"Analysis of deep level system transformation by photoionization spectroscopy"

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Outline:

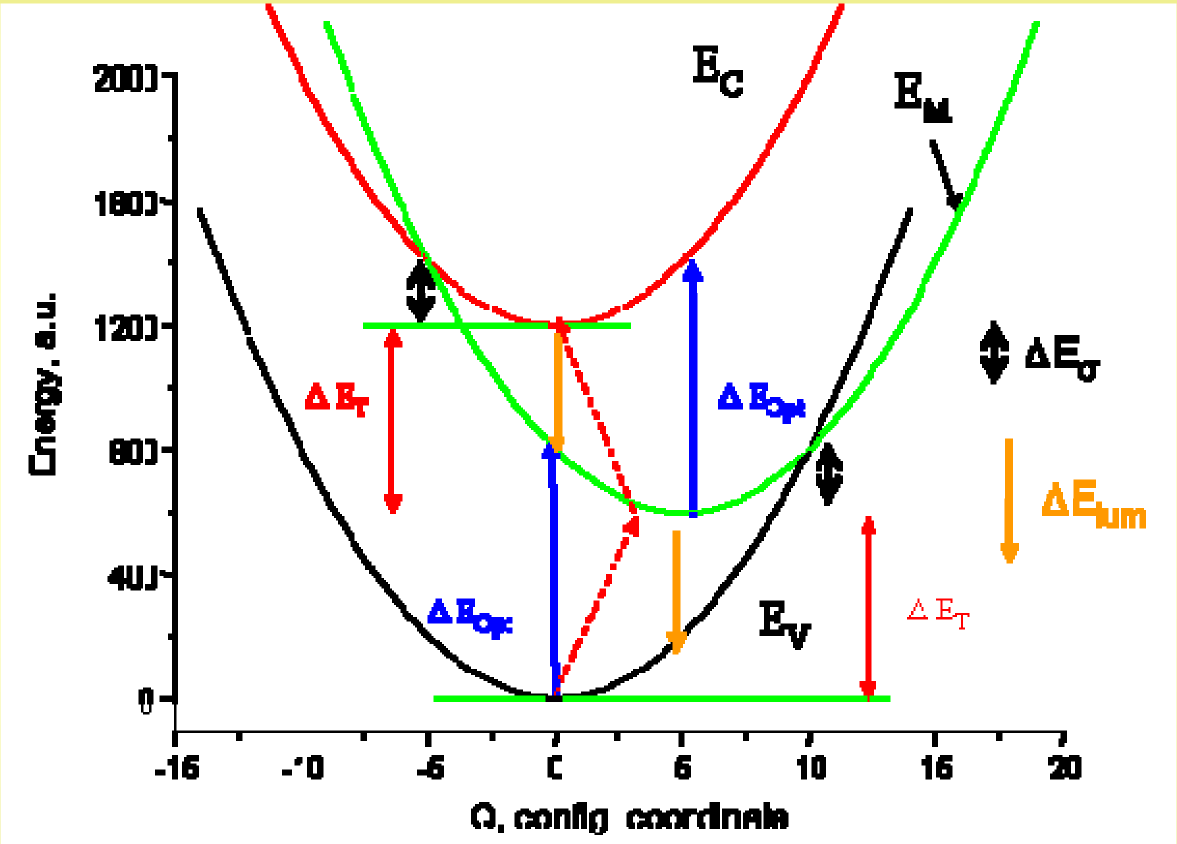
I. The photoconductivity specral response method possibilities
II. The peculiarities of the samples;
III. The results of analyze of the deep levels parameters in the differently irradiated and treated samples
IV. Conclusions.

The main features of the extrinsic photoconductivity spectrum:

Positive (or specific):

- It depends:
  - on the photon capture cross-section dependence on the photon energy & on the deep level concentration
- The deep level photo-activation energy is bigger than the thermal activation.
- It is a supplementary method to the extrinsic luminescence, DLTS & TSC methods for the defect identification.

Traps and recombination centers: deep centre model



Temperature dependencies of conductivity, DLTS, thermally stimulated conductivity allows to measure ΔE_T , ΔE_σ

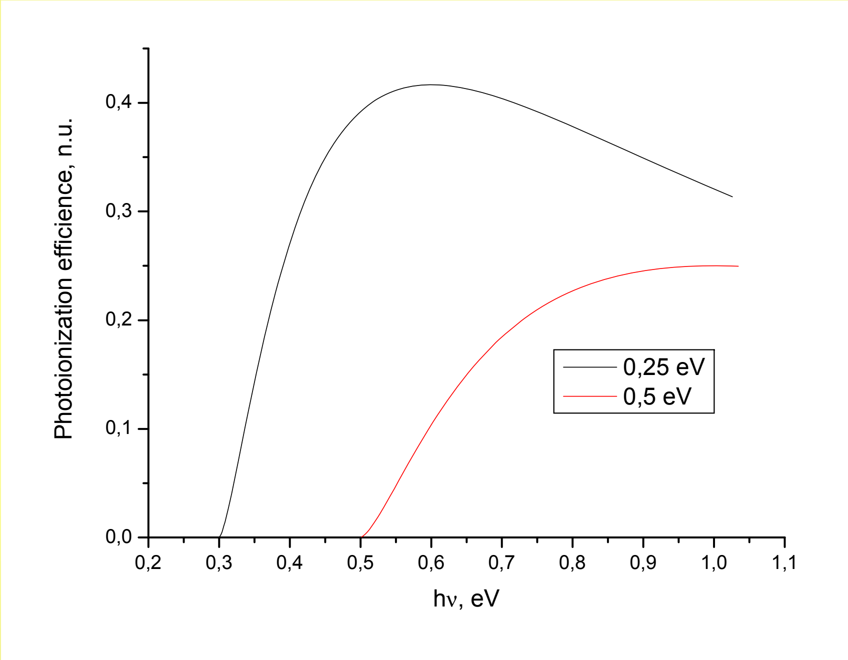
Photoconductivity spectra - ΔE_{Opt}

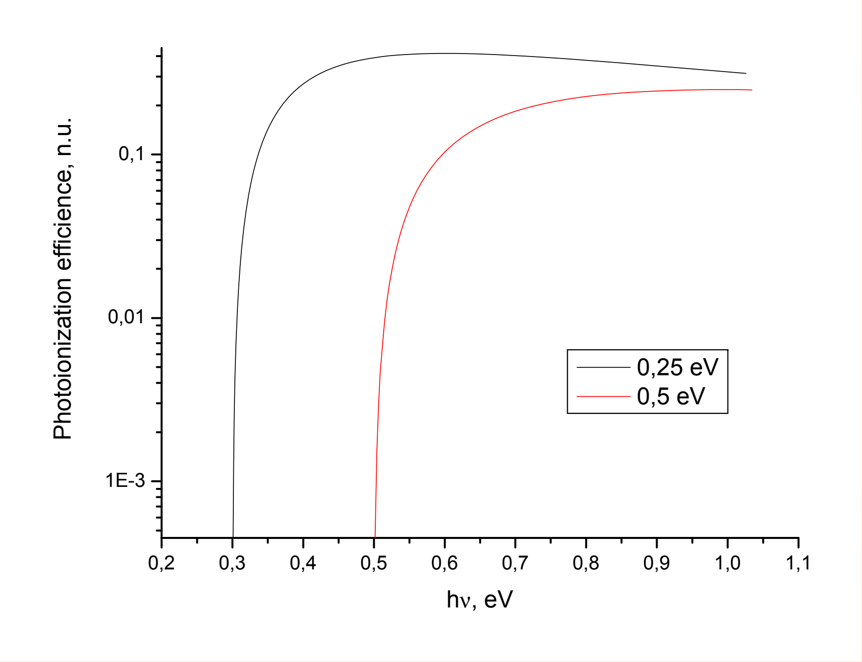
Luminescence spectra: ΔE_{lum}

The shape of spectral dependence of photo-ionization depends on electron-phonon coupling, but at low T this effect can be neglected, i.e. Luckovsky model can be used. (We perform measurements @ 11-18 K)

Lukovsky (δ-potential) model:

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





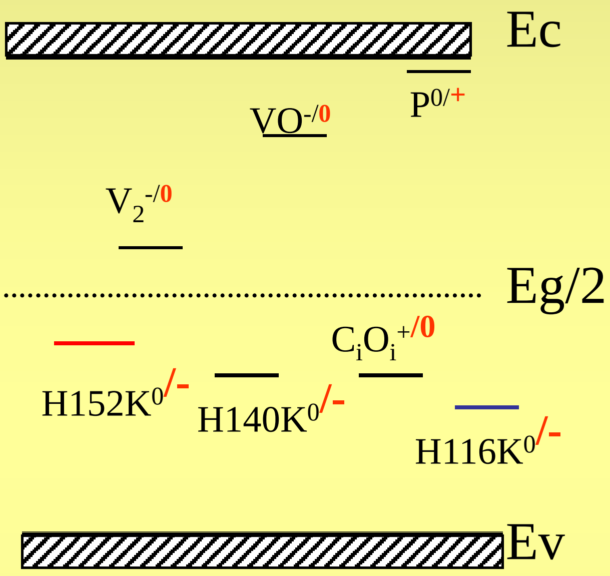
This model (at low temperatures) does not valid:

for the hydrogen type defect and for the inter-deep level state transitions

Experimentally feature: If $h\nu > \Delta E_{opt}$, there is a possibility for the two step excitation of the intrinsic photoconductivity (the additional effects).

What is possible to search? From earlier data (Ioana):

The levels position in the bandgap



The parameters for the zero field emission rates describing the experimental results are:

$E_i^{116K} = E_v + 0.33eV$ ($0.285eV^*$) and
$\sigma_p^{116K} = 4\cdot10^{-14}$ ($4\cdot10^{-15}*$)cm^2

$E_i^{140K} = E_v + 0.36eV$ and $\sigma_p^{140K} = 2.5\cdot10^{-15}$ cm^2

$E_i^{152K} = E_v + 0.42eV$ ($0.36eV^*$) and
$\sigma_p^{152K} = 2.3\cdot10^{-14}$ ($2\cdot10^{-15}*$) cm^2

* - aparent ionization energy and capture cross sections when no field dependence of emission rates is accounted

At 15-18 K these levels could cause the photoconductivity components at:
$h\nu > E_c - E_i^T$, i.e.,

116 K $h\nu >$ 0,84 eV (0,884 eV)
140 K $h\nu >$ 0,81 eV
152 K $h\nu >$ 0,75 eV (0,81 eV)

The method requirements:

The correct measurement of photo-ionization spectrum is recommended

to perform measurements:

in the homogeneous samples with the Ohmic contacts

and

during measurement to keep the constant photocurrent.

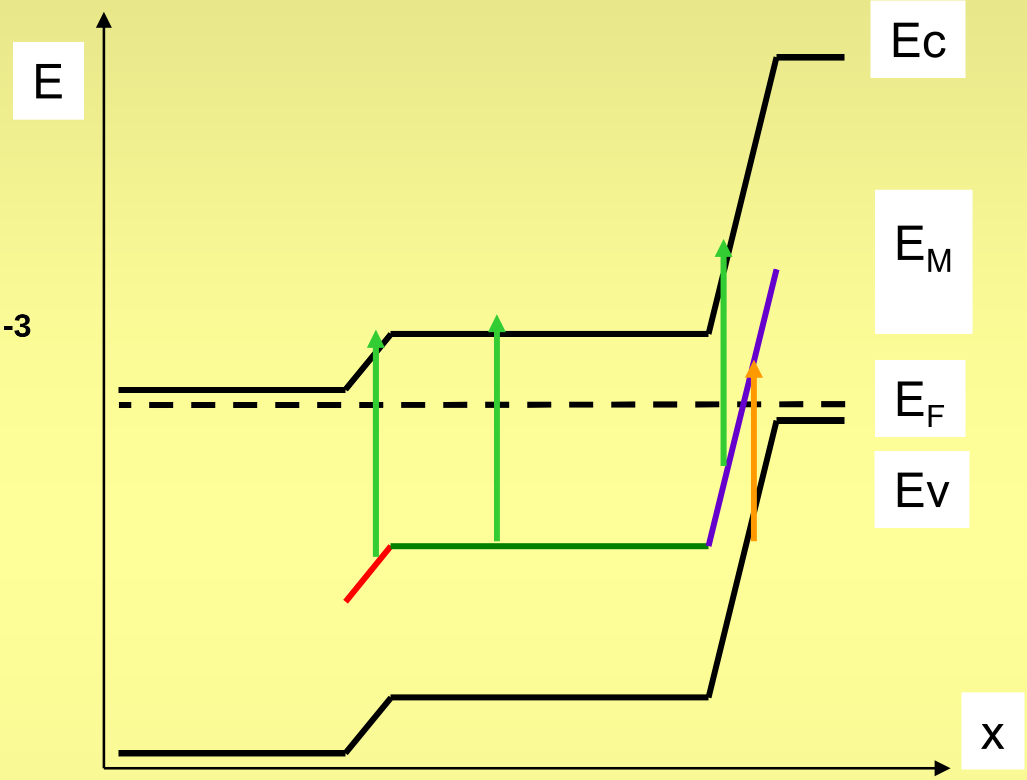
Then the intensity of excitation is proportional to the inverse photoionization cross-section that allows to measure the activation energy and the signal amplitude is related to the centre concentration.

Our case is much more problematic:

- **The samples are diodes: the photo-e.m.f. appears;**
- **The extraction of carriers and the remaining charge influence**
- **The dependence on electric field in the sample possible changes during the treatment.**

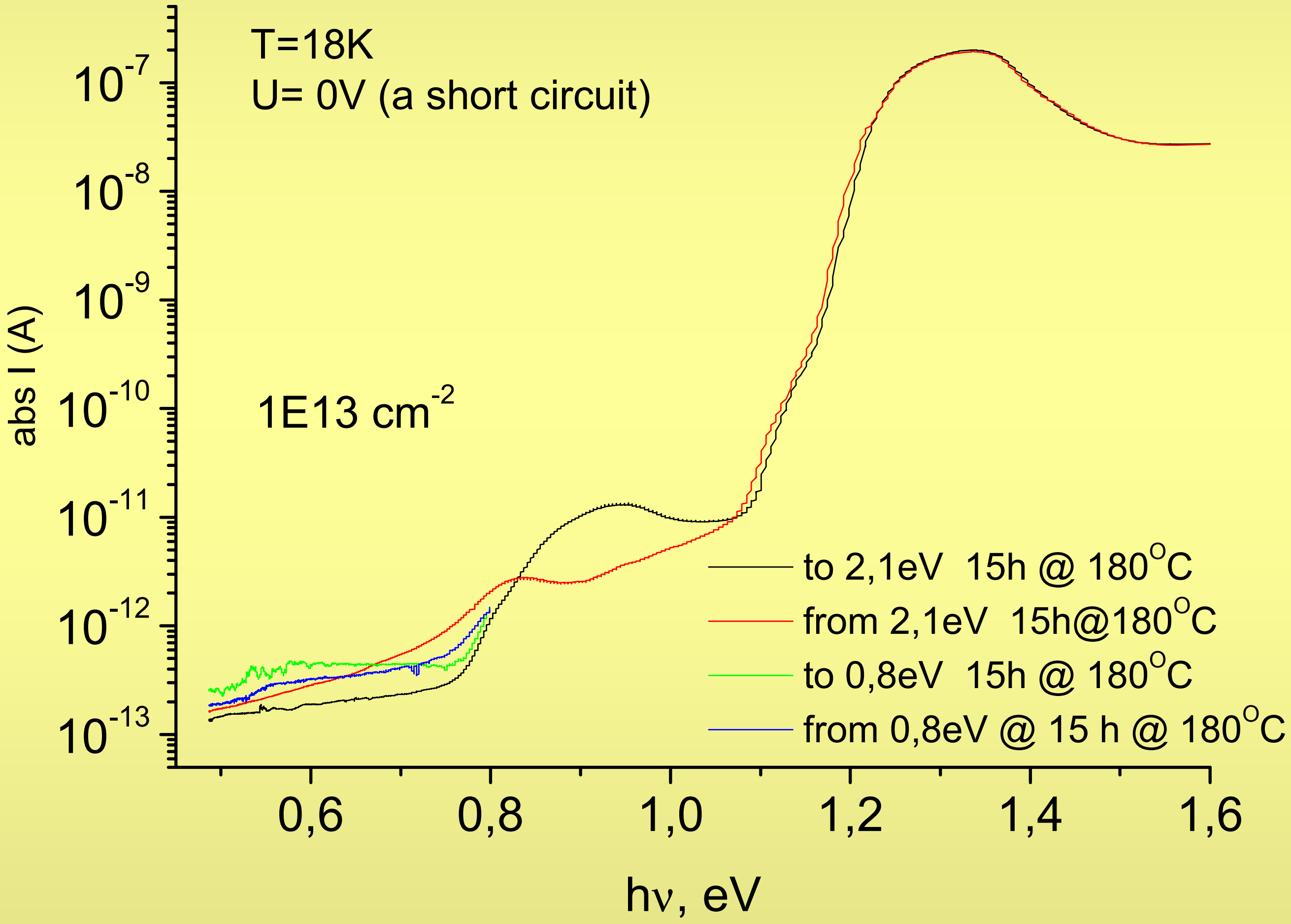
The samples peculiarities

Si Diodes:
WODEAN n-MCZ (OKMETIC), P-doped 900 Ωcm, Neff = 4.8 10^{12} cm^{-3}
<u>Diode processing:</u> CiS Erfurt,
thinned to d = 95 μm
rear contact:
P-implanted: Neff = 4.8 10^{12} cm^{-3}
P-diffused: Neff = 7.7 10^{12} cm^{-3}
(TD generation during thermal process)

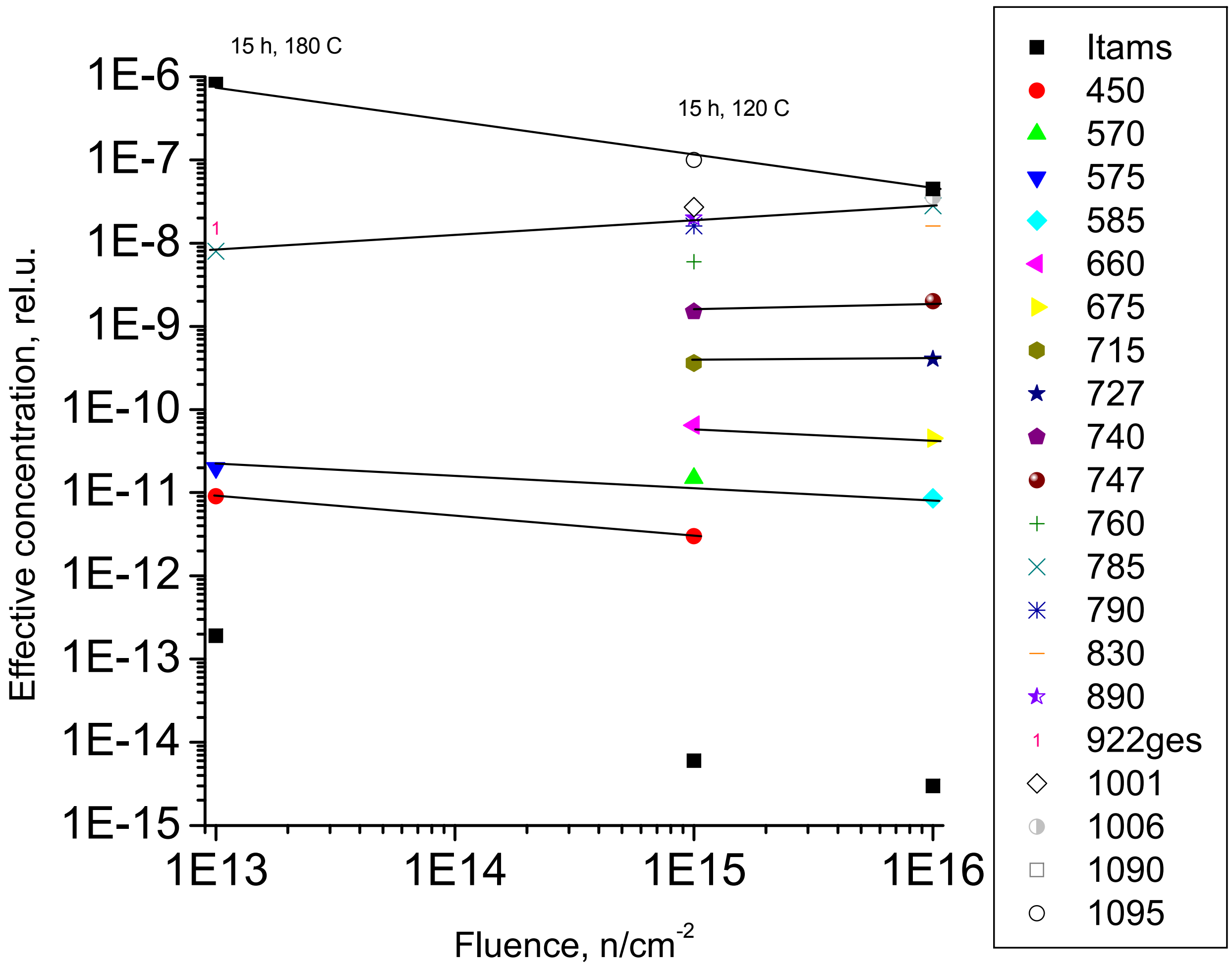


- The problems (e.g., remaining space charge), can be transformed into the qualitative recognition of the sample structure.

Photovoltage in irradiated Si diode



Deep levels contribution to PC



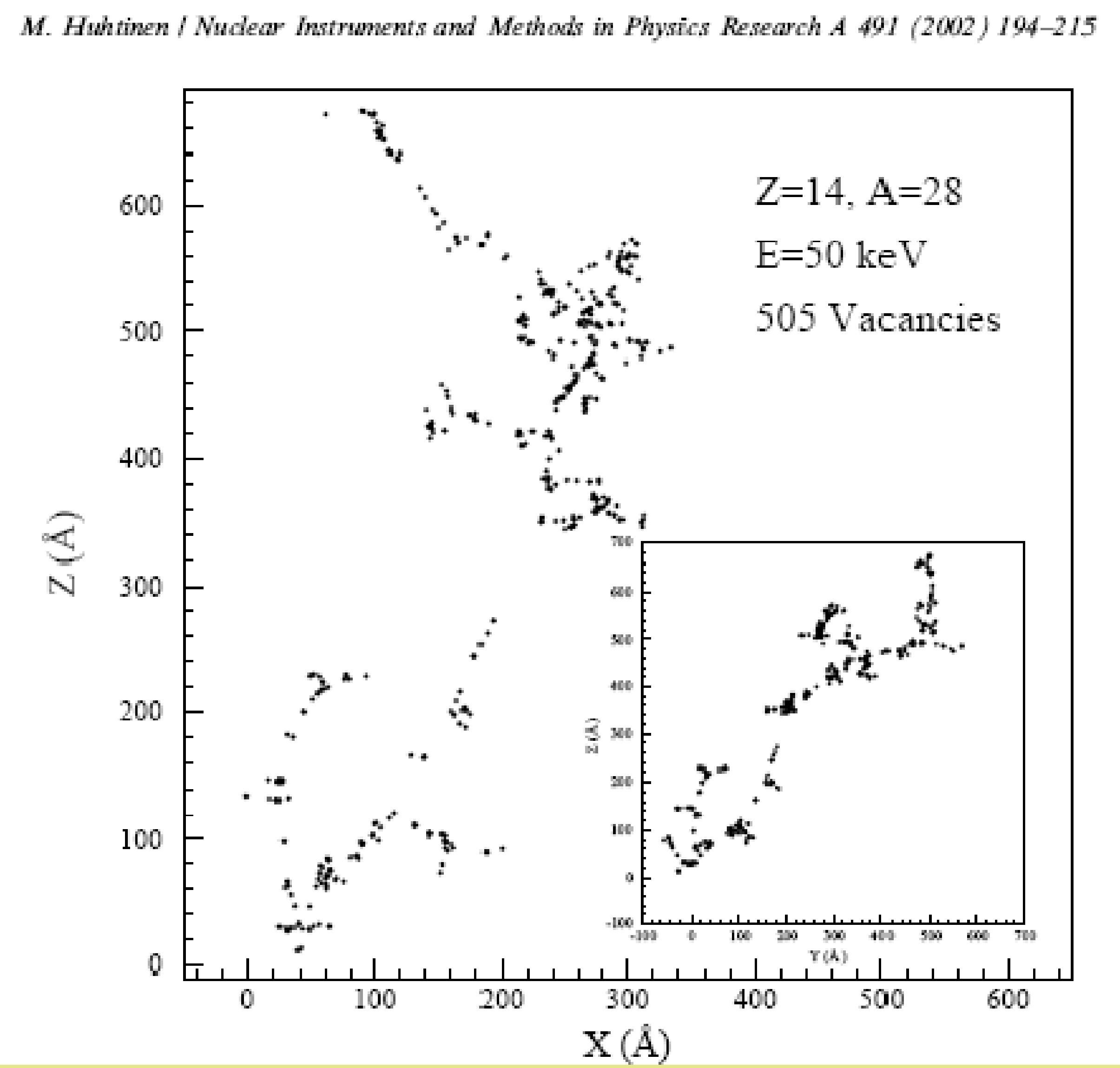
The main centres:
0,450 eV
0,575 eV
0,670 eV
0,720 eV
0,785-0,790 eV
1,09 eV

Processing:

The prepositions for a further analyze:

1. To be not afraid of many deep levels (the neutron – semiconductor interaction modeling allows it);

2. To be careful in the evaluation of the theory & experiment comparison.



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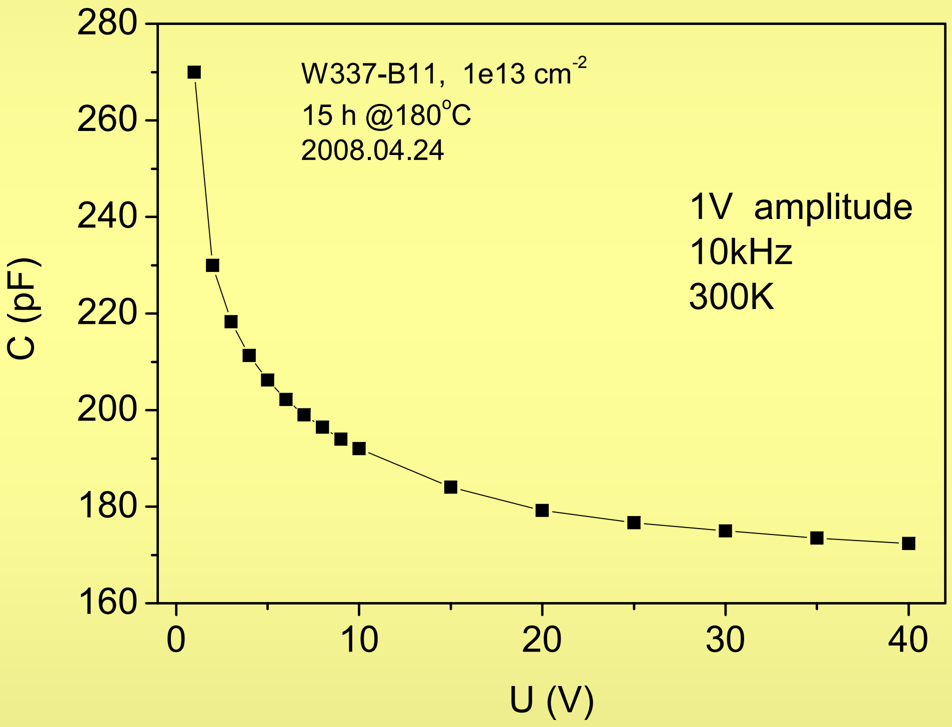
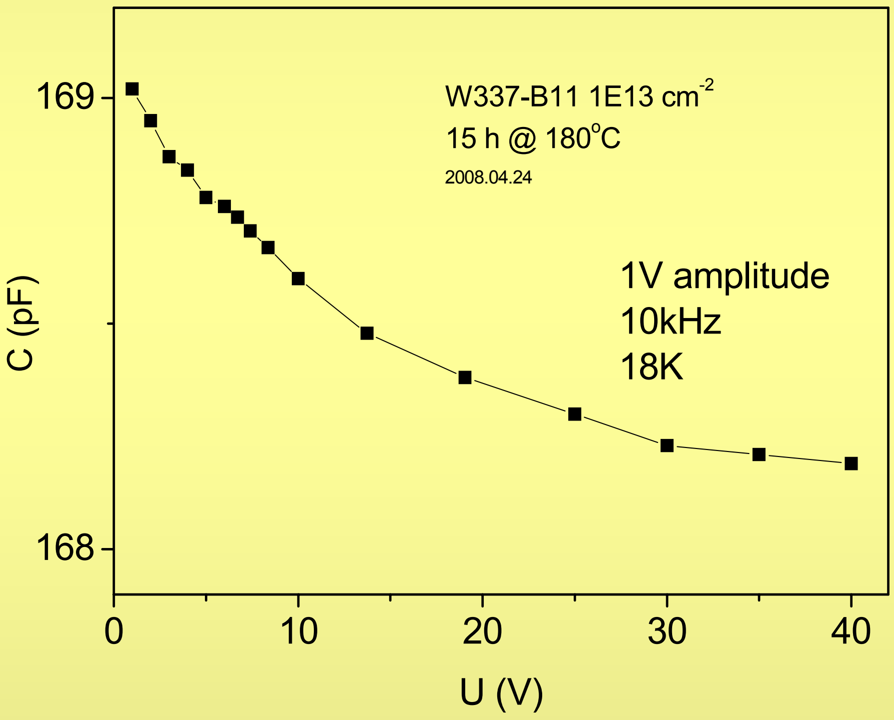
The spatial distribution of vacancies varies significantly from one event to the other.

C(U) @ 300 K & 18 K


W337-B11, 1e13 cm^{-2}
15 h @180°C
2008.04.24

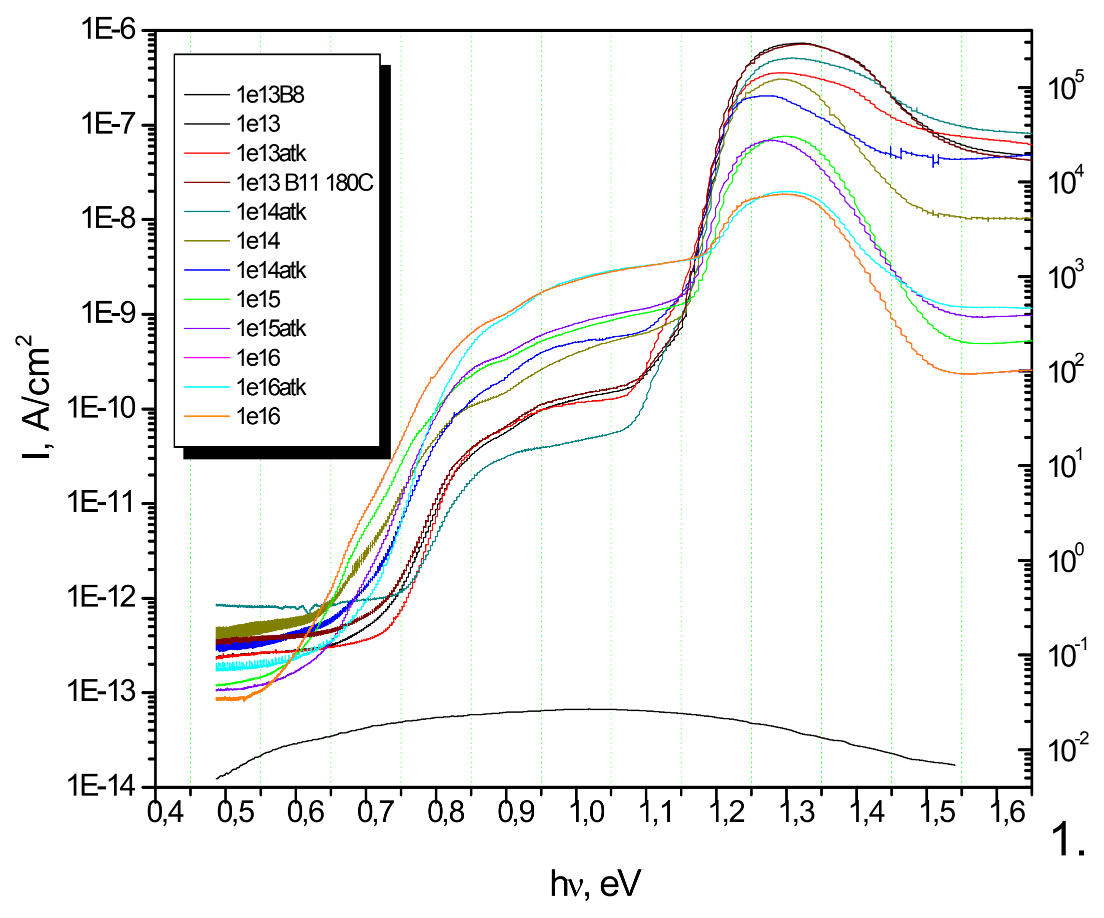
1V amplitude
10kHz
300K

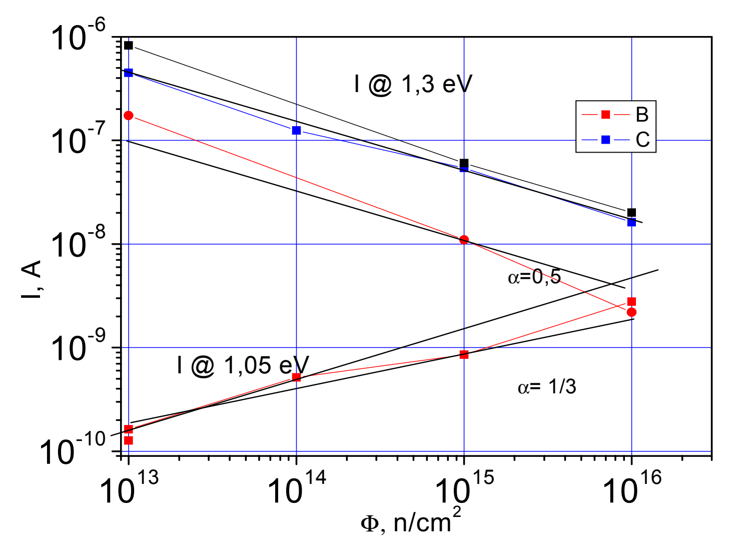

W337-B11 1E13 cm^{-2}
15 h @ 180°C
2008.04.24

1V amplitude
10kHz
18K

Bias more than 40 V is enough for extraction of carriers

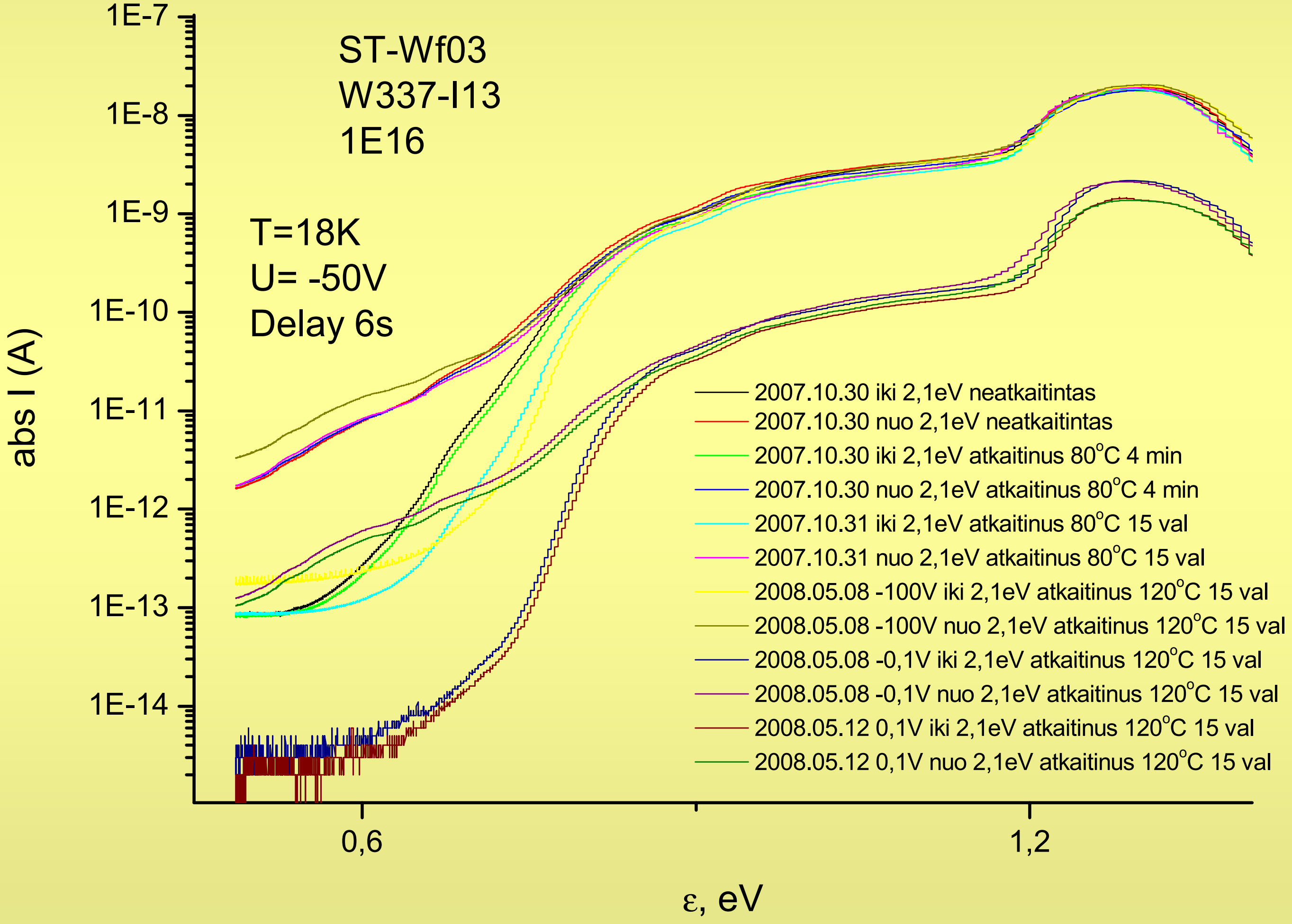
PC spectra in irradiated Si



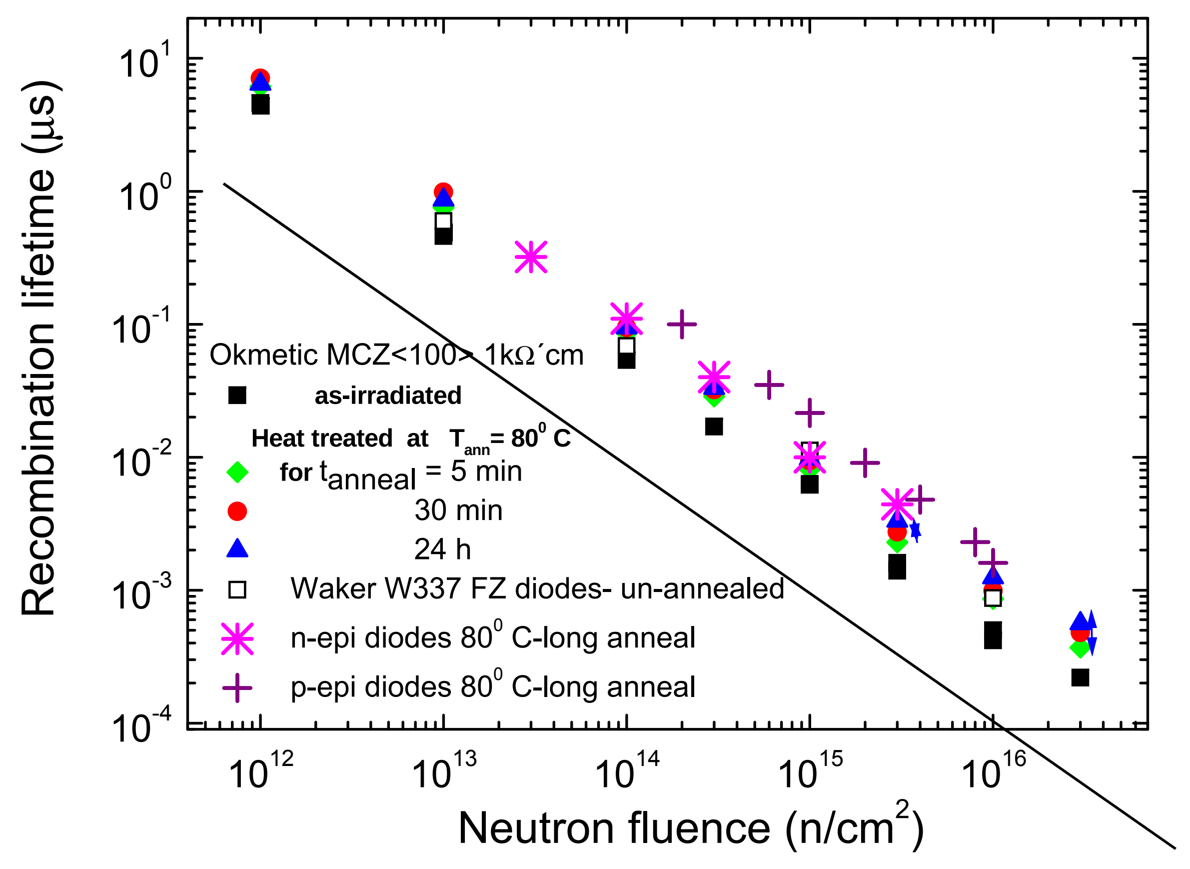


1. The lifetime decreases as a **square root on the fluence**
2. The total impurities contribution increase by power law α=**1/2 ÷ 1/3**

PC at low and high bias



Decay time constant vs irradiation

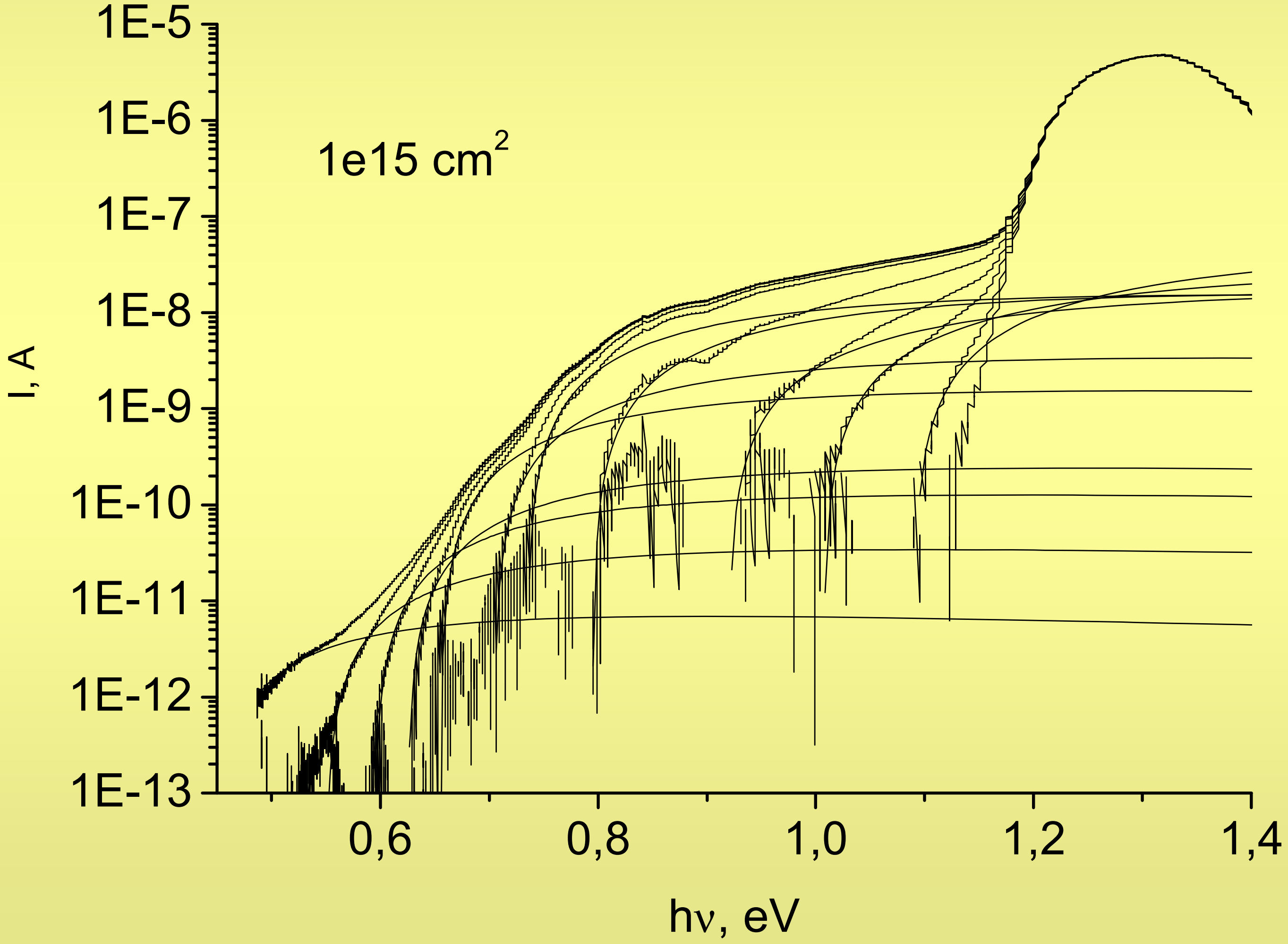


Why are the dependences on fluence of the decay constant and instantaneous lifetime different?

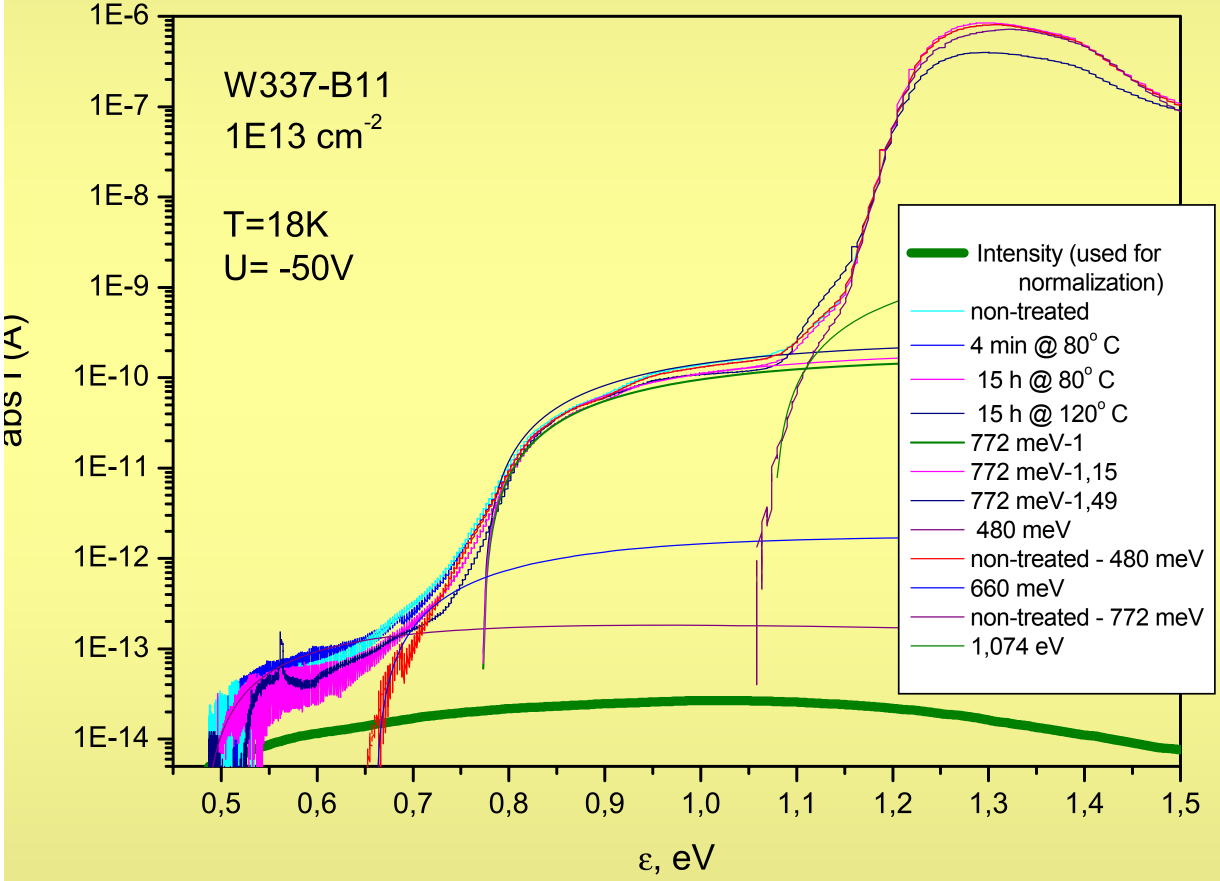
That shows the additional process in the carrier capture, that is still hidden!

Local field redistribution can also play role,
but it appears only for the more shallow local levels

An example of analyse



Avoiding the accumulation of errors: analyze of the main features.



Where are these levels in the bandgap?

ΔE = 1.17 eV @ 18 K

1.07 eV, i.e. E_M-E_v> 0.1 eV

970 meV (???) E_C-E_M>0.2 eV

885 meV, i.e., E_C-E_M>0.285 eV

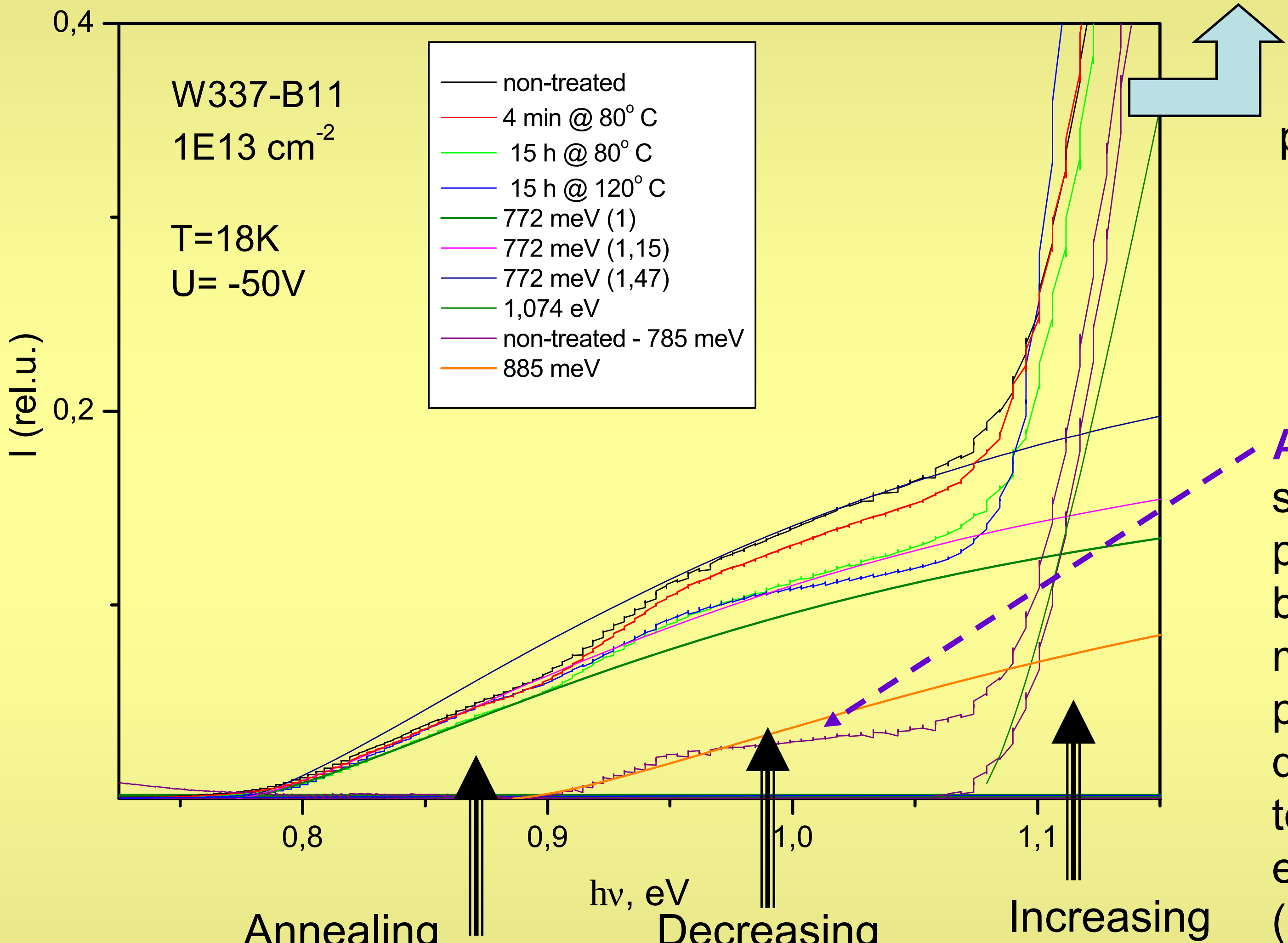
772 meV, i.e E_C-E_M>0.398 eV

660 meV, i.e E_C-E_M>0.51 eV

480 meV, i.e E_C-E_M>0.48 eV

> to = If neglect the difference of $\Delta E_{\text{Optical}}$ and $\Delta E_{\text{Thermal}}$

In a linear scale: a few main features



Intrinsic photoconductivity (~ absorption coefficient)

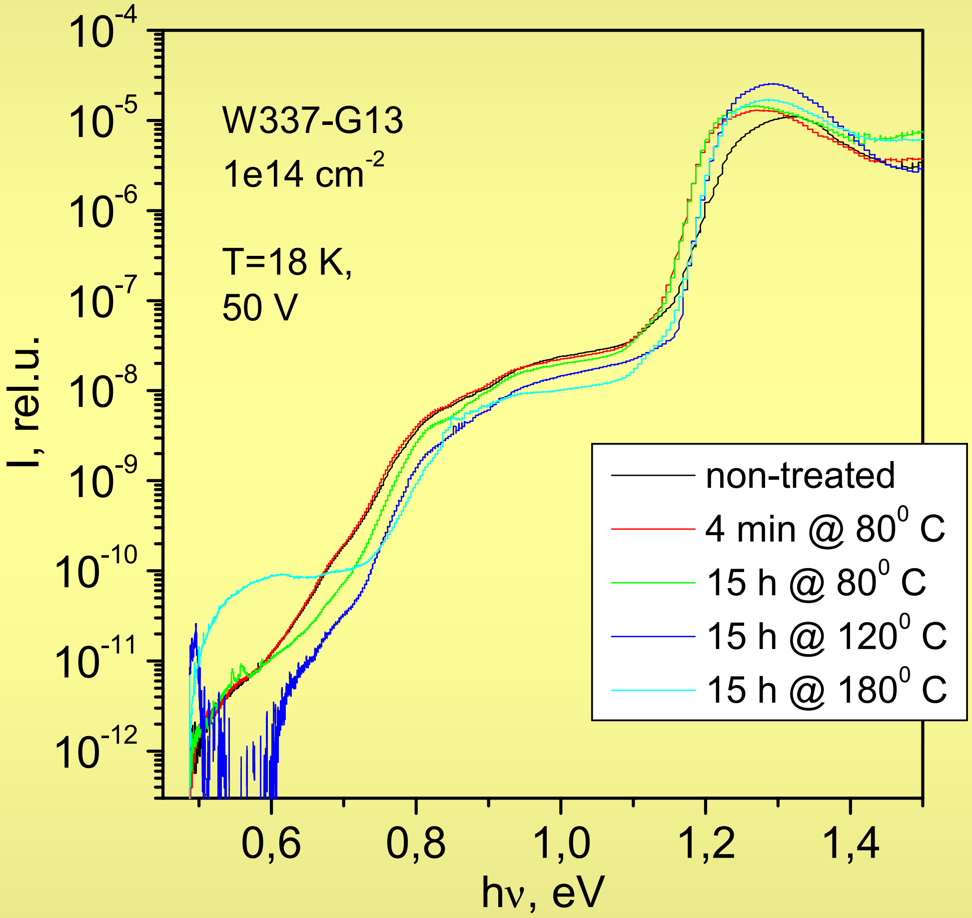
A peculiarity: a strange shape of the photoconductivity band: It is probable more complicated phenomena. The PC quenching effect due to the two step excitation is possible (IR quenching level could be at 970 meV)

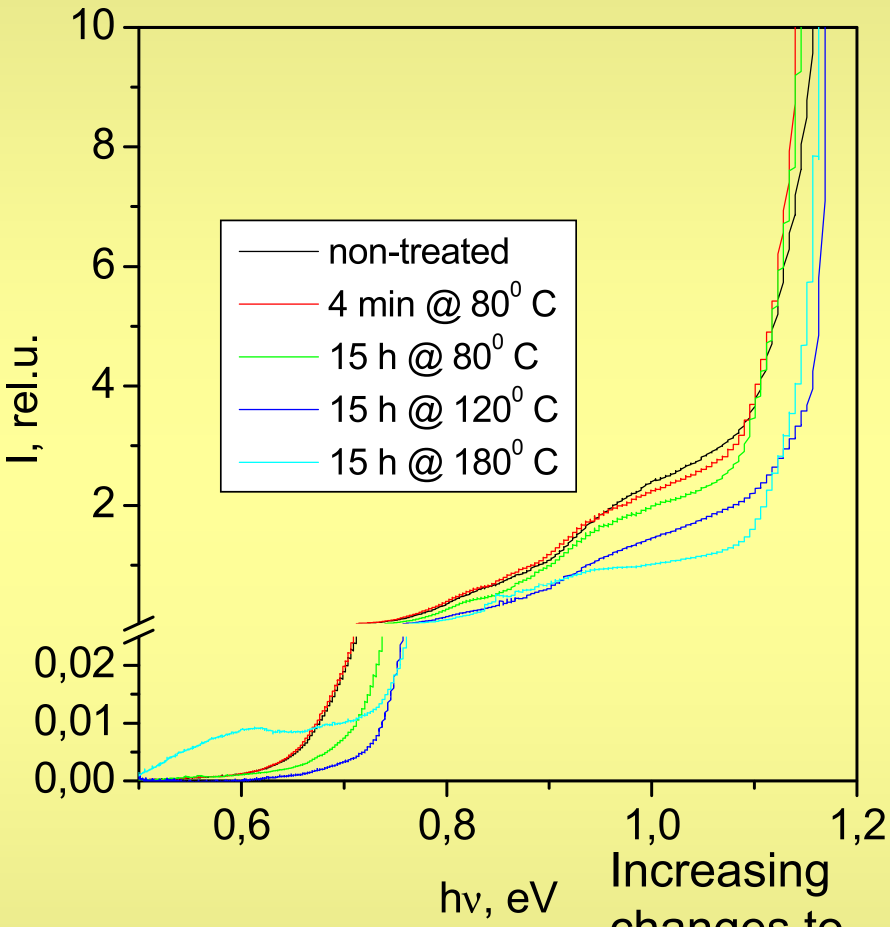
Annealing does not influence

Decreasing due to annealing

Increasing due to annealing

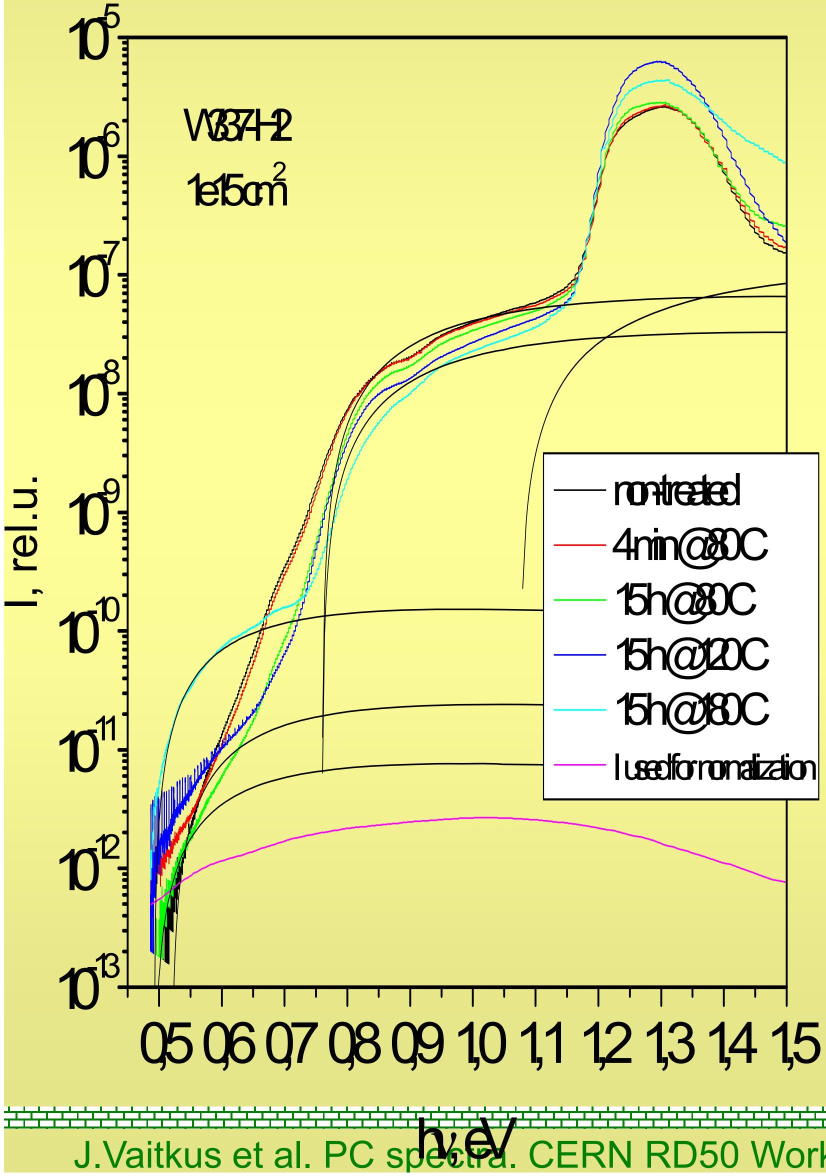
1e14 cm^2

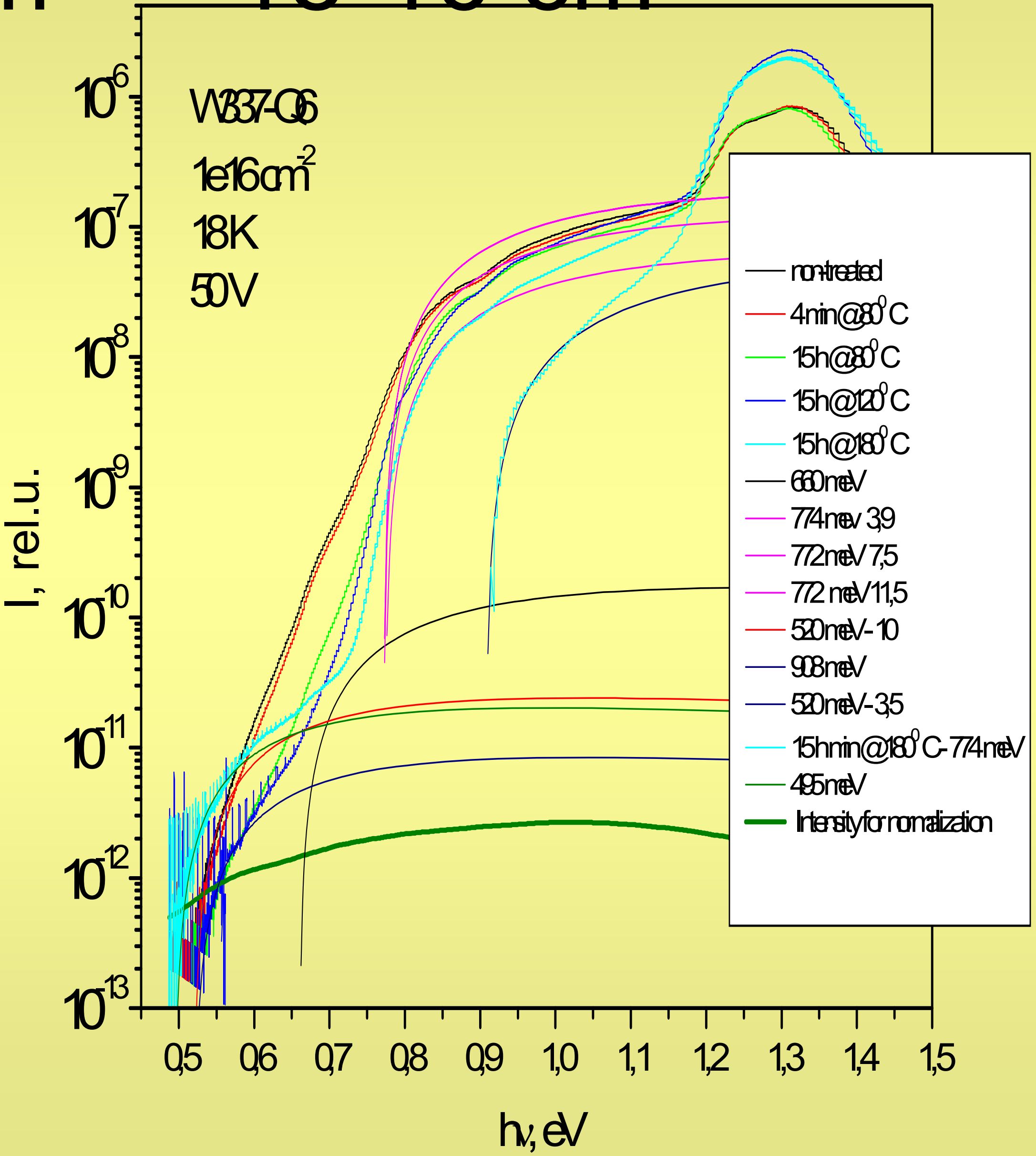




Increasing changes to decreasing at higher T of annealing

1e-15 cm^{-2} & 1e-16 cm^{-2}





Conclusions:

- Deep levels can be revealed by PC spectrum
- Relative concentration can be evaluated (a change during annealing)
- The homogeneous samples with the Ohmic contacts could allow the higher quality measurement of parameters.

- In the nearest future we will have a possibility to cover wider impurity spectrum (up to 70 meV)