Remarks on the measurement of thermally stimulated current

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Everybody knows (1):

- The particles generates the electron and hole packages that chanhe the conductivity of the detector, and the signals are recorded.
- If the electrons and holes are extracted a maximal signal is obtained, but:
  - a part of e-h pairs recombine, and
  - a part can be captured in the traps therefore do not participate in the signal formation if their thermal excitation time constant s are longer than signal acquisition time.
- Therefore a knowledge about the traps is necessary for evaluation of material and detector ability for ionizing radiation detectors.

Everybody knows (2):

The parameters of traps can be investigated **by**:

- kinetics (growth and decay) of photoconductivity by excitation in extrinsic and intrinsic range;
- Transient capacitance of p-i-n junction (DLTS),
  - But this method is not available in the samples irradiated to high fluence
- Thermally stimulated conductivity
  - By linear temperature scan of earlier excited sample **(TSC);**
  - By linear temperature scan of response time constant **(I-DLTS)**

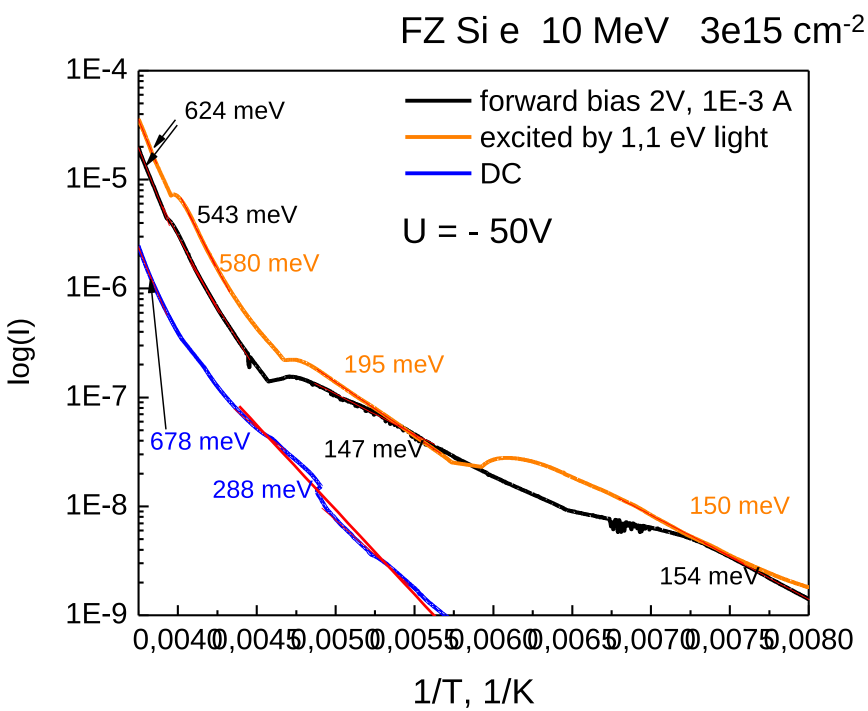
TSC

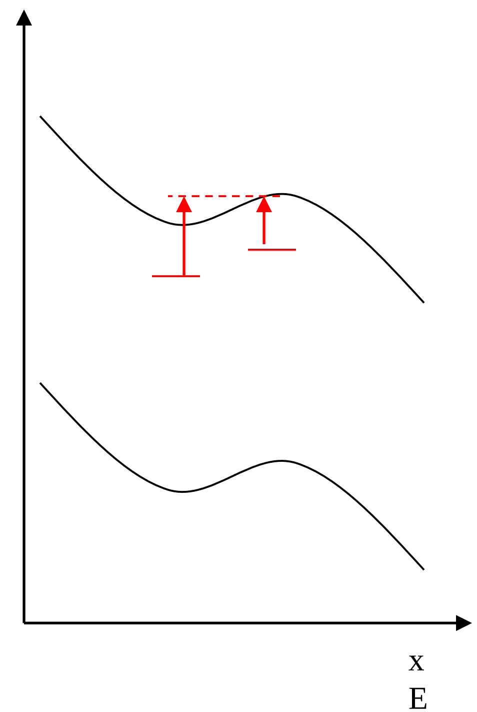
- Two methods - at low T:
  - – Injection of carriers by applying the forward bias, and measurement at
    - Reverse bias (extraction of carriers)
    - Zero bias – depolarization current
  - – Excitation by light and measurement at reverse bias (if the sample is p-i-n structure)
  - – Two regimes in both cases:
    - By linear increasing T (recommended to measure at different velocity of temperature growth);
    - By linear increasing T up to a TSC peak, lowering the T, and cycle repeated (multiple-TSC)

Intermediate conclusion:

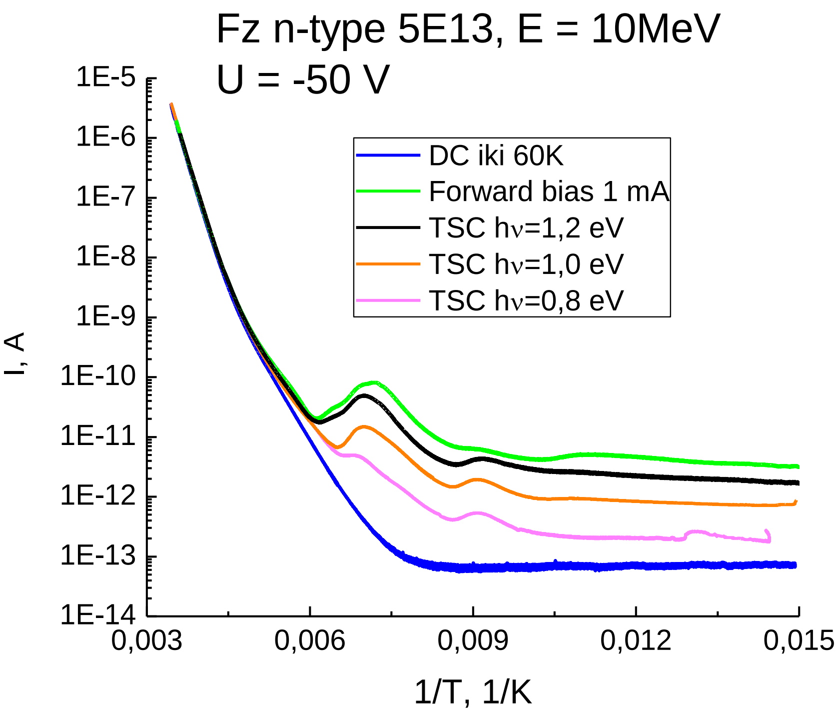
there are many ways to investigate traps by thermally stimulated effects, and all these models are well analyzed in the literature …

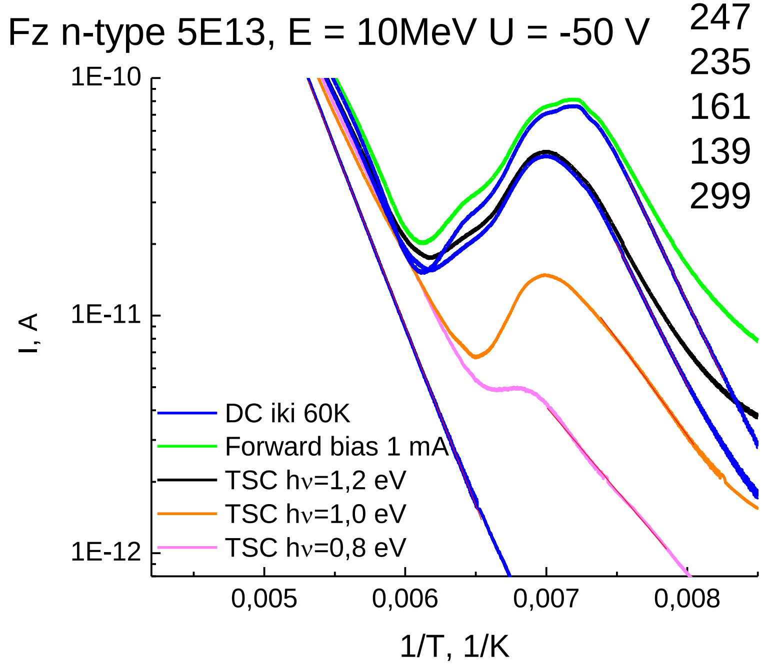
- We, and not only we, use TSC for investigation of traps in irradiated Si, and the light **or** the forward bias regime have been used.
- The results were different, but TSC was measured in different samples.
- We decided to measure it in the same sample …





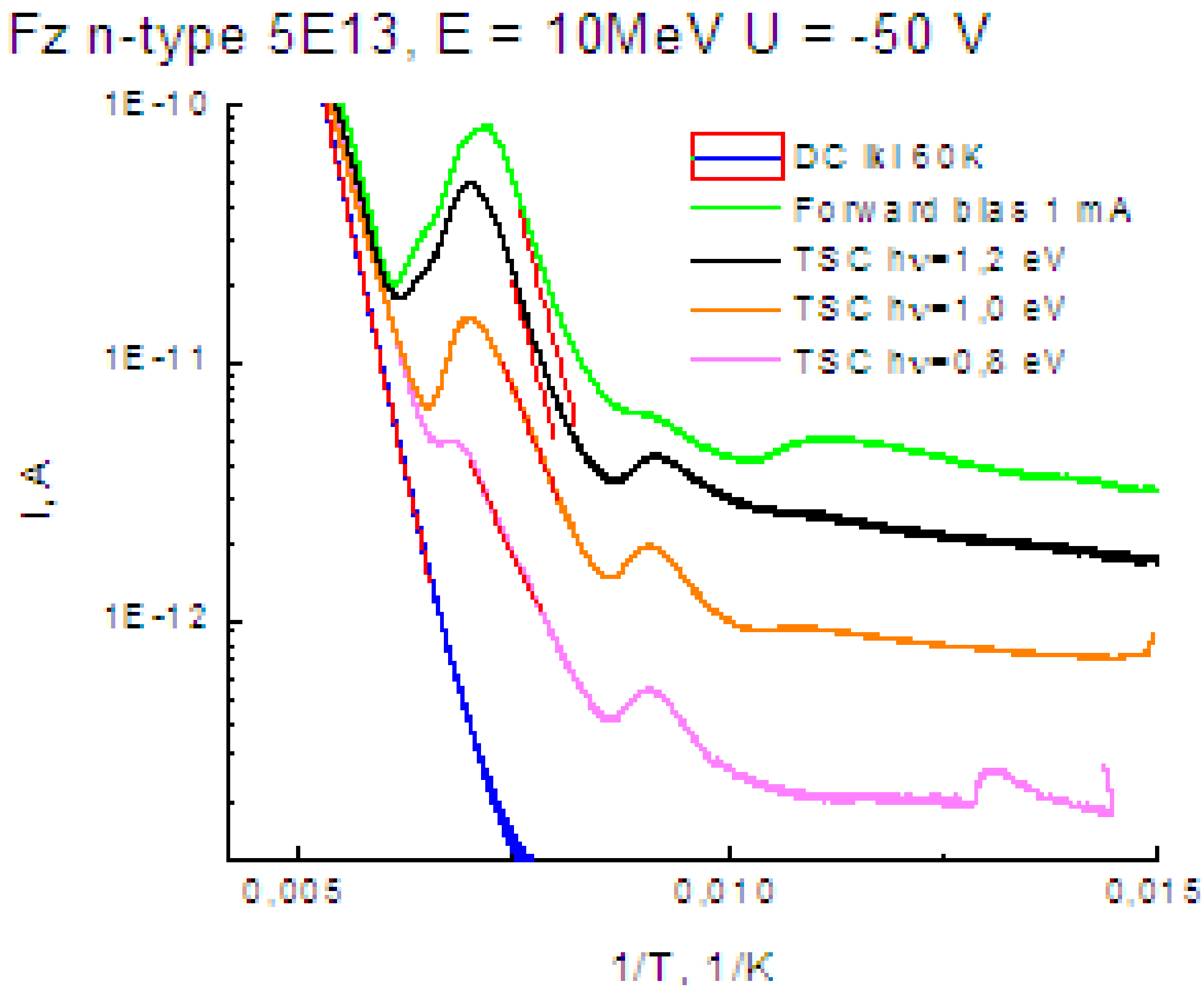
The modulation of the conductivity band bottom depends on the filling of deep levels:





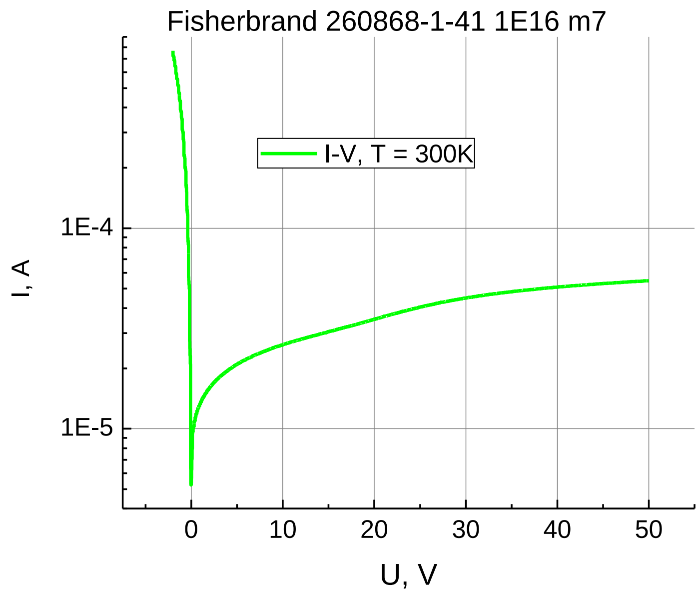
247 meV (F.bias)
235 meV (1,2 eV)
161 meV (1,0 eV)
139 meV (0,8 eV)
299 meV (DC)

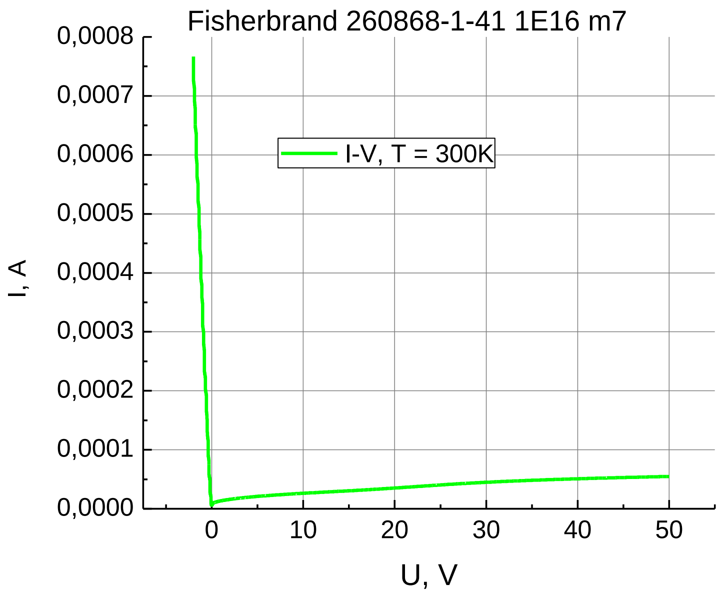
As the measurement is performed by excitation and wait until free carriers will trap or recombine, the independent on temperatte current shows a filling up all traps.



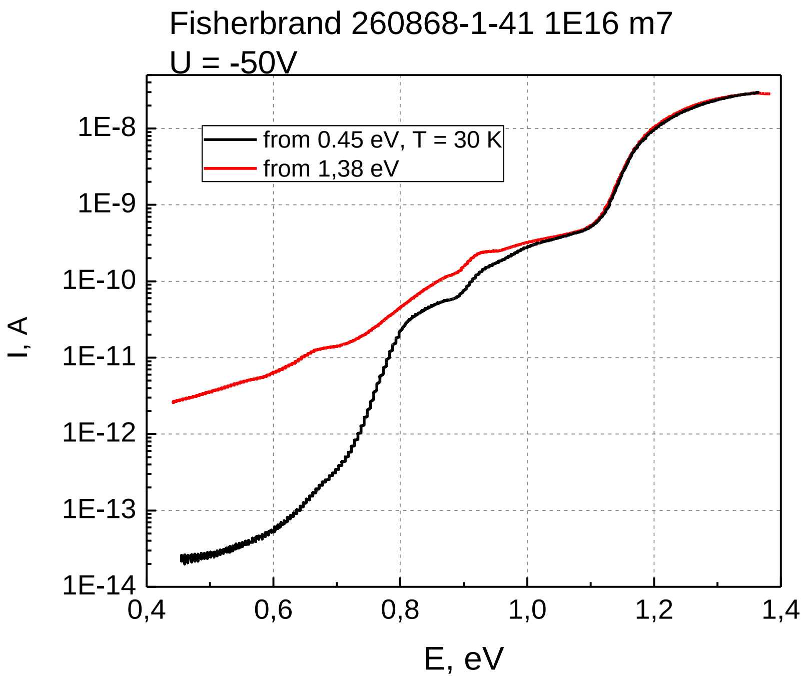
Fz n-type 5E13, E = 10MeV U = -50 V
1E-10
1E-11
1E-12
I, A
0,005
0,010
0,015
1/T, 1/K
DC ki 60K
Forward bias 1 mA
TSC hv=1,2 eV
TSC hv=1,0 eV
TSC hv=0,8 eV

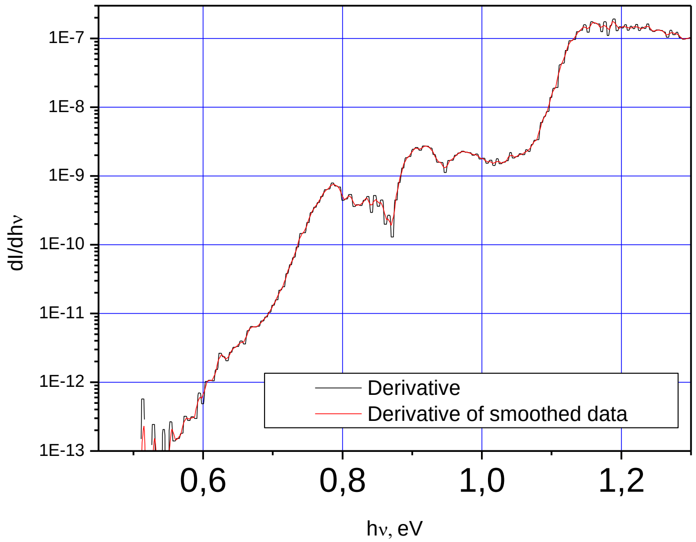
For more detail investigation we chose the neutron irradiated sample





Photoresponse spectrum





The main deep levels optical activation energy - appr. 0,7 eV, 0,9 eV, 1,05 eV

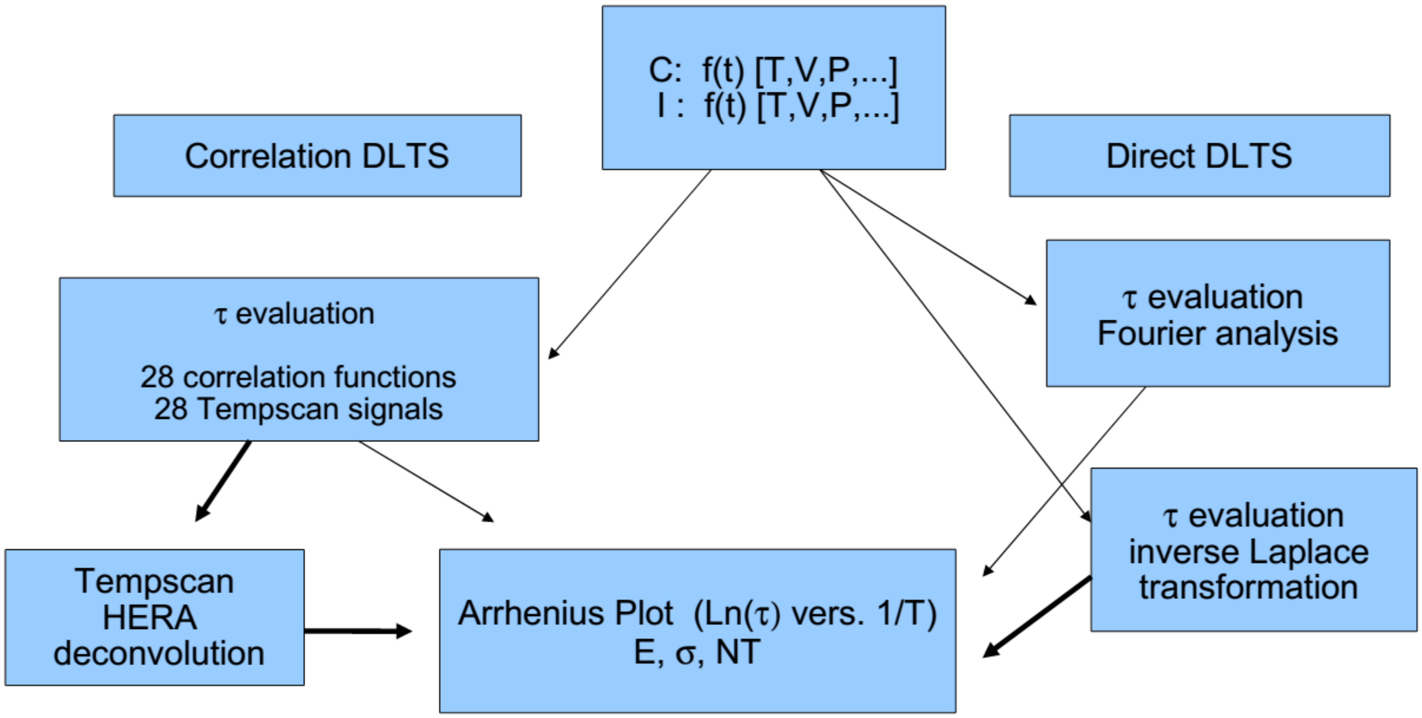
As thermal activation energy are smaller, the strong electron-phonon interaction exists (i.e., recombination induced transforms can be observed)

HERA DLTS-System FT 1030

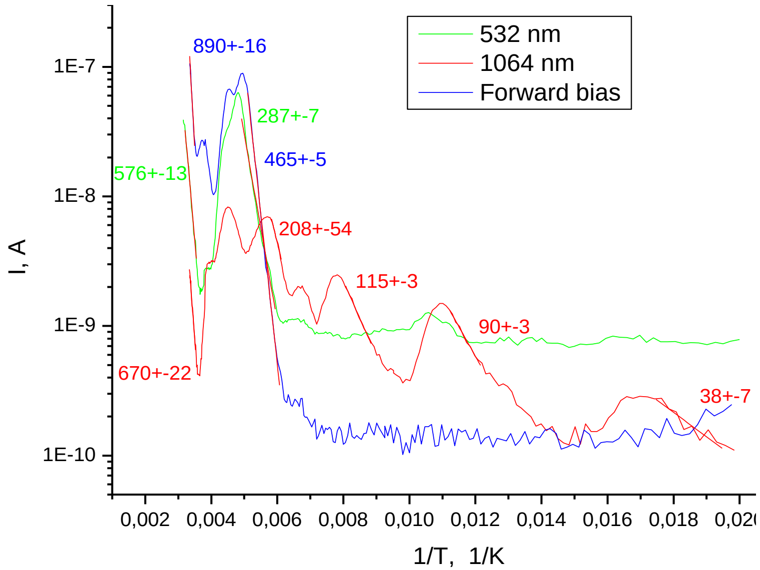
Hardware setup: PC, CTI-CRYOCRYOGENICS cryogenic system, CHAGCHUN NEW INDUSTRIES 1064 and 532 nm laser modules, Boonton 72B capacitance meter, Boonton bridge, LakeShore 336 Temperature Controller, Agilent 81107A pulse generator.

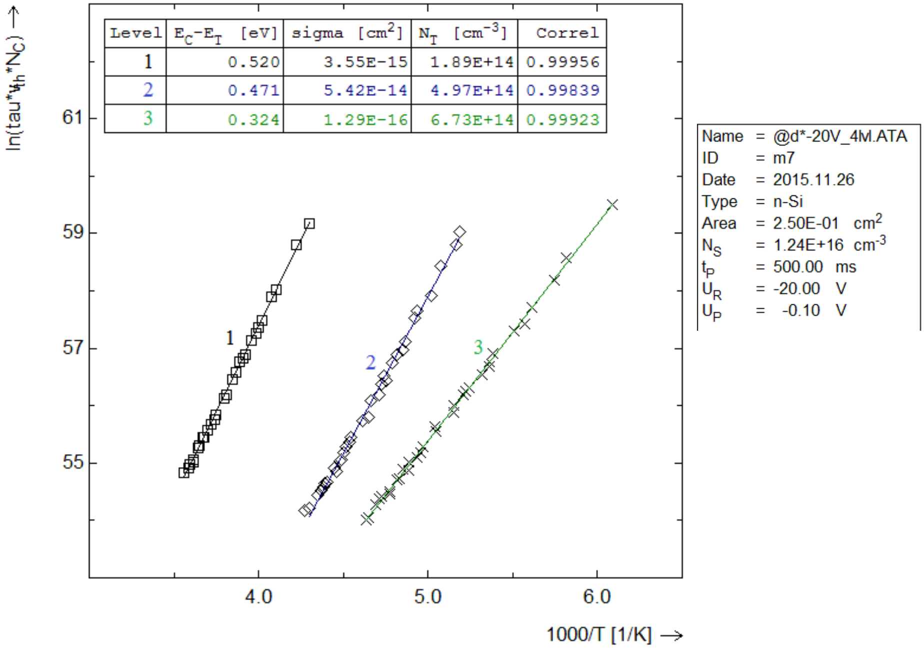
HERA DLTS

- Correlation DLTS (Tempscan, Periodwidthscan, Frequencyscan)
- Fourier DLTS (Direct Transient Analysis)
- Laplace DLTS (Direct Transient Analysis)
- Deconvolution HERA DLTS (Tempscan , Periodwidthscan)

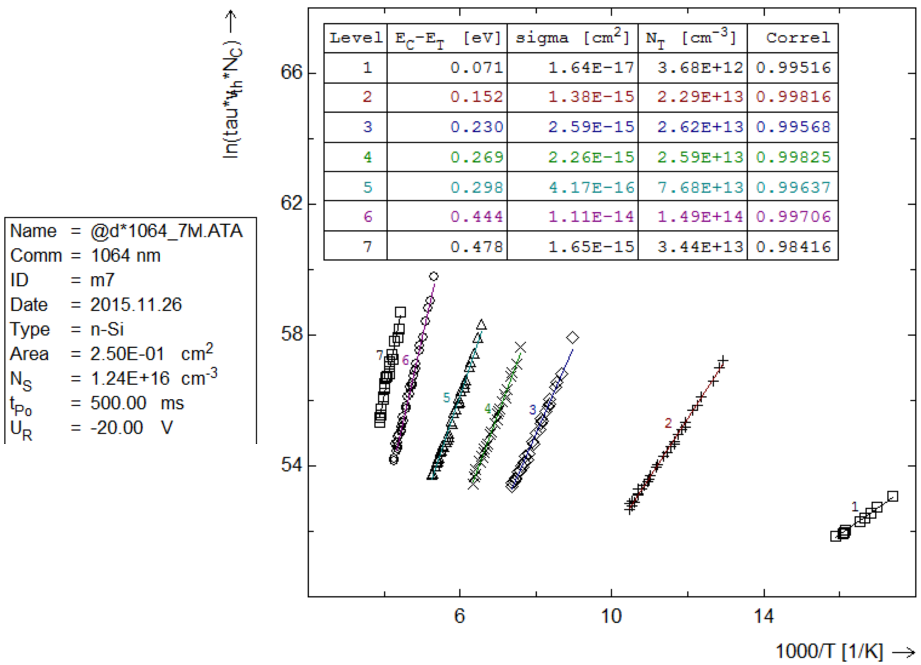


I-DLTS

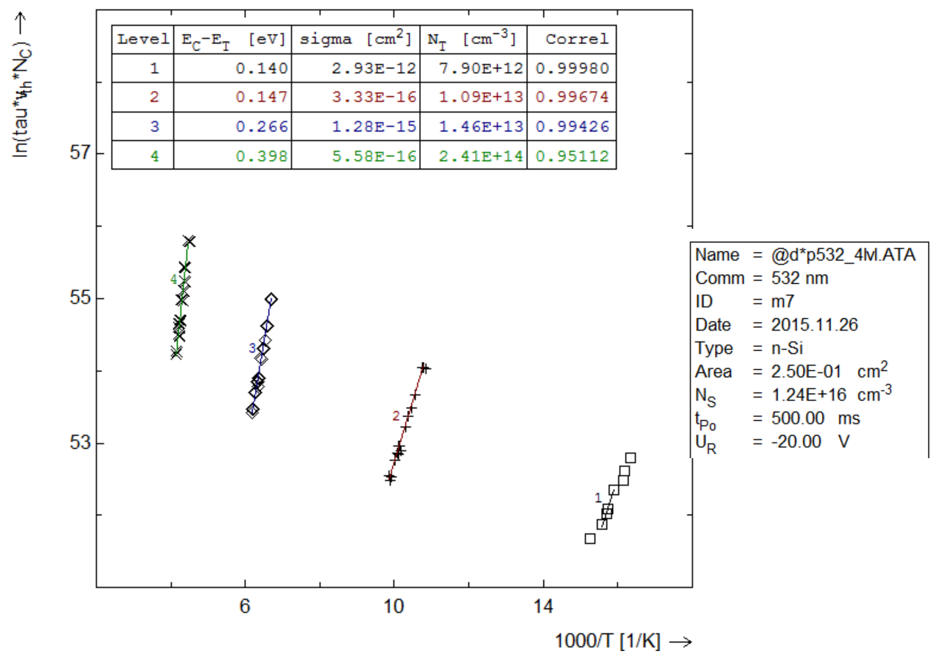




Level	E_C-E_T [eV]	sigma [cm^2]	N_T [cm^{-3}]	Correl
1	0.520	3.55E-15	1.89E+14	0.99956
2	0.471	5.42E-14	4.97E+14	0.99839
3	0.324	1.29E-16	6.73E+14	0.99923

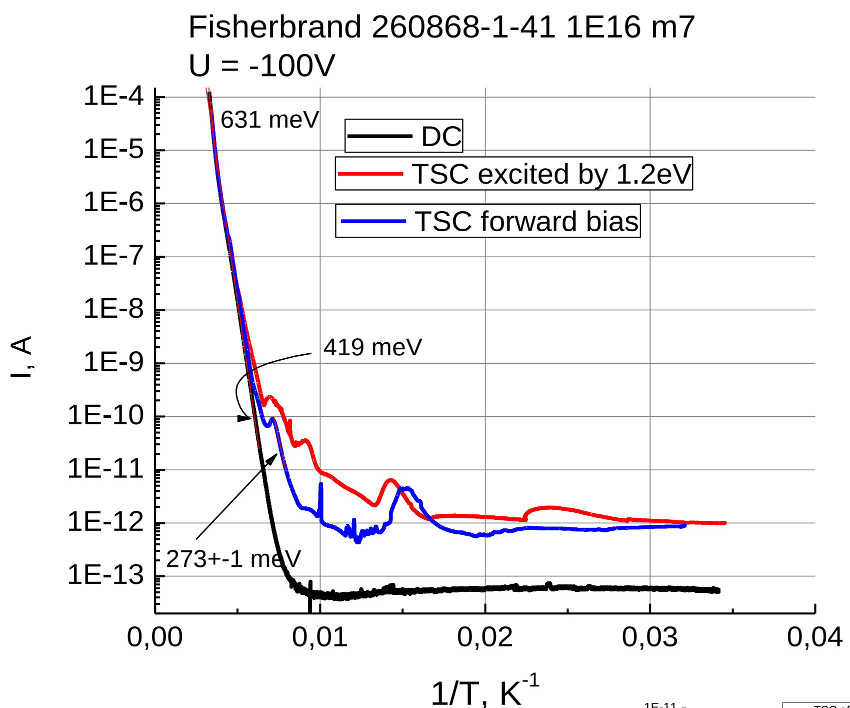


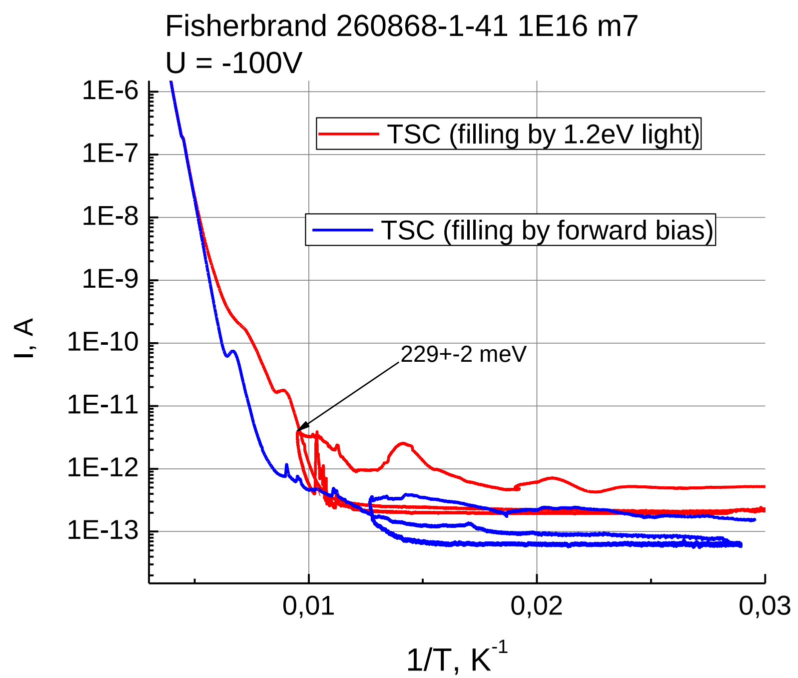
Level	E_C-E_T [eV]	sigma [cm^2]	N_T [cm^{-3}]	Correl
1	0.071	1.64E-17	3.68E+12	0.99516
2	0.152	1.38E-15	2.29E+13	0.99816
3	0.230	2.59E-15	2.62E+13	0.99568
4	0.269	2.26E-15	2.59E+13	0.99825
5	0.298	4.17E-16	7.68E+13	0.99637
6	0.444	1.11E-14	1.49E+14	0.99706
7	0.478	1.65E-15	3.44E+13	0.98416

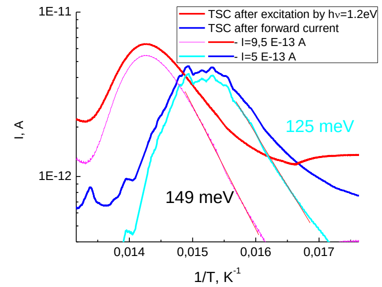


Level	E_C-E_T [eV]	sigma [cm^2]	N_T [cm^{-3}]	Correl
1	0.140	2.93E-12	7.90E+12	0.99980
2	0.147	3.33E-16	1.09E+13	0.99674
3	0.266	1.28E-15	1.46E+13	0.99426
4	0.398	5.58E-16	2.41E+14	0.95112

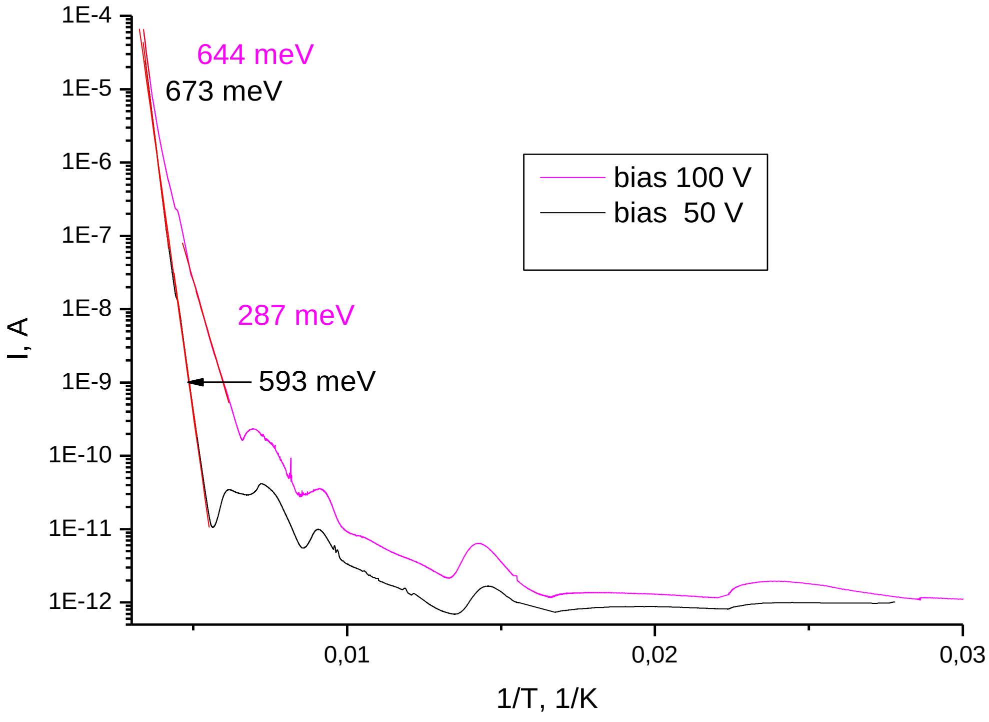
Measurement by a single and multiple heating TSC







TSC @ different bias



Instead of conclusions

- It is why in the title was written “Remarks”…
- The TSC is very attractive method, but it is necessary to perform systematic studies to find out where are the traps
- or why different filling gave different result
- And: during the detector working regime both carriers contribute …

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THANK YOU
FOR YOUR ATTENTION!