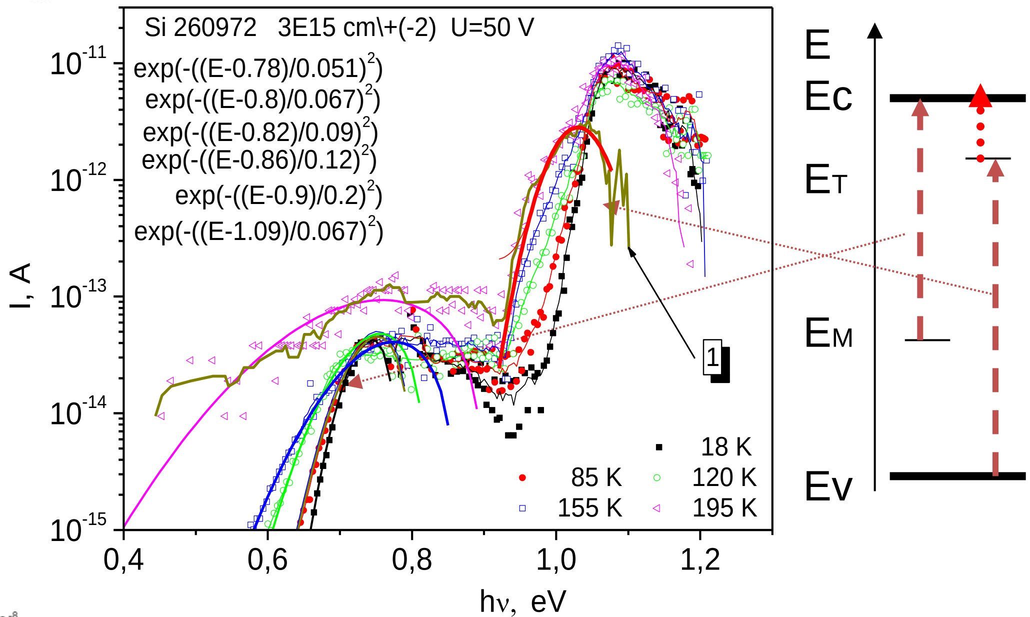
Lukovsky model

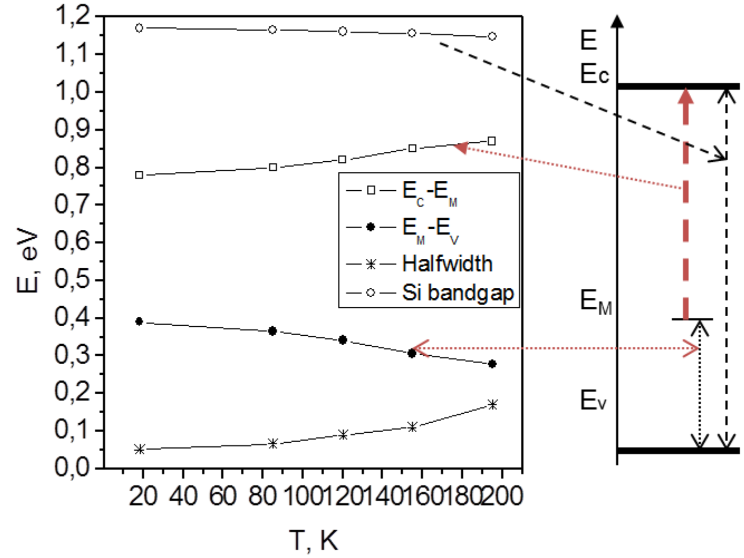


The spectral dependences of differential photoresponse in Si at different T, and fitting to a derivative of Gaussian or Lukovsky model.

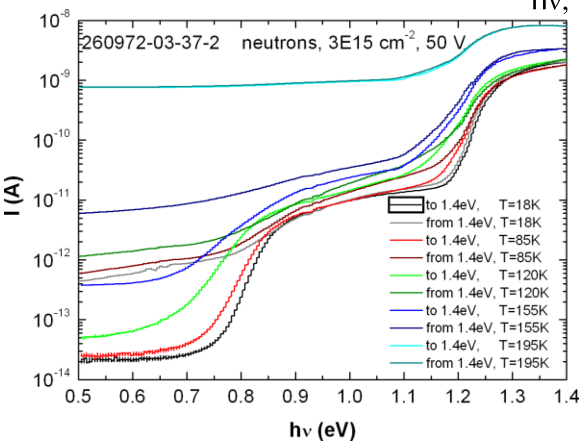
Gaussian model

The spectral dependence of differential photoresponse spectral dependence: a case of analyze of temperature dependence of extrinsic PC





The dependence of the half width of the Gaussian function on T, and the activation energies of deep level corresponding to Ec and Ev



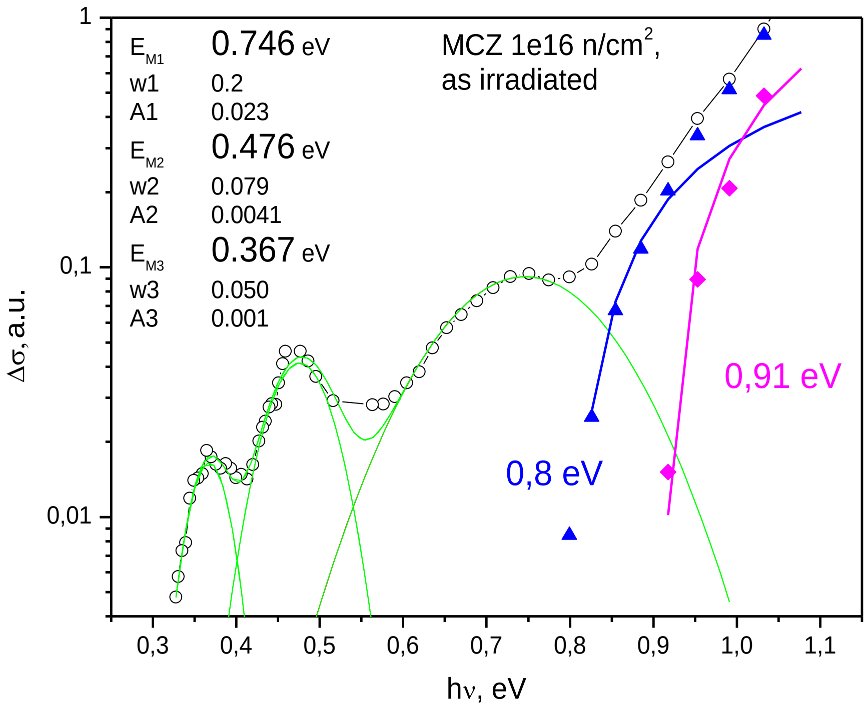
The spectral dependences of full & differential photoresponses in Si at different T, and fitting to a derivative of Gaussian model.

The intermediate conclusions:

1) If it exists the temperature dependence of PC band tail, the strong e-phonon interaction exists, and **the recombination induced annealing can take place;**

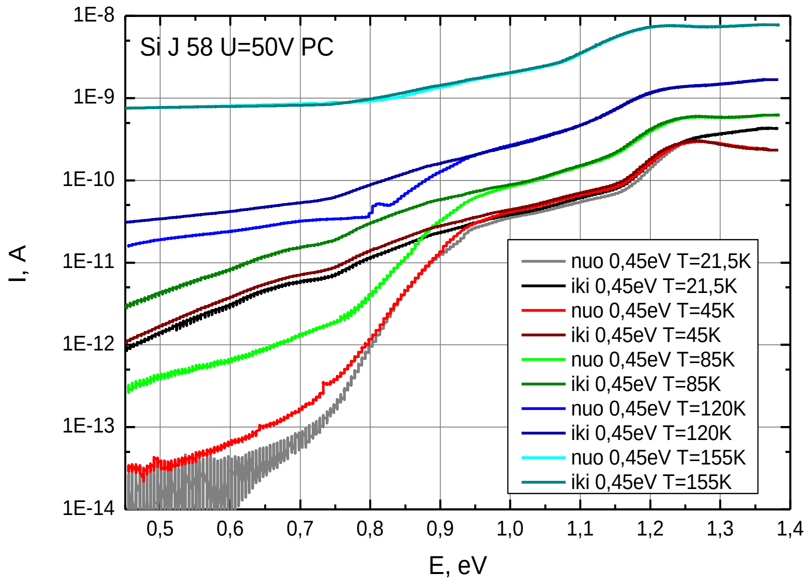
2) The clusters are different in the different wafers (ingots?) of Si !!!

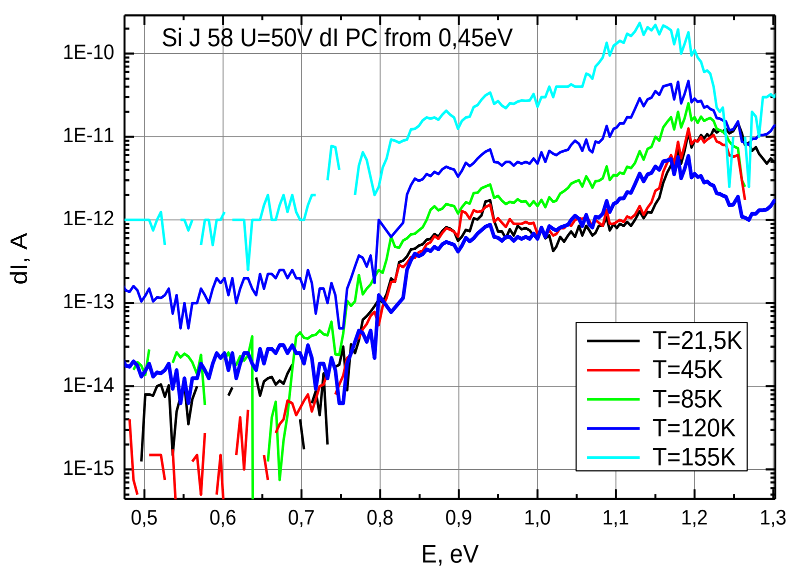
Photoresponse on excitation by 40 fs pulses of the tunable laser



Some scattered examples

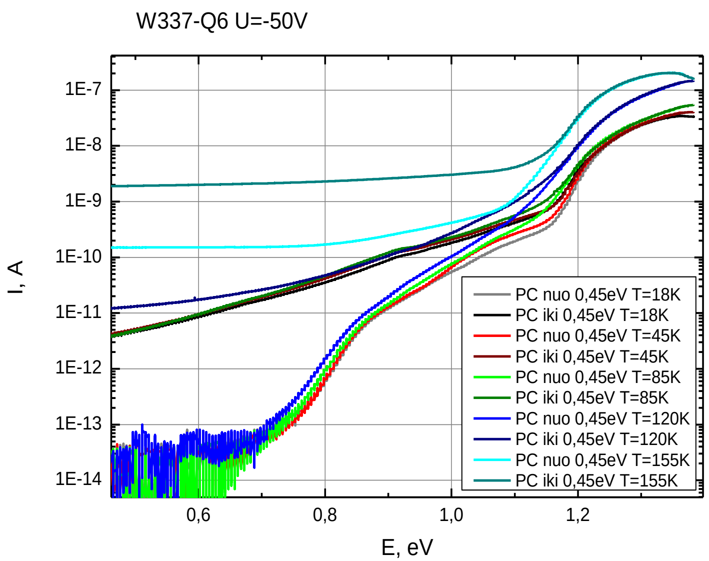
Si(MCZ)

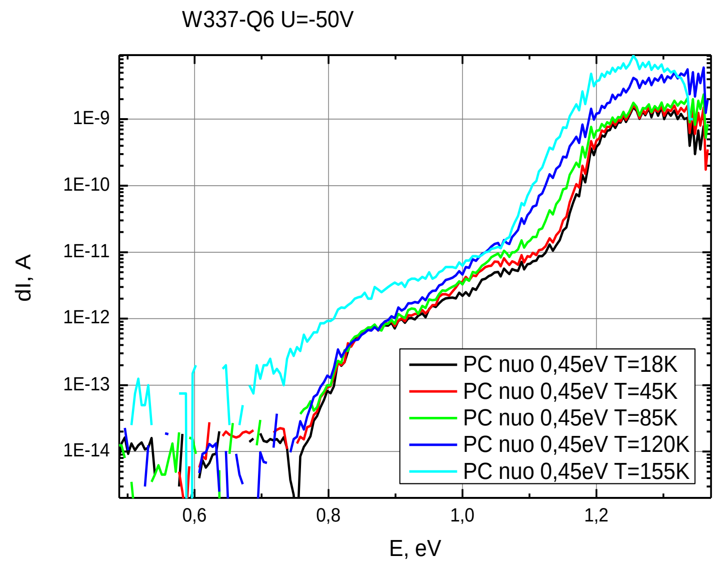




Absence of the spectrum dependence on temperature

Si(FZ)


W337-Q6 U=-50V
1E-7
1E-8
1E-9
1E-10
1E-11
1E-12
1E-13
1E-14
I, A
0,6
0,8
1,0
1,2
E, eV
PC nuo 0,45eV T=18K
PC iki 0,45eV T=18K
PC nuo 0,45eV T=45K
PC iki 0,45eV T=45K
PC nuo 0,45eV T=85K
PC iki 0,45eV T=85K
PC nuo 0,45eV T=120K
PC iki 0,45eV T=120K
PC nuo 0,45eV T=155K
PC iki 0,45eV T=155K

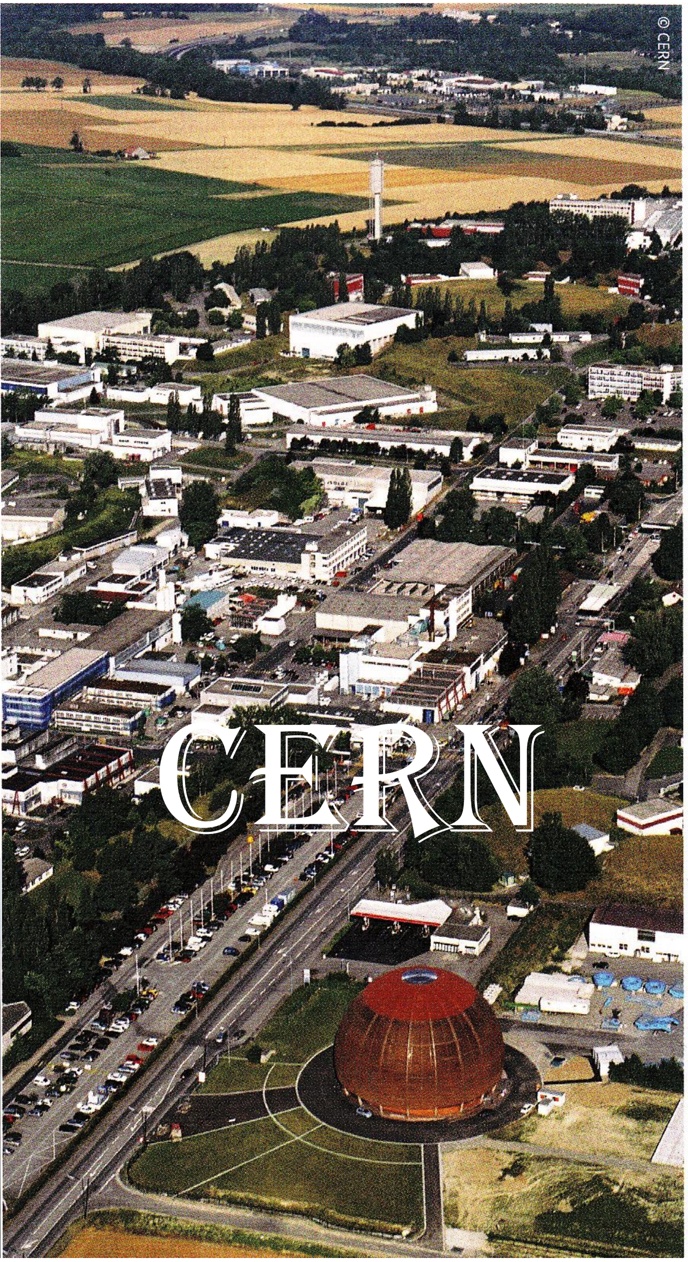

W337-Q6 U=-50V
1E-9
1E-10
1E-11
1E-12
1E-13
1E-14
dI, A
0,6
0,8
1,0
1,2
E, eV
PC nuo 0,45eV T=18K
PC nuo 0,45eV T=45K
PC nuo 0,45eV T=85K
PC nuo 0,45eV T=120K
PC nuo 0,45eV T=155K

Instead of conclusions:

- Nano-size radiation defects in Si are enough complicated and still it is a space for proposals to change properties of defects and semiconductor parameters.
- Photoresponse spectra at low T is a tool to characterize Si, but cannot say, which one is better.
- Maybe a summary of the WODEAN project could be useful for the formulating of recommendation, or maybe it is necessary to plan a new initiative (if our voice could influence a choice the SILICON for the s-LHC)

This work is coherent with CERN RD50 collaboration.
Thanks to Research Council of Lithuania for grants MIP-068/2011 and VP1-3.1-ŠMM-07-K-03-010 and the Lithuanian Academy of Sciences for continuing support of this research and grants CERN-VU-2013-2014.

THANK YOU FOR YOUR ATTENTION!



Summary:

It is proposed to use the photoresponse spectra measurement at low temperature to recognize an existence of deep levels characterized by strong electron-phonon interaction and of traps responsible for a long memory of excitation.

Investigation of different types of Silicon wafers (a few series of MCZ,FZ, epi) allow to reveal the properties of sample that are related with a possible origin of the material stability. It was observed two effects that are seen to be related to the performance of detector fabricated from this material: 1) There are three types of Si. In two groups it was observed a difference in the existence of the levels that cause the long relaxation the free carriers, i.e., accumulation of non-equilibrium carriers, but in one group these levels were excited by photons less than 0.8 eV, in another group by photons less than 1.1 eV. In a third group this effect was absent. 2) The spectral dependence of extrinsic response was dependent on temperature in one group, and the characteristic parameters of spectra were independent on temperature in another group. The differential photoresponse method of deep level analyze was proposed and the parameters of levels were determined in the silicon that has the excitation accumulation effect. It was demonstrated that deep levels near to valence band are differently involved in electron-phonon interaction. The crystals in which electron-phonon interaction is efficient has a feature to demonstrate the defect transform induced by nonequilibrium carrier recombination or trapping. The same type levels were observed by photoresponse spectra measurement excited by short pulses emitted by a tunable laser. The measurement of photoresponse spectra in the test crystals could be used for the selection of silicon crystals that are more stable and less pronounced trapping effects.