Annealing studies on ATLAS12 sensors

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Introduction

- Aims:
  - Annealing Studies on ATLAS12 sensors.
  - Observation of capacitance spectroscopy vs. Annealing.

- Materials:
  - p-type detectors, irradiated with 25 $\frac{GeV}{c}$ protons at fluences between 5e13$\frac{n_{eq}}{cm^2}$ and 2e15 $\frac{n_{eq}}{cm^2}$.
  - One set of detectors annealed at 60°C, one set annealed at RT (ca. 23°C) .

- Methods:
  - Determination of the scaling factor via the trend of charge collection vs. t_{ann}
    - Only for the reverse annealing part.
    - Using characteristic voltages for every fluence.
    - For low fluences determination with only leakage current.
  - Determination of the effective doping concentration and its behaviour vs. t_{ann}:
    - Observation of impedance (capacitance) vs. Frequency vs. Voltage.
    - Detectors irradiated with 1e14 $\frac{n_{eq}}{cm^2}$ and 2e14 $\frac{n_{eq}}{cm^2}$, ongoing annealing .
    - So far only standard analysis of capacitance vs. Voltage.

Background

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Annealing effects depending on time and temperature:

$$\Delta N_{eff} = N_A + N_C + N_Y \;= N_0 e^{-\frac{t}{\tau}} + N_C + N_\infty\left(1 - e^{-kt}\right)$$

$$k, \frac{1}{\tau} \propto e^{-\frac{\varepsilon}{k_B T}}$$ [Moll]

-> faster movement of defects at higher temperatures.

1- Scaling factor between RT and 60°C Annealing

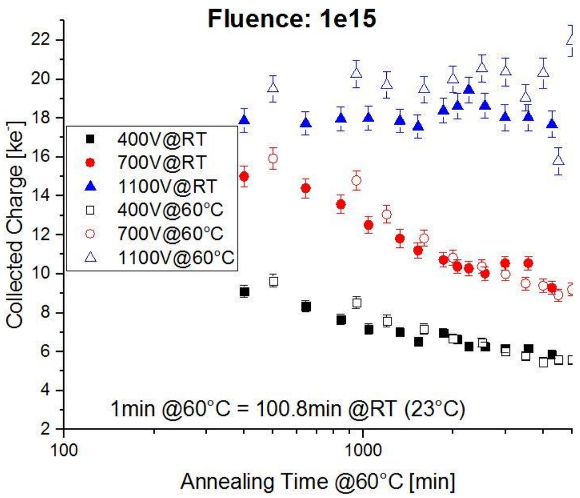
We determined this factor graphically:

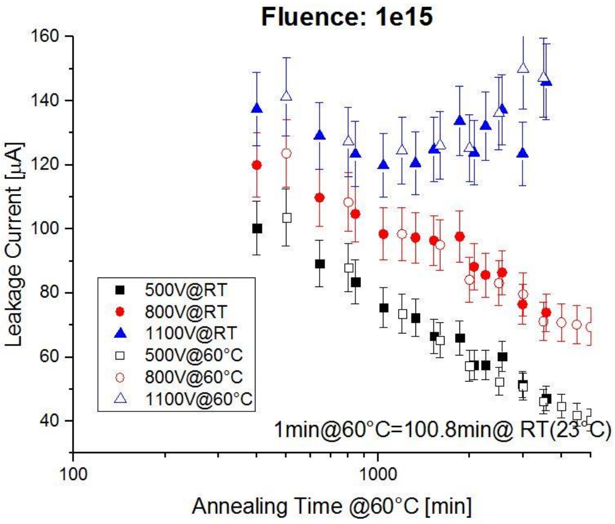
- Only the reverse annealing part was considered.
- The trend of the collected charge and/or leakage current for RT was stretched for characteristic voltages until it agreed with the trend of the 60°C annealing.

2- Neff vs. Time:

- Evaluation of the annealing parameters (k and τ) .
- Observation through capacitance spectroscopy.

Factor between RT and 60°C Annealing (ATLAS12)





Fluence[$\frac{n_{eq}}{cm^3}$]	5e13	1e14	5e14	1e15	2e15
Scaling Factor k	$108 \pm 8^*$	$101 \pm 15^*$	108 ± 12	101 ± 9	108 ± 8

* determined only via leakage current trend. All Errors roughly estimated by fit accuracy.

- The determined scaling factor value is 100-110 , the value from literature [Moll, PhD thesis] is around 325.

  -> Far smaller than expected.

Factor between RT and 60°C Annealing (ATLAS12)

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Scaling Factor k	$108 \pm 8^*$	$101 \pm 15^*$	108 ± 12	101 ± 9	108 ± 8

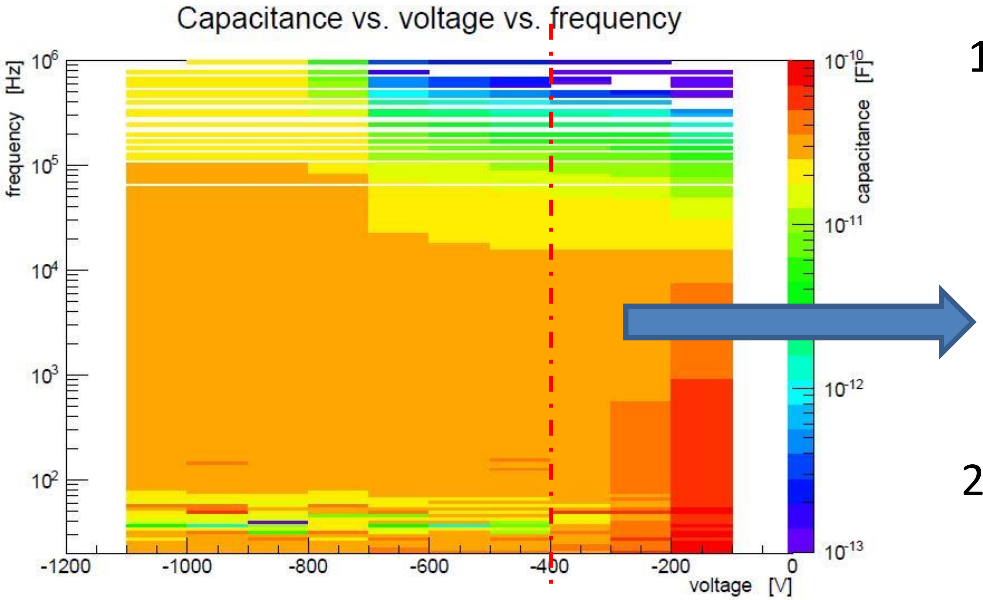
Possible reasons for the big difference:

- Different oxygen concentration: different defects annealing with oxygen impurities.
- Effect of change in detector type (n-type to p-type detectors): different defect annealing with dopants.

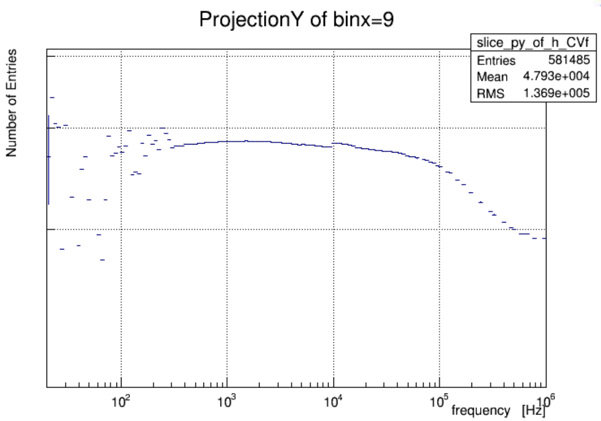
- Or different sensor properties than before?
  -> Investigation on the effective doping concentration behaviour might help in observing eventual differences in nature, activation energy and half life time of annealing processes.

- Capacitance analysis:

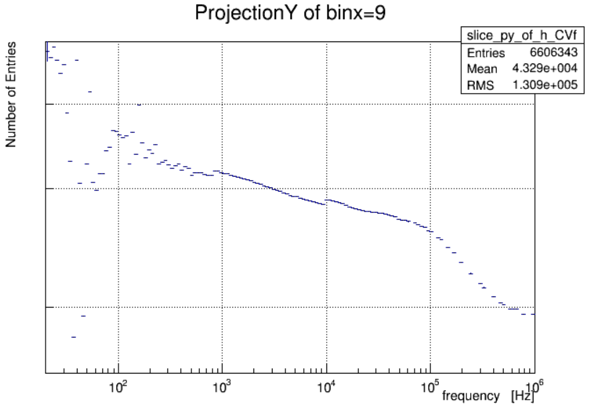
Sensor: W649-C-P17, 2e14 , 500min annealed:



1e14



2e14

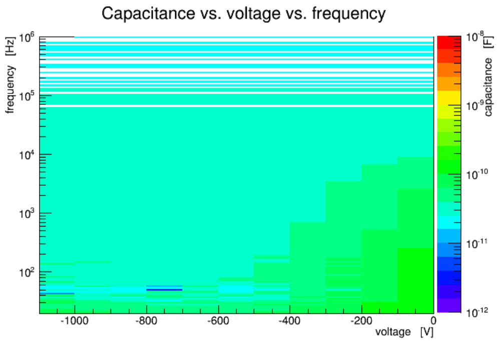


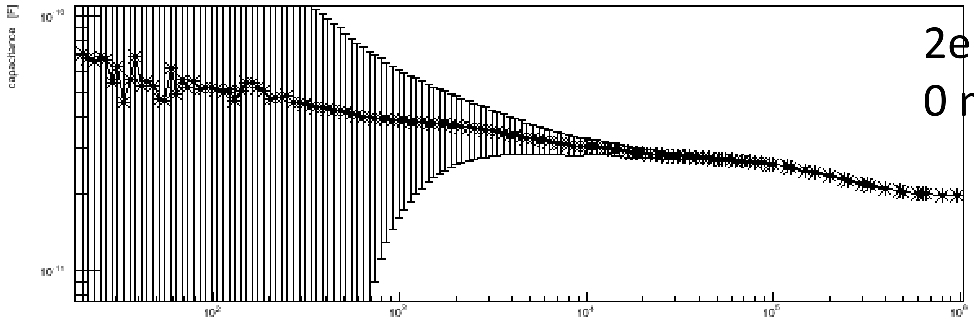
- For low fluences, at low frequencies the quite constant capacitance shows that we can observe the effective doping concentration. More difficult for higher fluences.
- At high frequency deep defects are not able to react fast enough to contribute to the diferential capacitance [e.g. Li, IEEE TNS, 41 – 4, 1994].
- At very high frequencies the strip effect brings down the capacitance.

Impedance measurements: work in progress

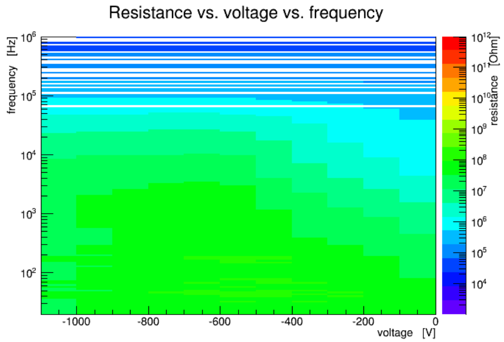
- Capacitance analysis:
  - *If from one side the frequency behaviour is a limit for the Neff studies, from the other it offers a perspective on the defect behaviour:*
    - *This will be studied versus annealing….*

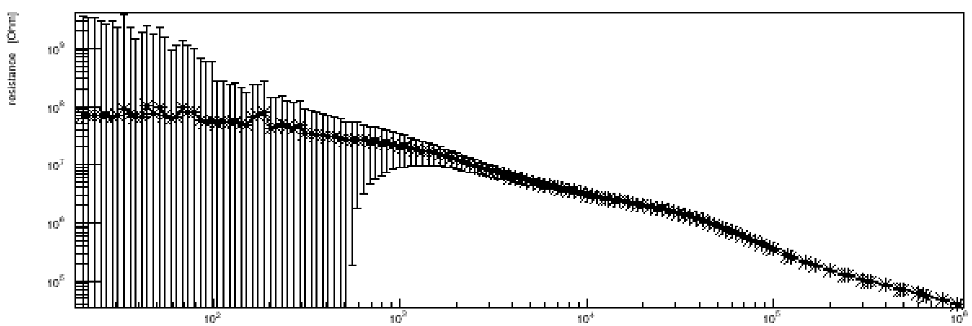
1. We are observing the capacitance and resistance versus frequency, at every annealing step.





2e14 Neq/cm2,
0 min annealing.





- Resistance change in frequency as well as the capacitance:
  - Due to defect reaction times.

Impedance measurements: work in progress

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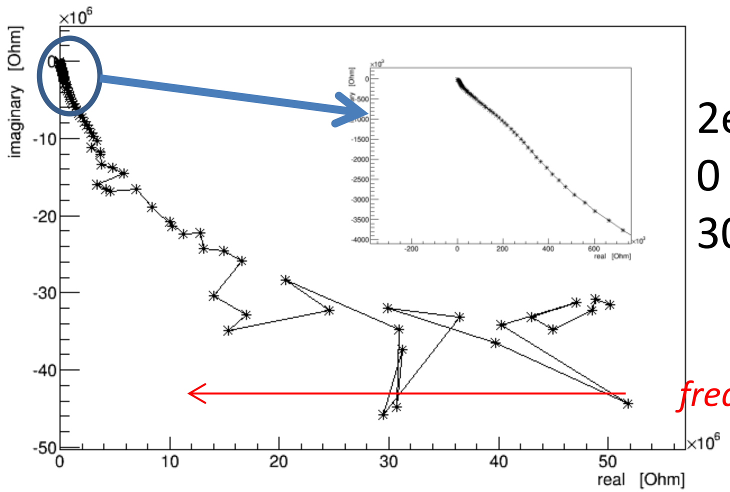
- Capacitance analysis:
  - *If from one side the frequency behaviour is a limit for the Neff studies, from the other it offers a perspective on the defect behaviour:*
    - *This will be studied versus annealing….*

1. We are observing the capacitance and resistance versus frequency, at every annealing step.
2. The complex plot varying frequency shows time constants of defects. This technique has been used in the past for defect spectroscopy in silicon sensors [Li, IEEE TNS, 1994] but also been extensively used for example in solar cells.



frequency

2e14 Neq/cm2,
0 min annealing,
300V.

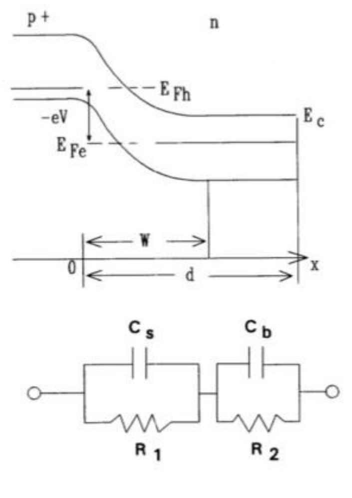
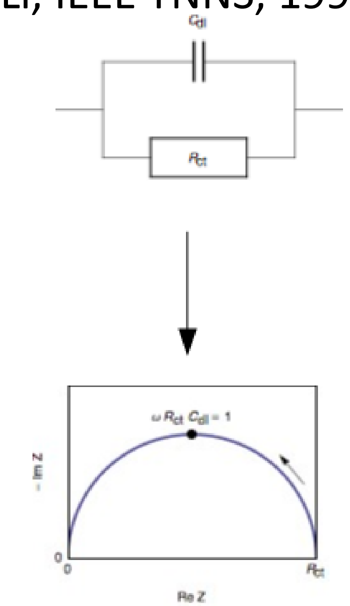


Fig. 14 Energy band diagram and equivalent circuit for a silicon detector in a C-V measurement

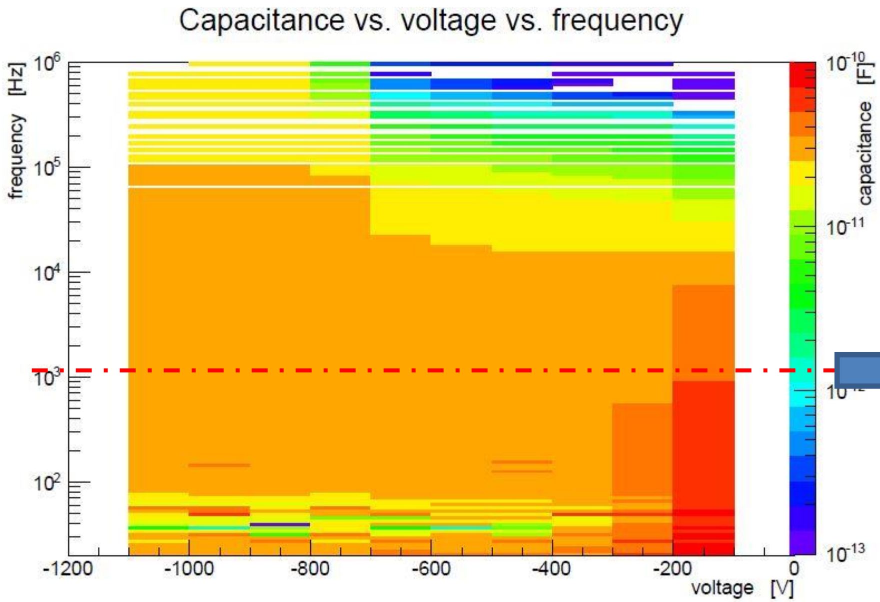
Li, IEEE TNNS, 1994

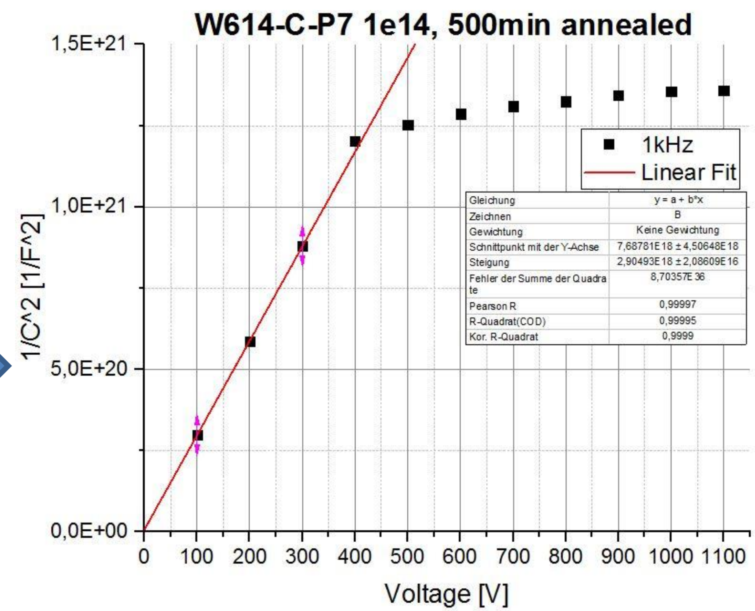


- The sensor irradiated at 2e14 Neq/cm2 shows a defect spectrum.
- (Inset: at very high frequency the strip effect give a small ripple…)
- *We will observe (and fit) the varying spectra versus annealing in order to have another point of view of the changing Neff. Work in progress…*

- Capacitance analysis:

Sensor: W649-C-P17, 2e14 , 500min annealed:





$$\frac{1}{C^2} = \frac{1}{A^2}\frac{2V}{\varepsilon q N_{eff}}$$

- C-V profiles at this fluence shows clear depletion and an investigation of the effective doping concentration is still possible considering low frequencies.
- Frequency behaviour (and resistive part) will be considered especially for higher fluences.

Impedance measurements

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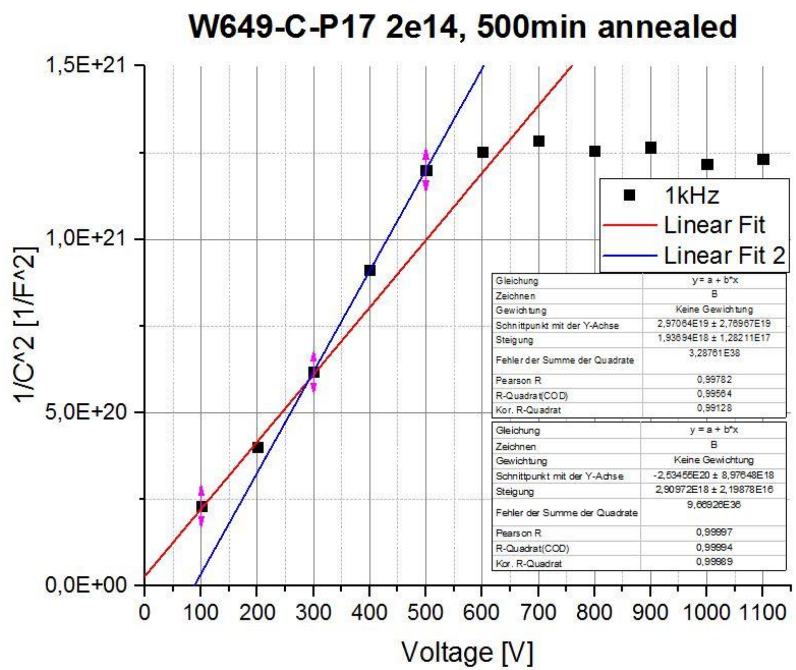
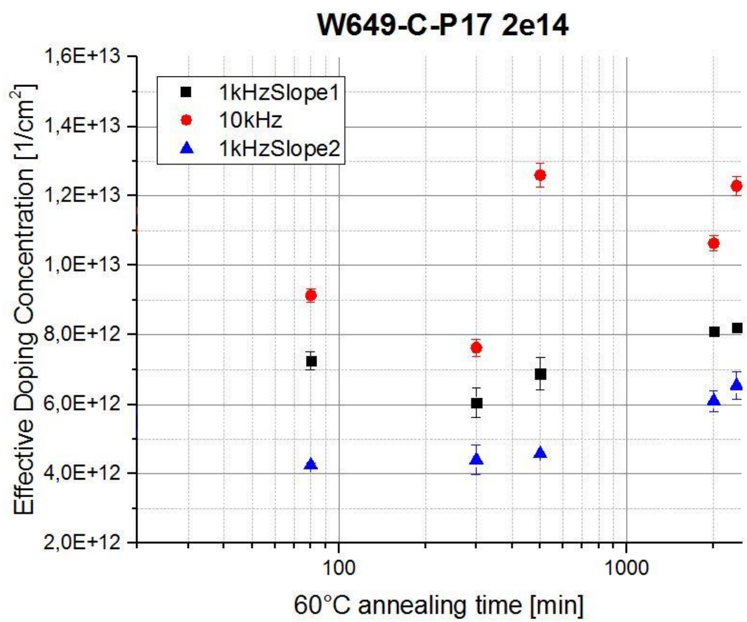
Fluence: 2e14 $\frac{n_{eq}}{cm^2}$

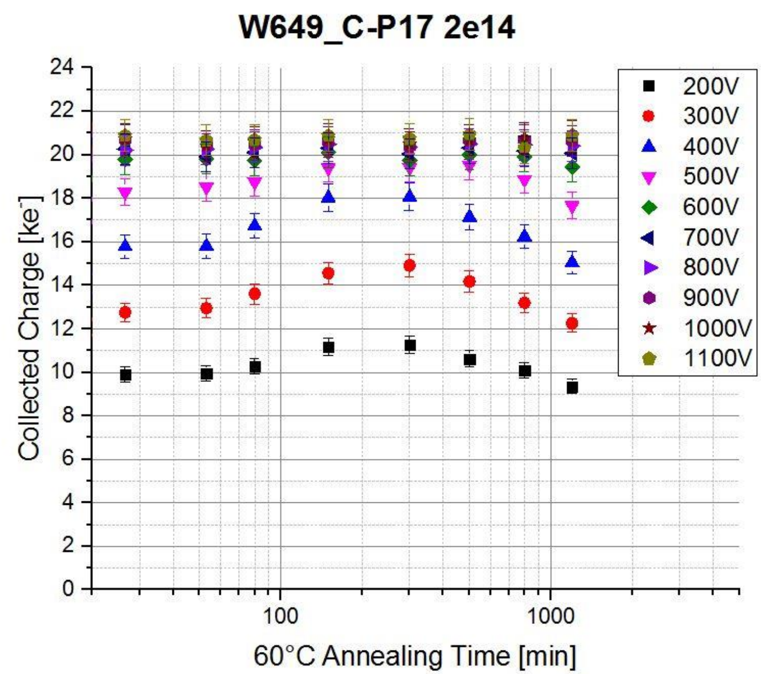


- Two different slopes for the 2e14 n_{eq}/cm^2 sensor at 1kHz.
  -> Behaviour not visible for lower fluences or high frequencies.
  -> First part might correspond to lateral depletion, taking in surface defects.
- Eff. Doping concentration for the second slope is lower. This should correspond to the bulk doping concentration.

Impedance measurements

Fluence: 2e14 $\frac{n_{eq}}{cm^2}$





- Charge collection behaviour is correlated with the extracted effective doping concentration:
  -> Decrease of the effective doping concentration during beneficial annealing until ~300/400min, increase of it during reverse annealing (ongoing).

Impedance measurements

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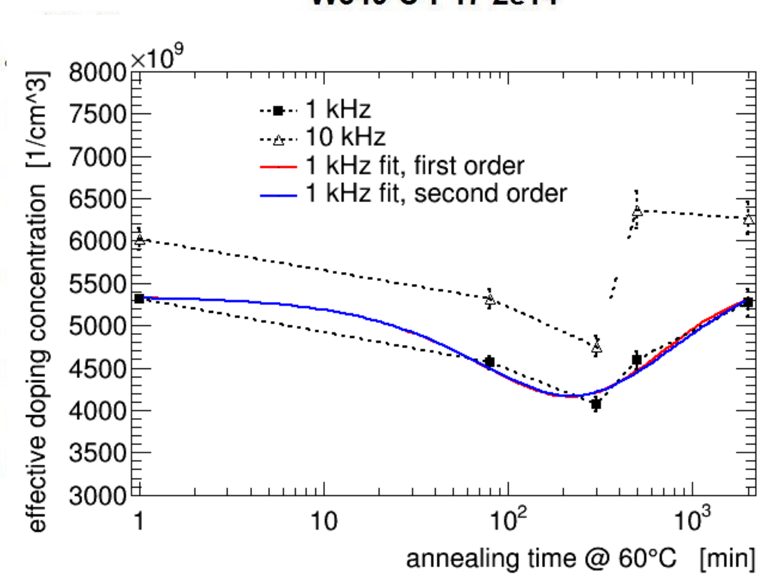
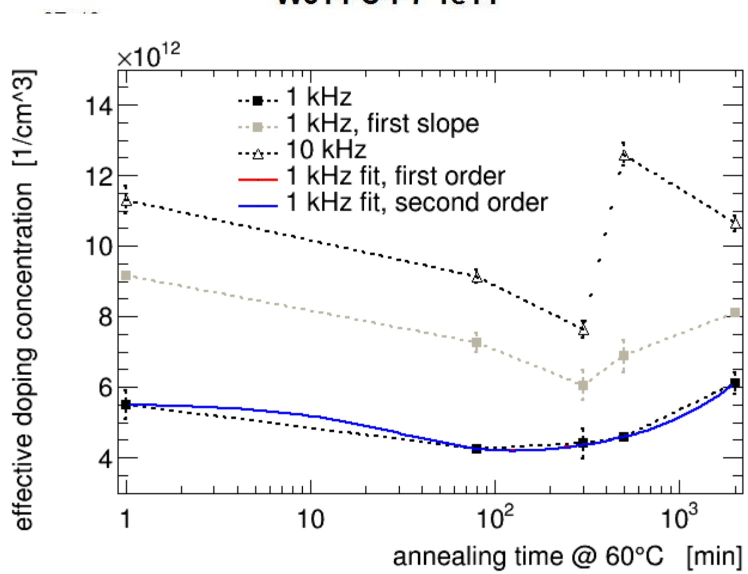
Fluence: 1e14 $\frac{n_{eq}}{cm^2}$ **Fluence: 2e14 $\frac{n_{eq}}{cm^2}$**





$$\Delta N_{eff} = N_0 e^{-\frac{t}{\tau}} + N_C + N_\infty \left(1 - e^{-kt}\right)$$

- Behaviour can be reproduced by first or second order model of defect annealing [Moll, Hamburg model].
- Parameters will be compared after collecting more data points.
- 10kHz behaviour suffer for the partial observation of defects. It will be used for interpreting annealing of shallow defects. Studies are ongoing.

Damage factor

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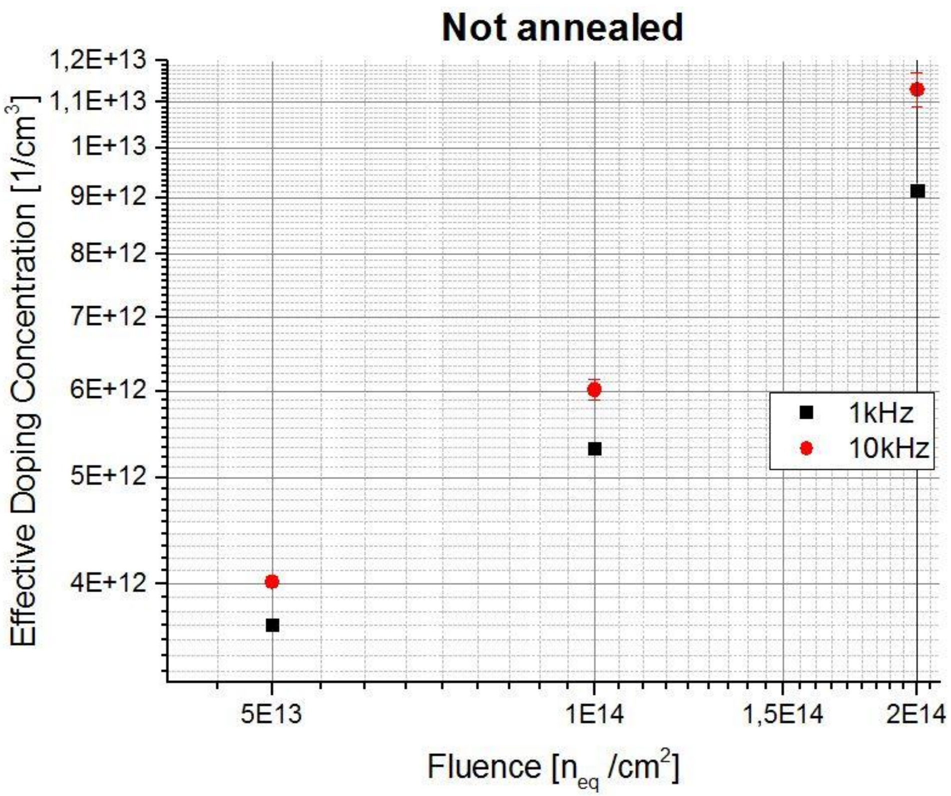


Effective doping concentration for the ATLAS12 sensors before annealing in dependence of the fluence, determined via capacitance measurements.

$$N_C = N_{C0}\left(1 - e^{-C\Phi}\right) + g_c\Phi$$

- Increase of Neff with fluence very well visible.
- With more fluences we will try to fit to extract the damage parameter.

- *After measuring an unirradiated sensor with same method and other with low fluences we will also investigate the acceptor removal.*

Summary

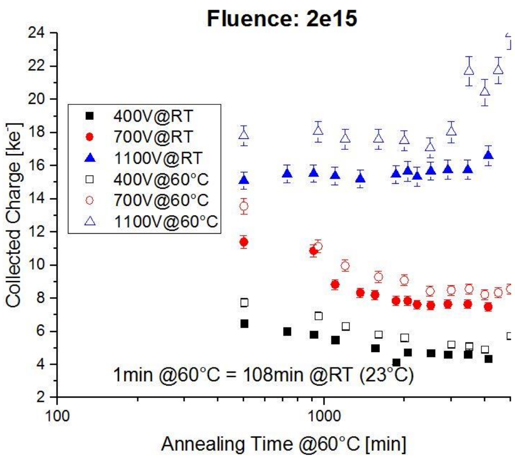
- Results and discussion:

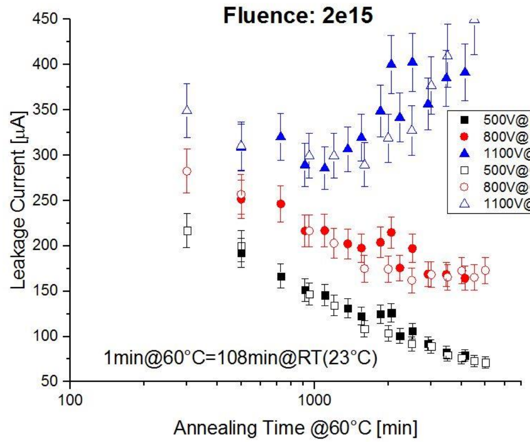
- The determined scaling factor between RT and 60°C is 100-110 , while the value from literature [Moll, PhD thesis] is around 325.
  -> Far smaller than expected!

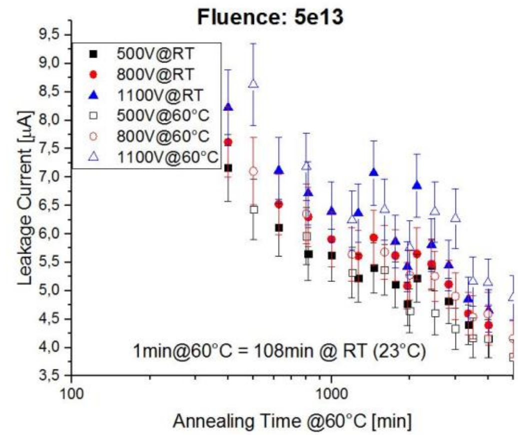
- The determined effective doping concentration fits in the expexted range .
- It behaves like expected with increasing annealing time and increasing fluence.
- The trend corresponds (inverted) to the trend of the collected charge.
- For higher fluence and lower frequency a difference between surface concentration and bulk concentration gets visible by two slopes.

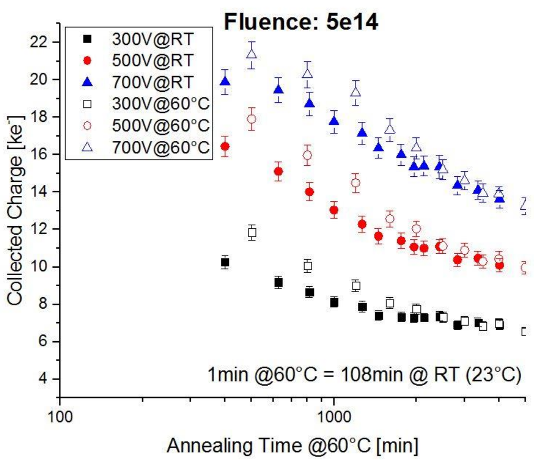
- Impedance measurements can be an useful tool for correlating the change of performance during annealing with change in defects, and explain differences between different sensors.

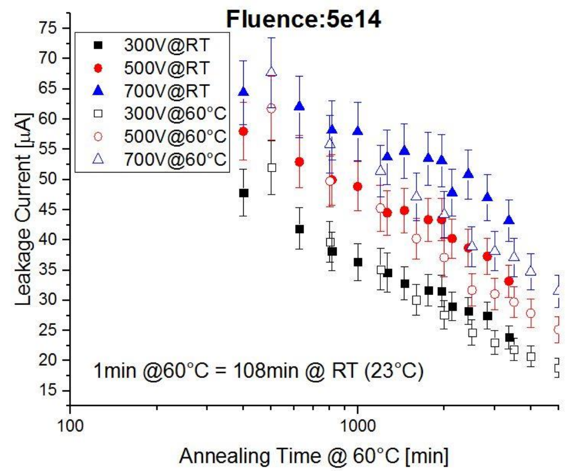
Backup: Factor

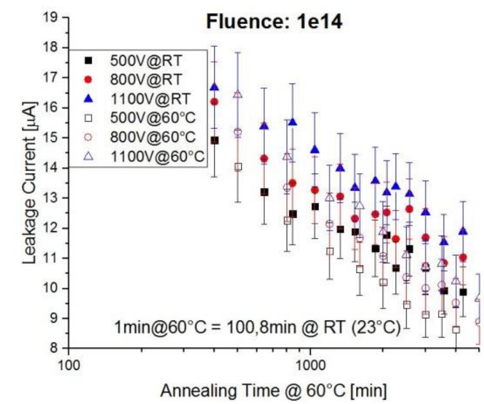












Backup: Effective doping concentration

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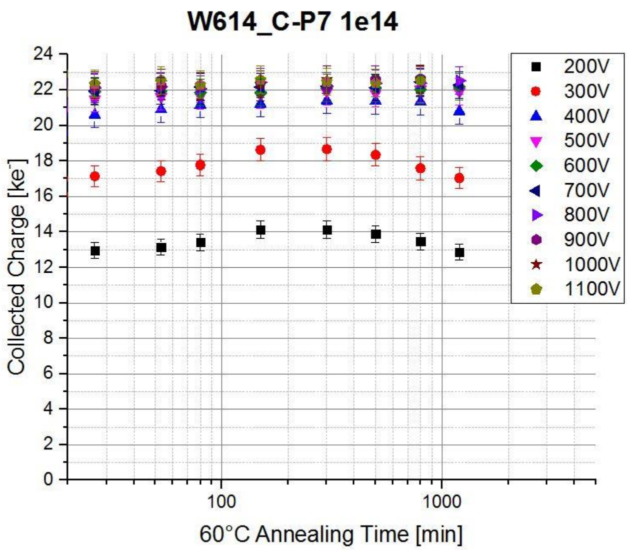

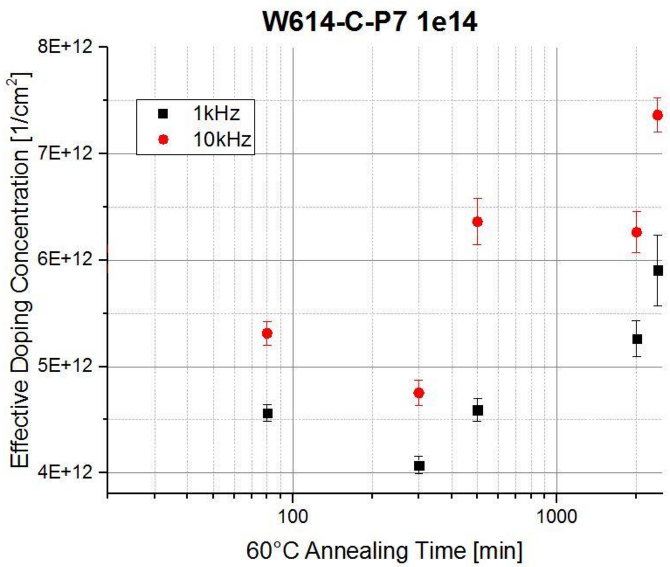

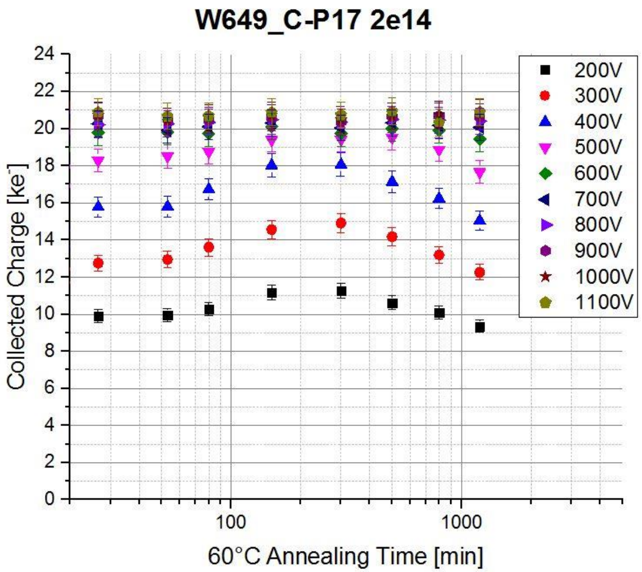

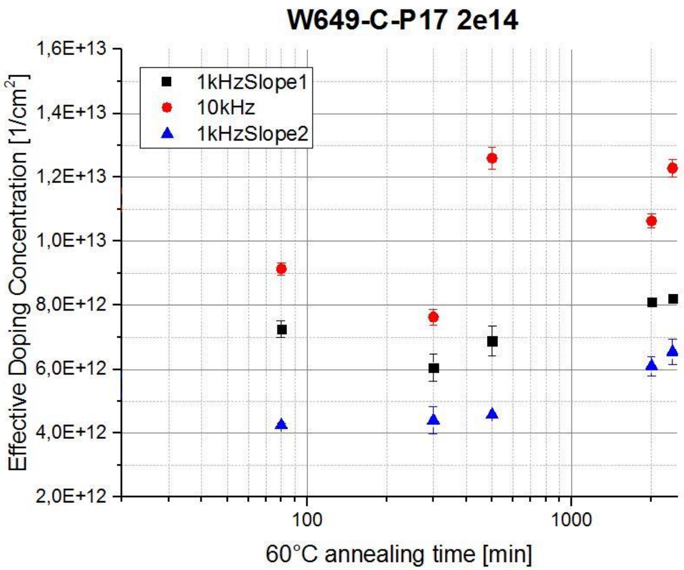

Backup: Neff

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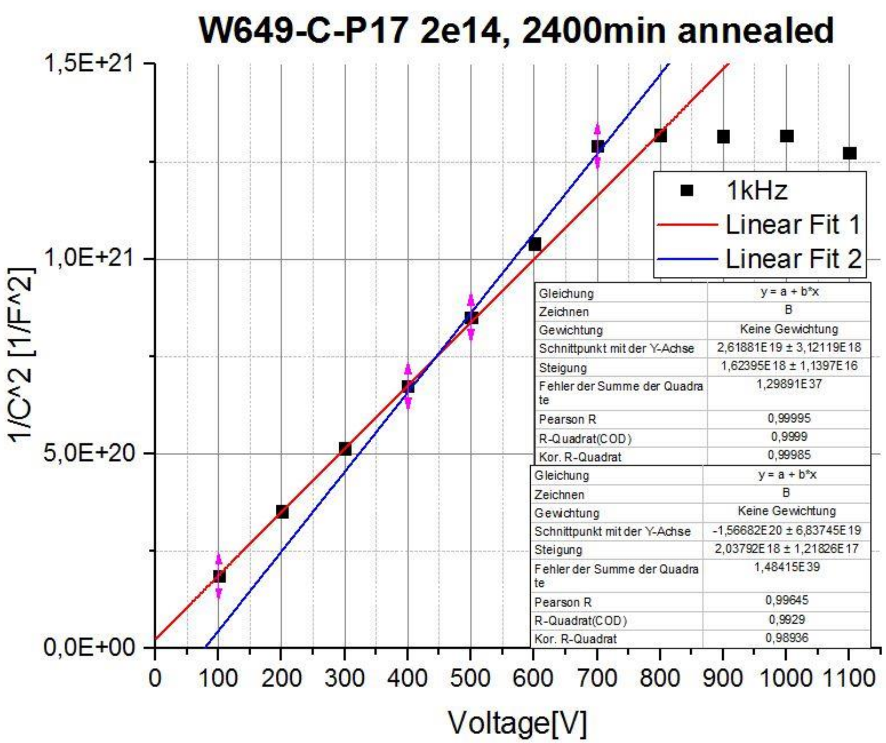
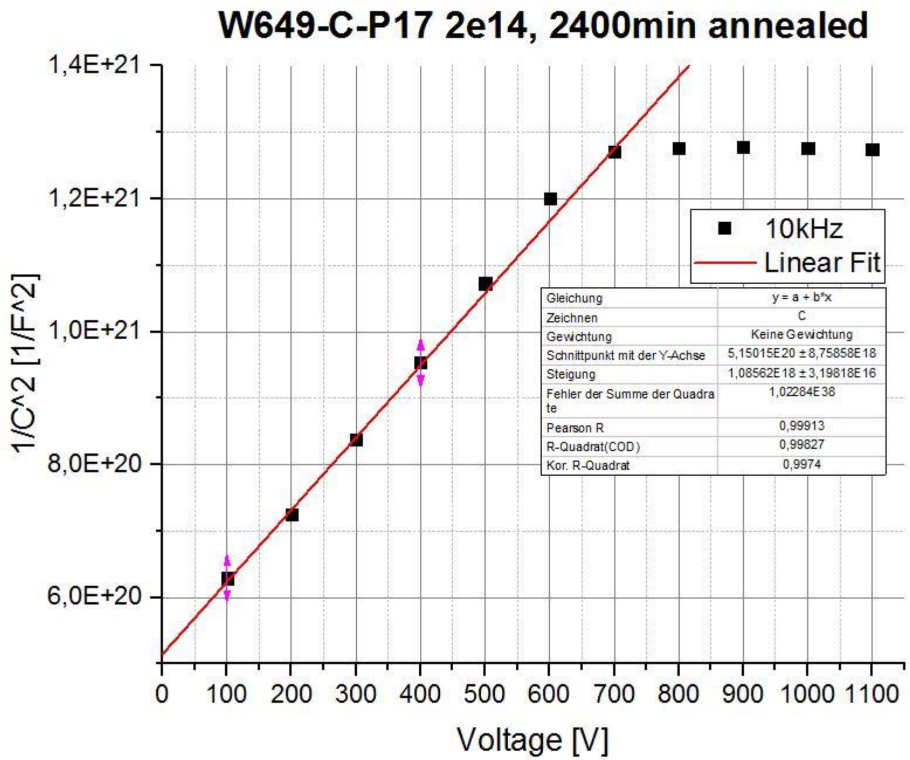
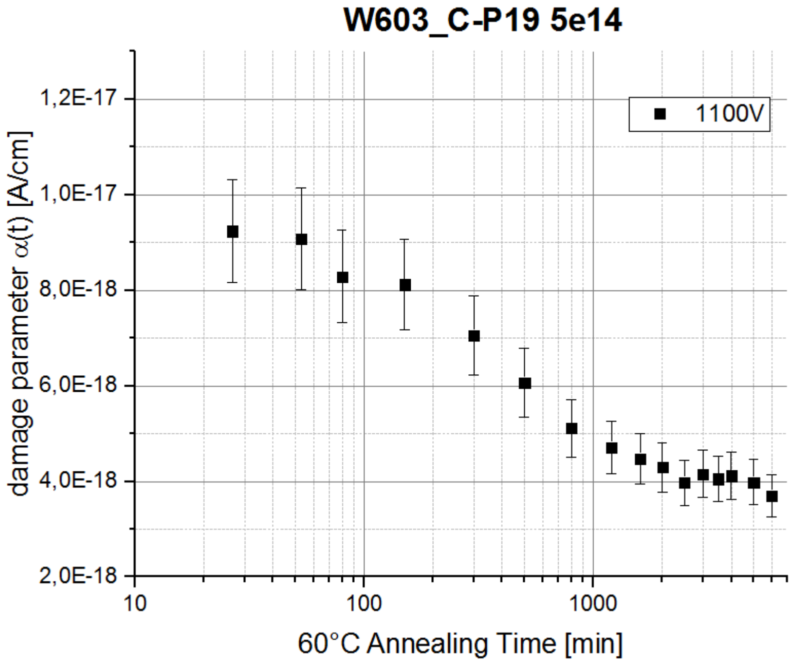




Backup: Alpha vs time



Values calculated with [Moll]

$$\alpha(t) = \frac{\Delta I}{\Phi_{eq} V}$$

Expected course confirmed – constant decrease during annealing time

It can be described with [Moll]: (works in progress…..)

$$\alpha(t) = \ \alpha_I \exp\left(-\frac{t}{\tau_I}\right) + \alpha_0 - \beta \ln\left(\frac{t}{t_0}\right)$$