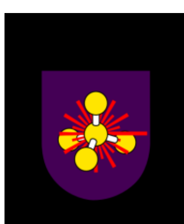

Deep level system Gaussian approximation according the extrinsic photoconductivity in irradiated Si diodes.

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Institute of Applied Research,

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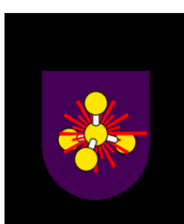
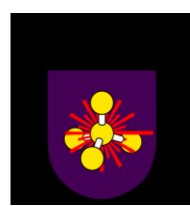


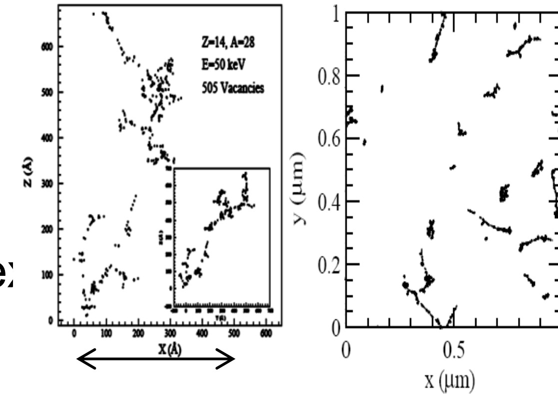
Why photoconductivity?

- If the deep centers are important, the optical excitation excites **ALL** centers (except of those, that due to a strong electron-phonon interaction create the metastable state without a possible optical transition in the extrinsic range, e.g., EL2* center in GaAs).
- Electrical methods feel the centers that are active
  - (e.g., if the center is surrounded by the repulsive barrier, it is almost not seen (except by carrier scattering, or its capture cross-section is very small))
- Therefore, if a correct model of semiconductor is awaited, then optical absorption **(low sensitivity),** or photoconductivity **(high sensitivity)** methods are applicable.

The actual deep level energy spectrum models:



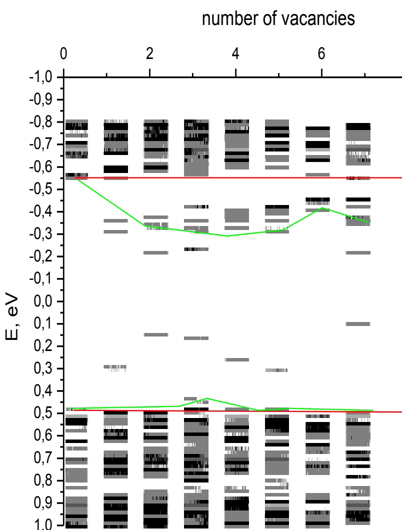
The kick off by neutron Si atom creates a track, consisting vacancies and Si disorder, some vacancies can be generated in a bulk (if the Si is irradiated by protons, then vacancies in the bulk concentration is bigger) (Huhtinen)



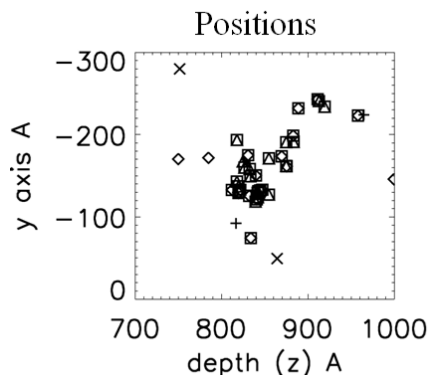
Initial distribution of vacancies produced by 1 MeV neutron in Si, a – a result of kick of Si atom, and b – if a fluence was 10^{14} cm^{-2}, according M.Huhtinen. NIMA 491 (2002) 194–215

Three type of defects have to be created:

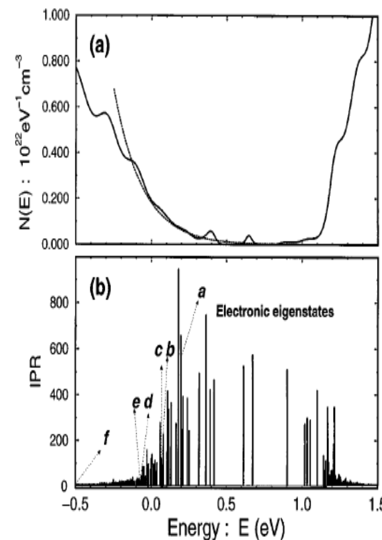
1) the vacancies, multi-vacancies, vacancy-interstitials complex
2) Vacancy-impurity complexes,
3) Clusters, consisting different complexes inside

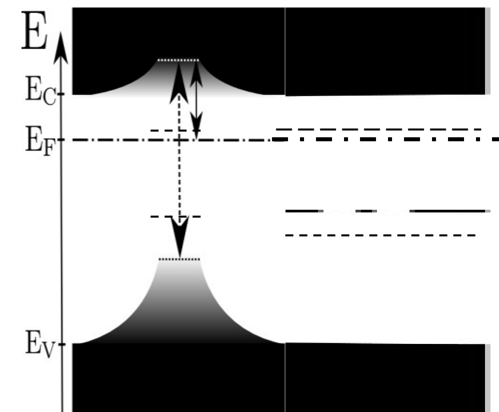


J.L. Hastings et al. Vacancy aggregates in silicon. Phys. Rev. B, 56, p. 10215 (1997).



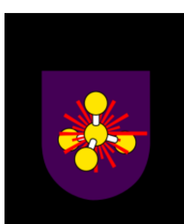
G.Davies, RD50





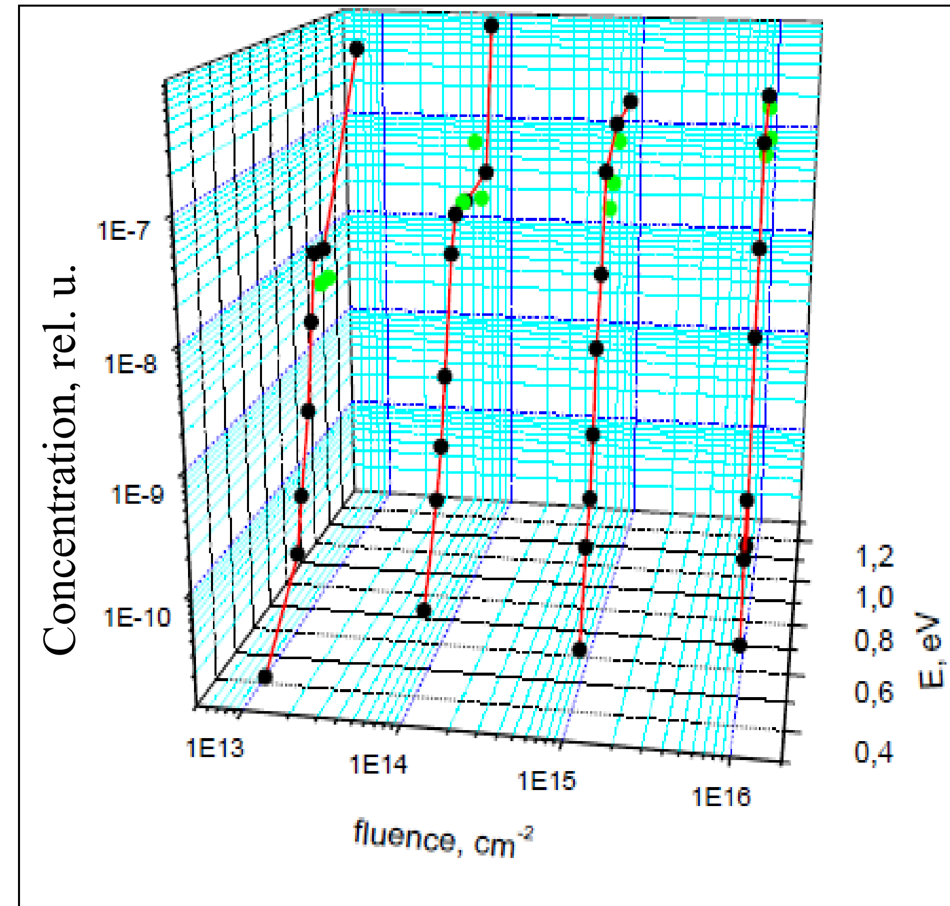
The valence tail is primarily due to structural disorder, the conduction tail is much more sensitive to temperature and originates in thermal disorder.

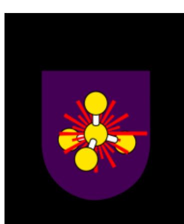
J. Dong, D. A. Drabold. Atomistic Structure of Band-Tail States in a-Si. Phys. Rev. Lett. 80,. 1928 (1998).



Earlier results (related to this talk)

- Investigation of deep centers in the irradiated Si
  - Our results presented in RD50 Workshops
- **This presentation, due to high number of centers, was found too complicated or not enough evident.**
- Therefore a possible distribution of deep level energies was analyzed and the approximation by Gaussian model is presented in this talk.





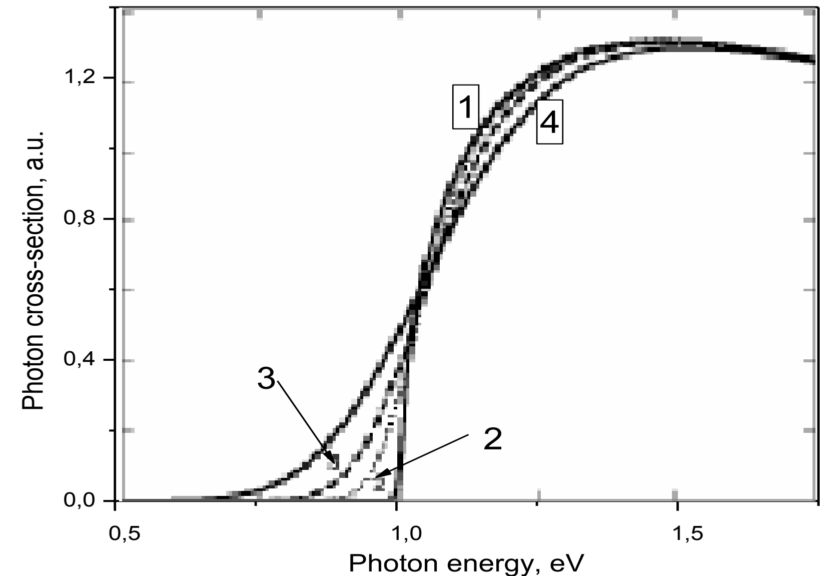
Basics about the deep levels

- If the deep level property δ-potential then Lukovsky model can be applied for the data analyze.

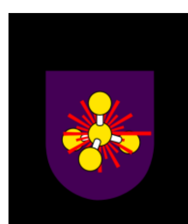
  $I \sim m \times \Delta E_M{}^{0,5}(h\nu - \Delta E_M)^{1,5}/(h\nu)^3)$

- This model (at low temperatures) does not valid:
  - for the hydrogen type defect

    &
  - for the inter-deep level state transitions
- Low temperature requires the attention on the filling of the traps and to avoid the influence of electron-phonon coupling



In this series of analyze we modified the measurement equipment:



Now the equal number of light quantum was kept at each wavelength of the excitation. In earlier measurements the linear dependence of photoresponse on excitation was proposed (and checked for some cases, but not for all samples).

Controlable light source

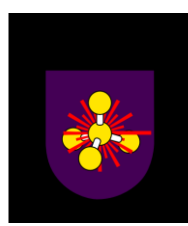
Helium cryostat

Measurement equipment

Grating monochromator for the additional excitation

Prism Monochromator for spectral measurements

Investigation of Traps and Recombination centers



E

E_C

E_V

Traps

Recombination centers (RC)

All levels can be recognized by photo-ionization spectra (the recombination-capture and two-step excitation makes the problem to measure the concentration, but not the activation energy !!!

The traps recognition in homogeneous sample –most common - by the **T**hermally **S**timulated **C**urrent methods

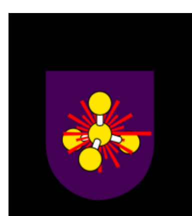
– illumination at low T,

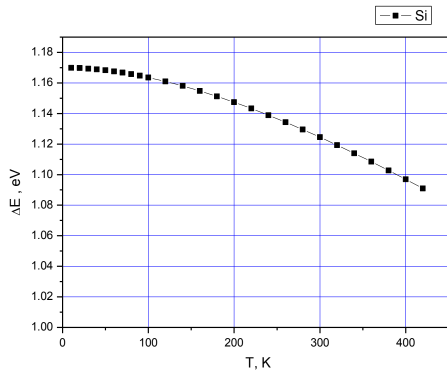
- Wait until free carrier recombine (if some of them do not recombine and the current does not disappear, it is a signal that the free *e* and localized *h* are separated by a barrier),

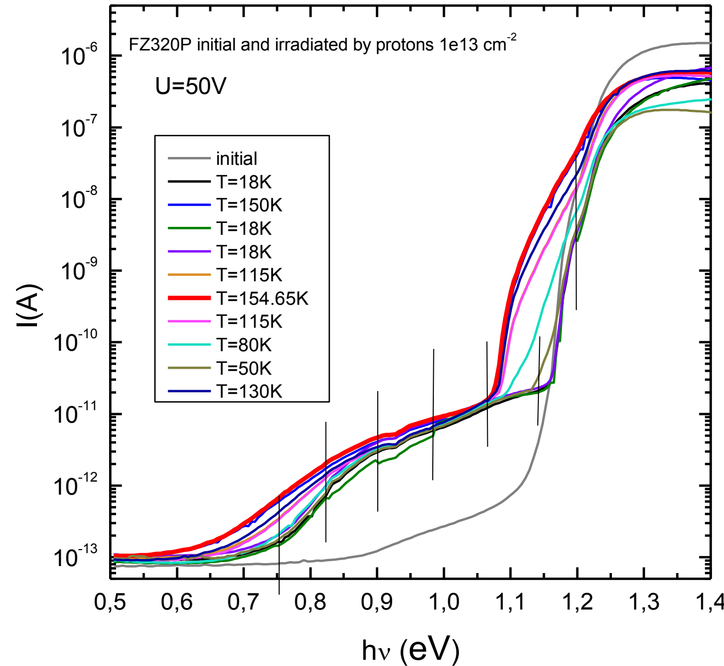
- linear increase of T **OR**
- Multiple heating and cooling by ΔT

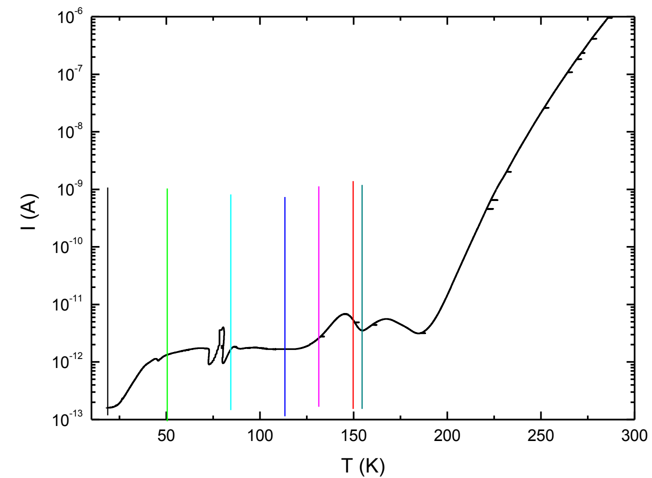
Two step excitation of carriers

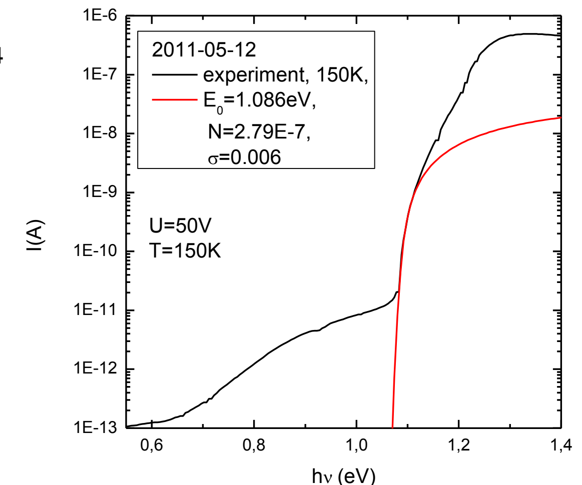
(the effect observed in the CMS CEC proton irradiated samples)



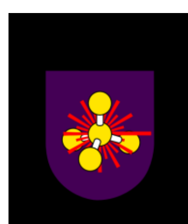






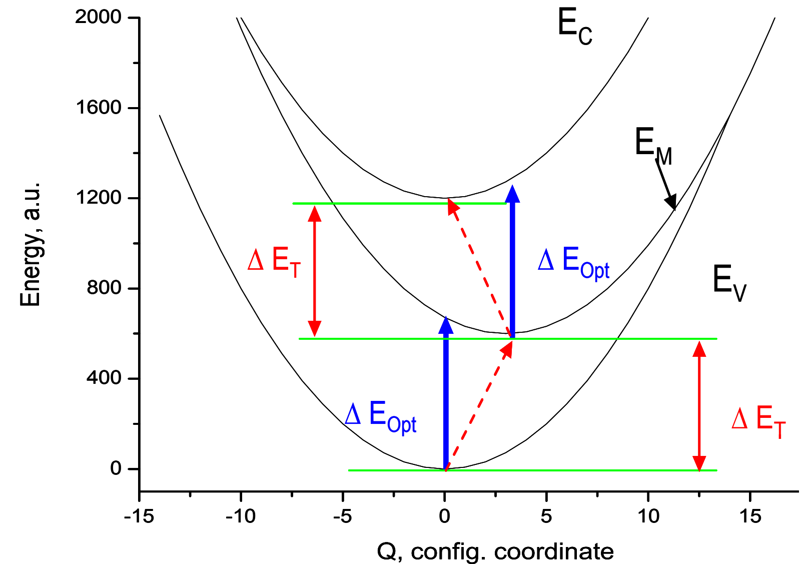


Measurement at higher T reveled the additional photoconductivity band due to the thermal excitation of electrons excited TO the deep center (1.086^{O} eV) and then by thermal excitation To the conductivity band. This trap ΔE_T ~ 0,257 eV (from TSC analysis)



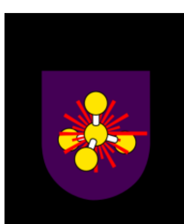
If electron-phonon coupling is important:

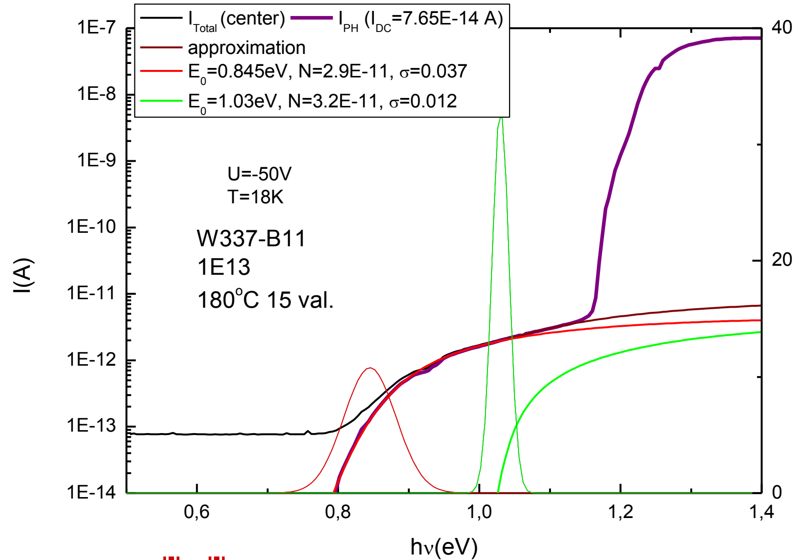
- At higher T measurement the electron-phonon coupling has to be included.
- If electron-phonon coupling is important, the configuration coordinate presentation has to be used.

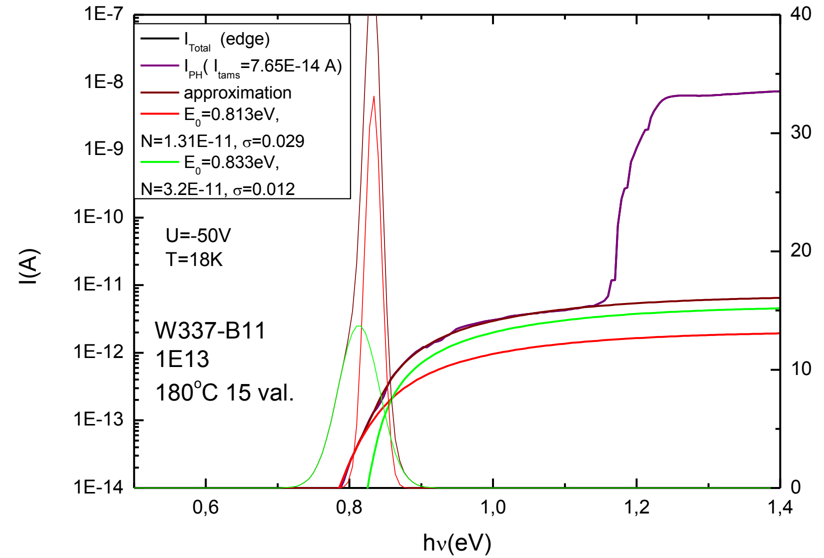


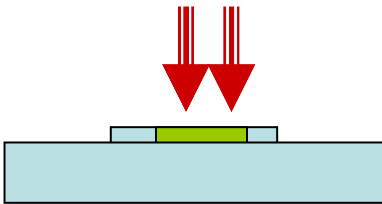
ΔE^{OPT} - ΔE^{TH} = Frank-Condon shift, in Si ~ 50-70 meV

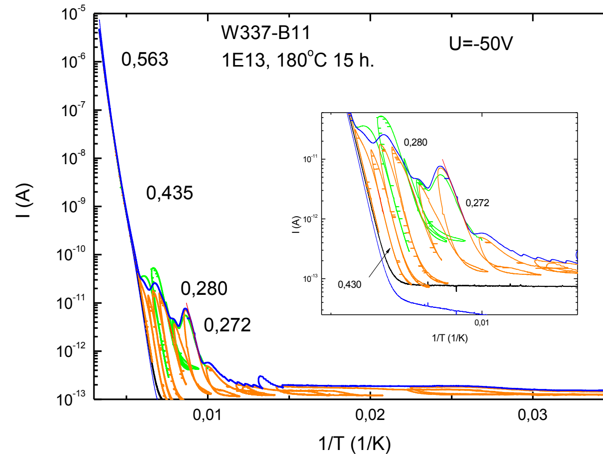
Wodean samples 1e13 cm^{-2}

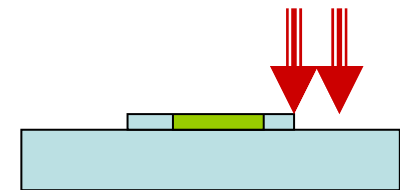


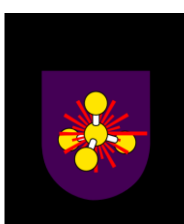




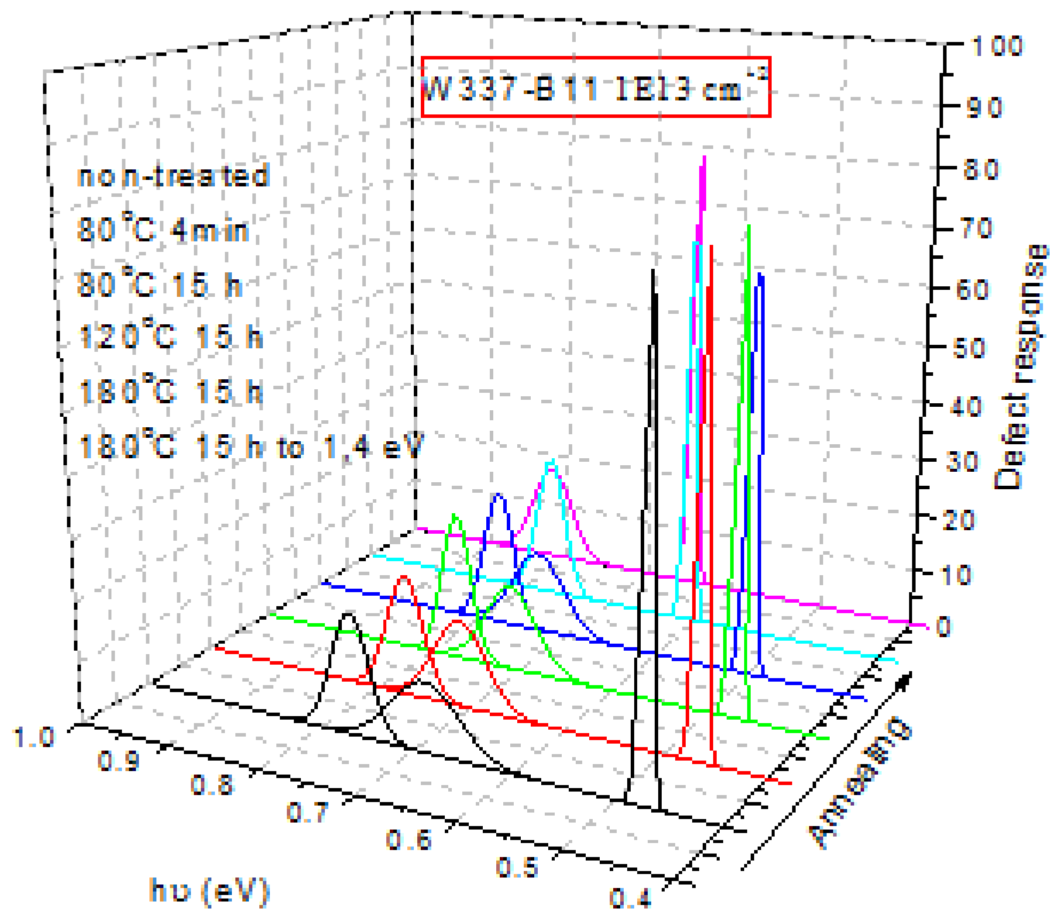


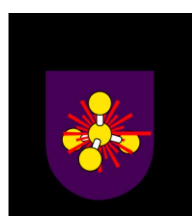




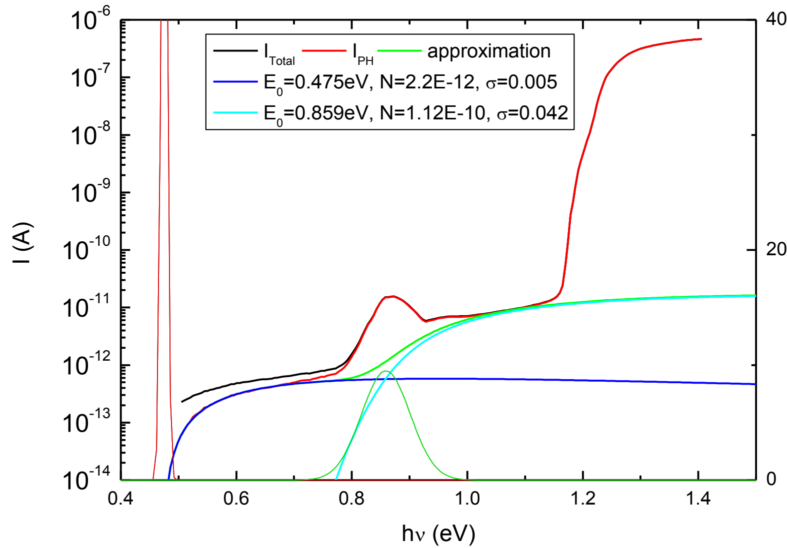


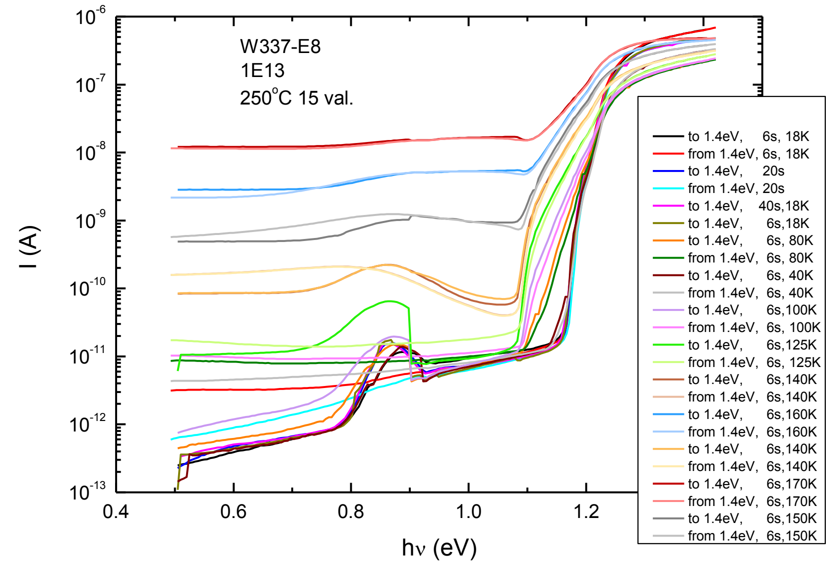
Annealing

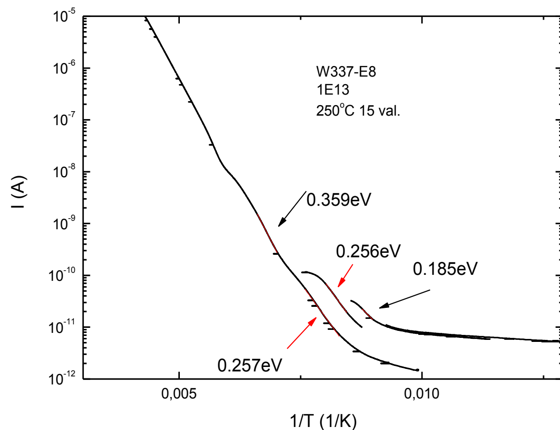


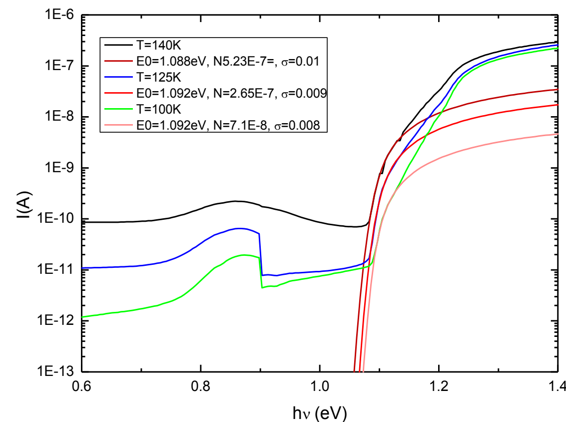


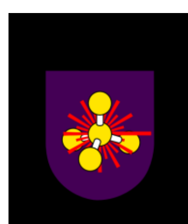
1e13 cm^{-2} with a peculiarity



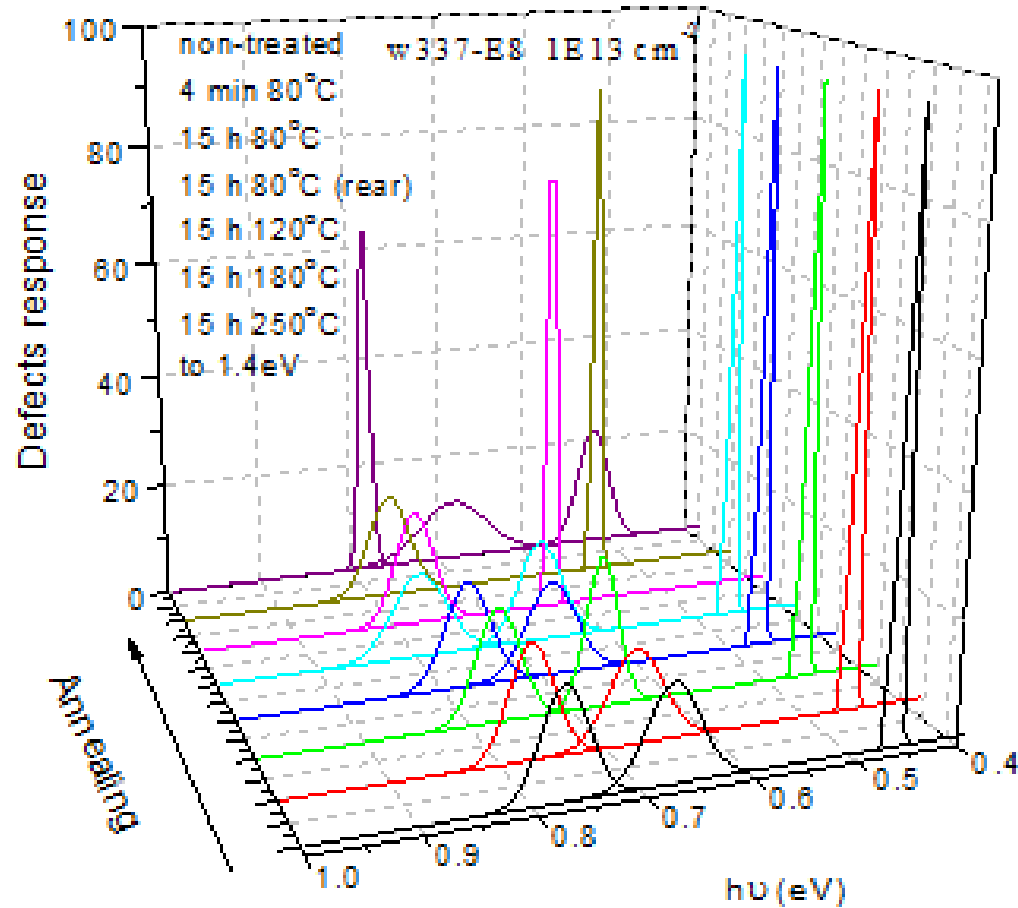


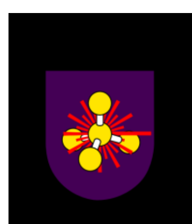




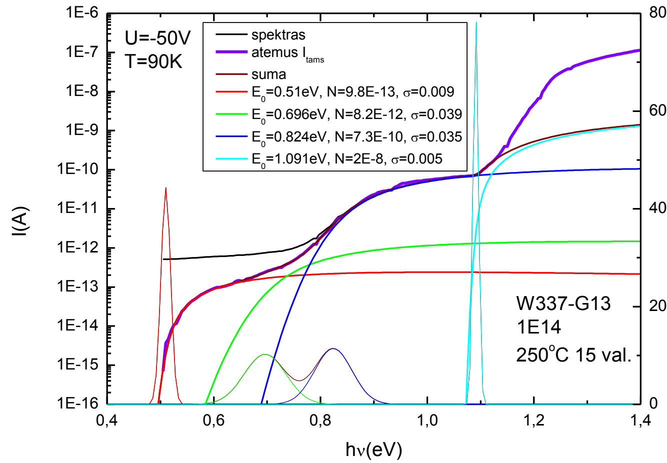


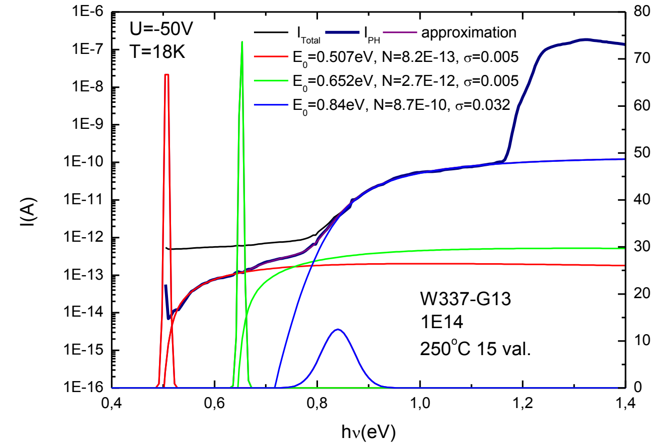
Annealing

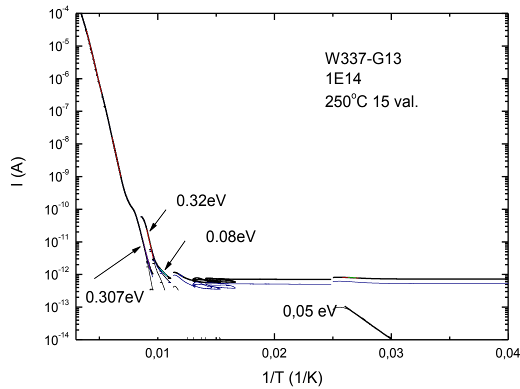


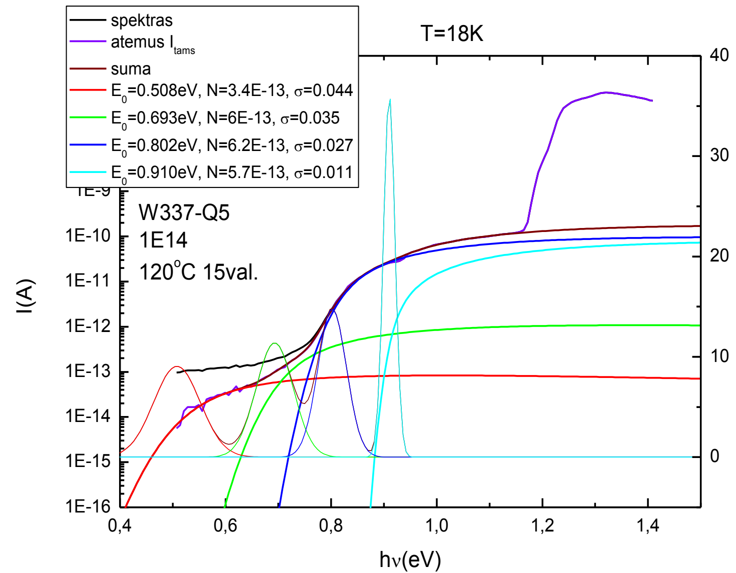


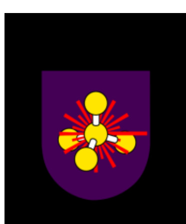
1e14 cm^{-2}











Annealing

non-treated
4 min 80°C
15 h 80°C
15 h 120°C
15 h 180°C
15 h 250°C
15 h 250°C to 1.4eV

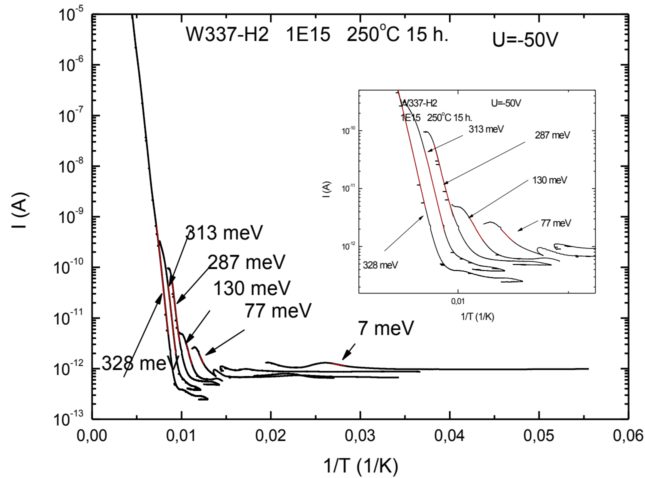
w337-G13 1E14 cm^{-2}

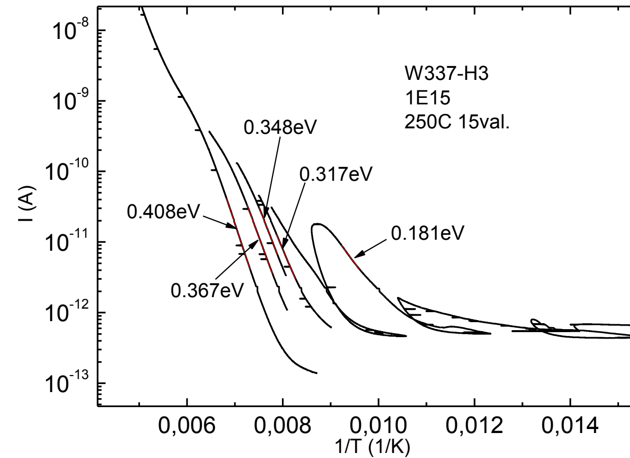
Defect response
100
90
80
70
60
50
40
30
20
10
0

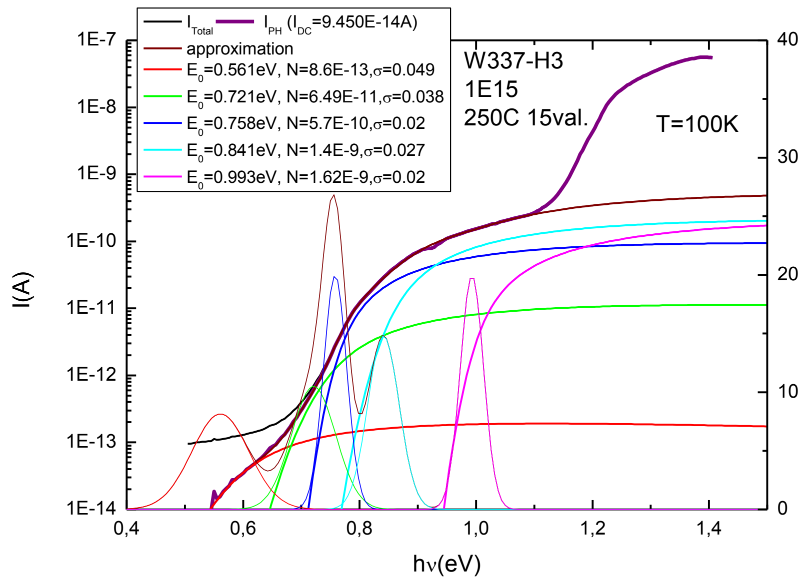
Annealing

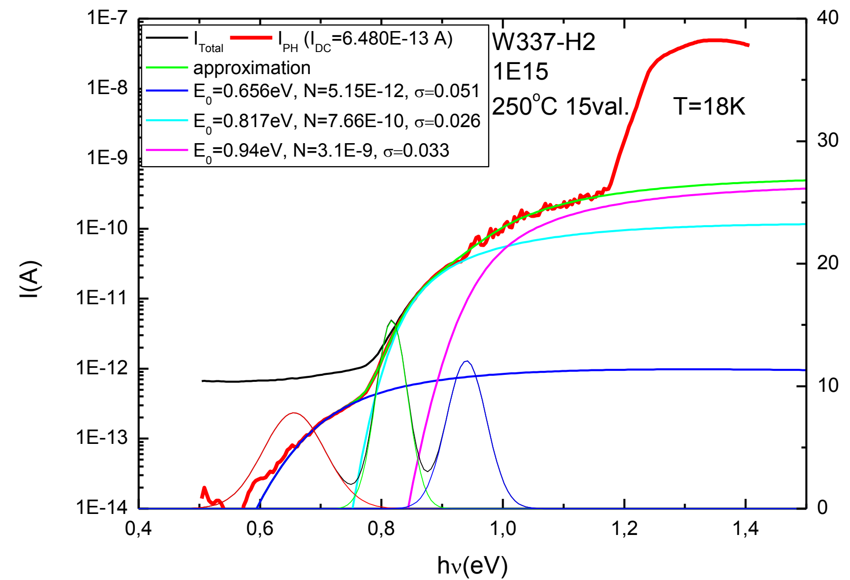
hυ (eV)
0.4
0.5
0.6
0.7
0.8
0.9
1.0

1e15 cm^{-2}

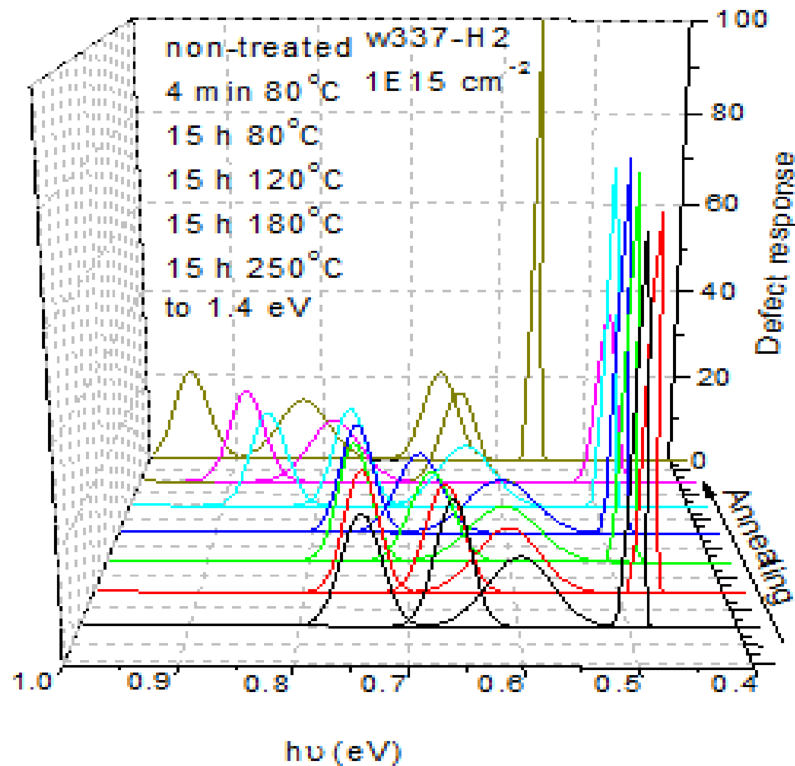


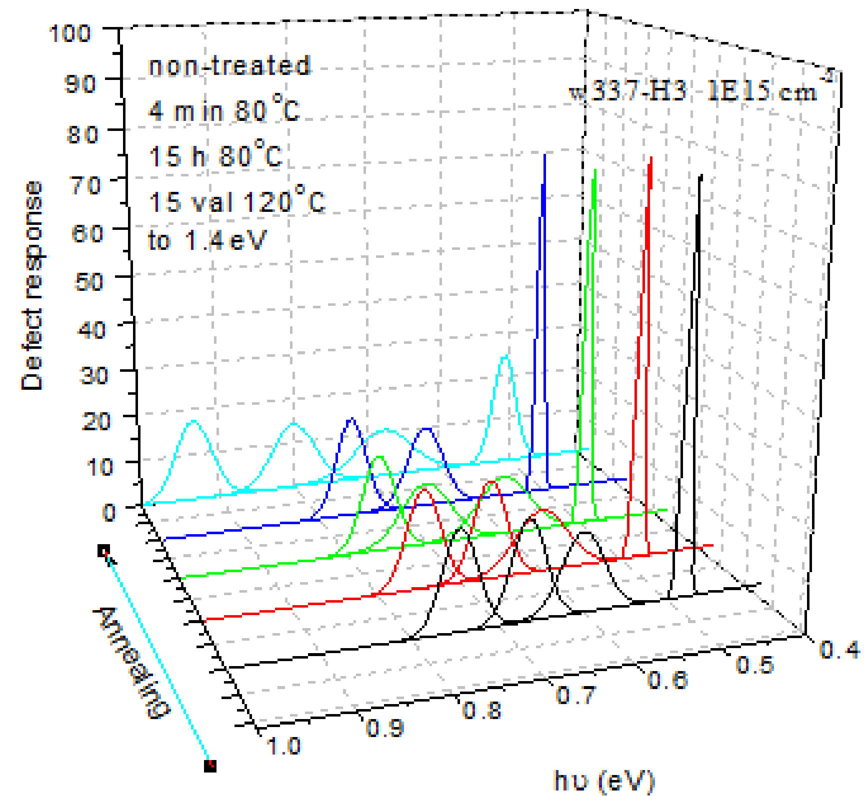






Annealing





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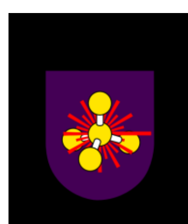
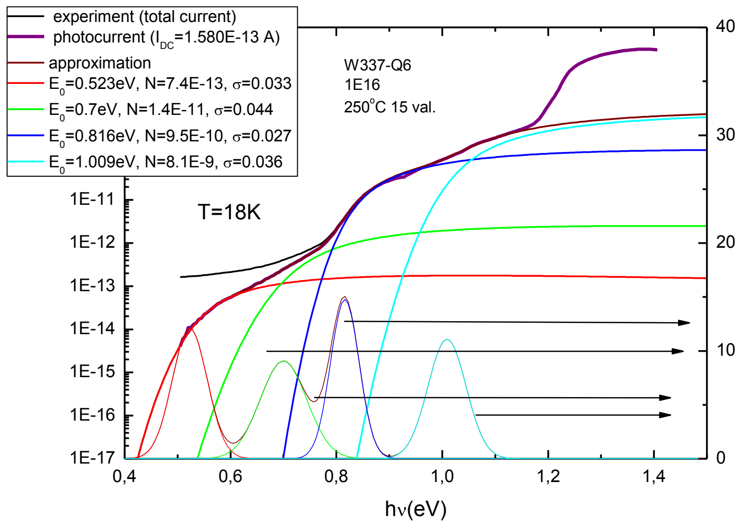
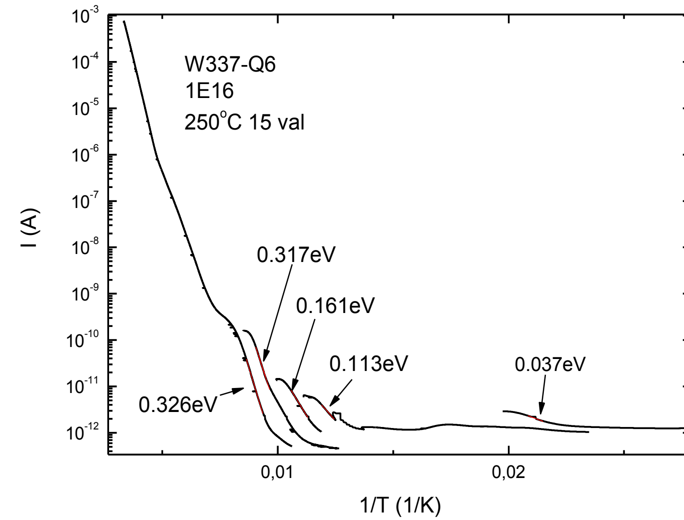
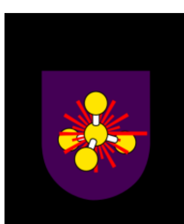


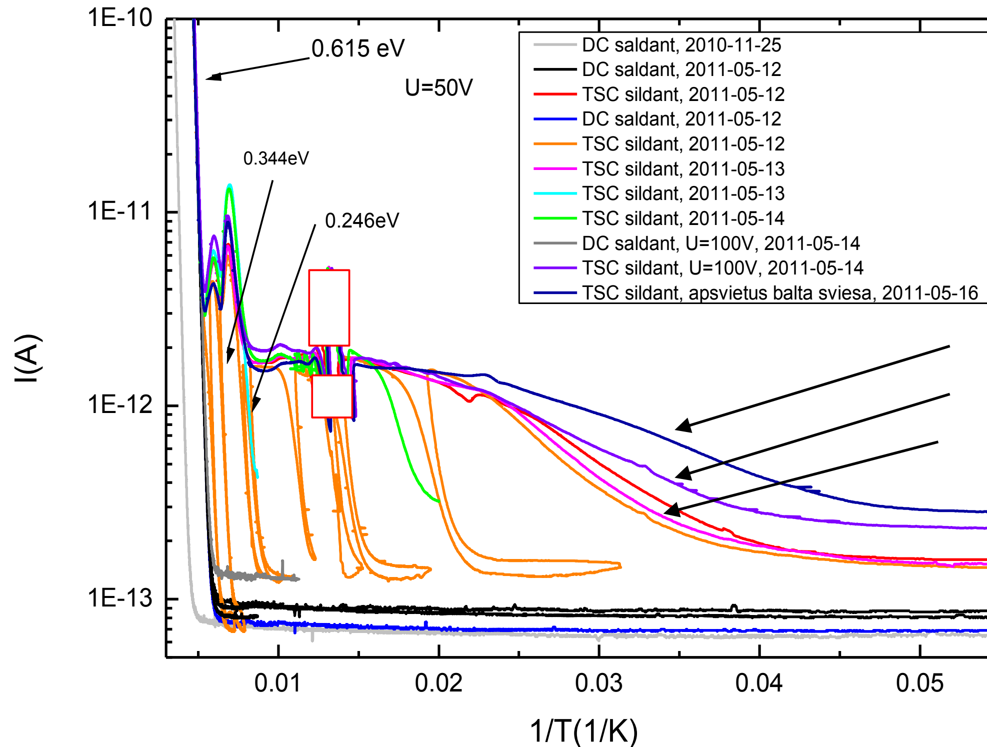
1e16 cm^{-2}





Intriguing low activation energy values



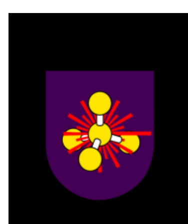


8 meV increased excitation

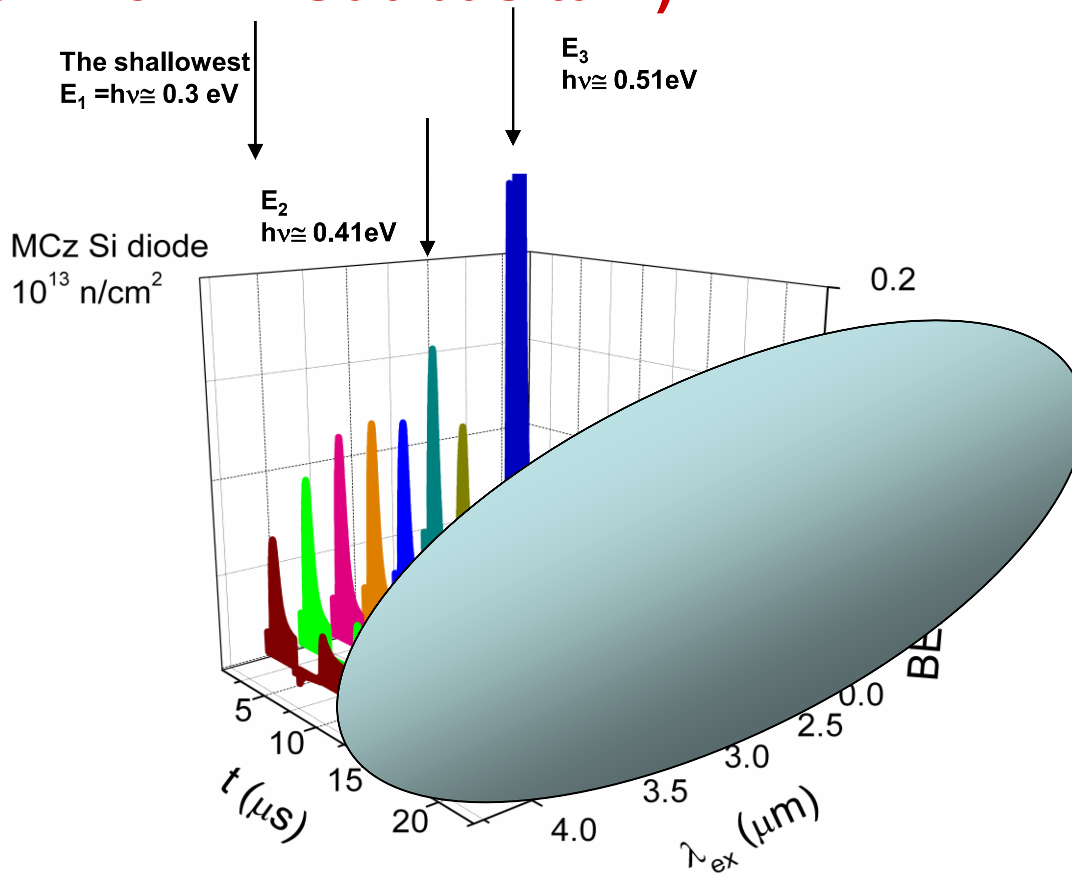
9 meV 100 V bias

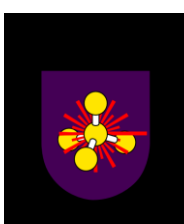
15 meV 50 V bias

Dependence on the bias and on the excitation (persistent photoconductivity) showc the existence of conductivity band bottom modulation (microinhomogeneities)



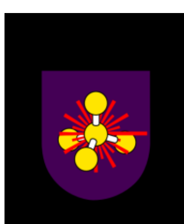
The similar photo-excitation spectra was measured at T=300 K (excitation by the fs light pulse) – the deep traps are partly filled. (Taken from E.Gaubas talk)





Conclusions:

- The deep levels in the irradiated Si are distributed in 3-4 bands, and these bands are as “fingeprints”. Therefore the modeling of the device properties should take it into account **(especially in analyze of the generation lifetime)**
- The micro-inhomogeneities of conductivity are responsible for the small values of the TSC activation energies (and it confirms earlier reported data obtained from Hall and magnetoresistance effects investigation)
- It would be interesting to analyze all data according the WODEAN program and to fix which contribution goes from “the bulk” and from “the clusters”



Thank You for Your Attention!