Annealing studies on ATLAS12 sensors

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Introduction

- Aims:

  - Quality assurance and test of the sensors provided by the ATLAS Strip Collaboration for the Upgrade of the ATLAS Experiment:
    - Full characterization of the sensor performance with the other groups, we focus on the annealing behaviour through charge collection, leakage current and impedance (capacitance) measurements.

  - Difference between room temperature and 60°C annealing in p-type sensors:
    - So far, mainly 60°C studies have been carried out.

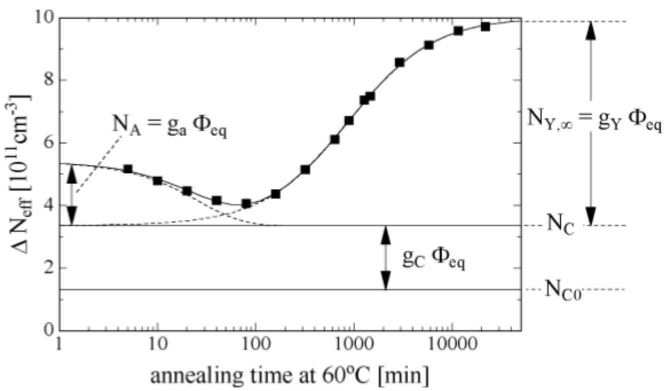
  - In the near future: impedance spectroscopy in irradiated sensors:
    - Hints about main defects behaviour (controlling the lifetime) vs. Annealing.

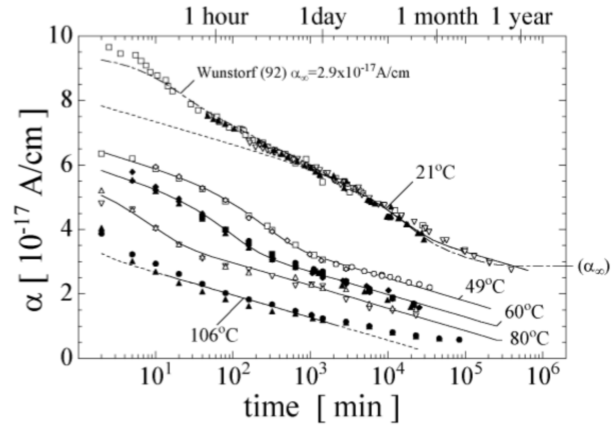
Introduction

- Materials:
  - p-type detectors, irradiated with 25 $\frac{GeV}{c}$ protons at fluences between 5e13$\frac{n_{eq}}{cm^2}$ and 2e15 $\frac{n_{eq}}{cm^2}$ (here up to 3e14 $\frac{n_{eq}}{cm^2}$).
  - 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}.
  - Determination of the effective doping concentration and its behaviour vs. t_{ann}:
    - Observation of impedance (capacitance) vs. frequency vs. voltage.
    - So far only standard analysis of capacitance vs. voltage.
  - Comparison of annealing time constants with values from the literature:
    - Differences with the values from Moll thesis have been already reported, we show possible reasons.

- Theory:
- Annealing depends on time and temperature:





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

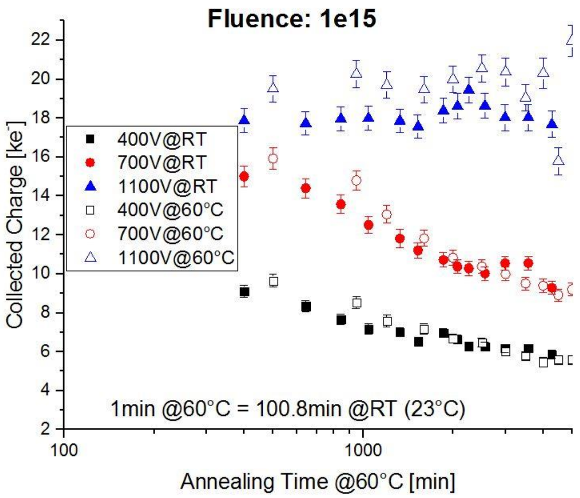
$$\alpha(t) = \frac{\Delta I}{\Phi_{eq} V}$$

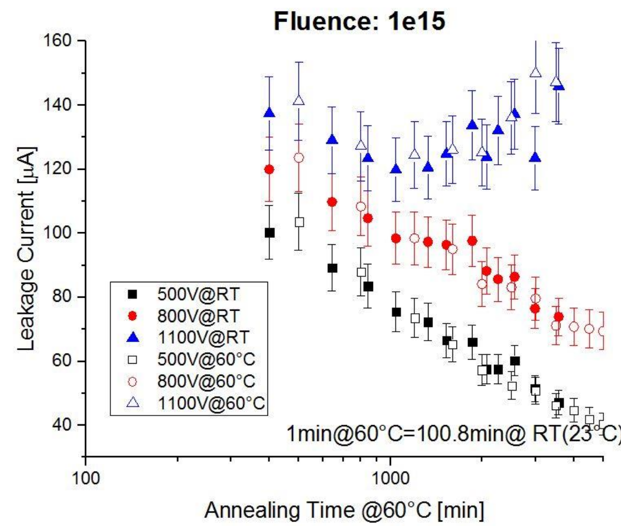
$$\alpha = \alpha_I e^{-\frac{t}{\tau}} + \alpha_0 - \beta \ln(t)$$

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

-> faster movement of defects at higher temperatures.

- Previous results:





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 previously known value is around 325.

-> Is this due to different sensors? P-type vs. N-type? Different oxygen concentration?

Impedance measurements

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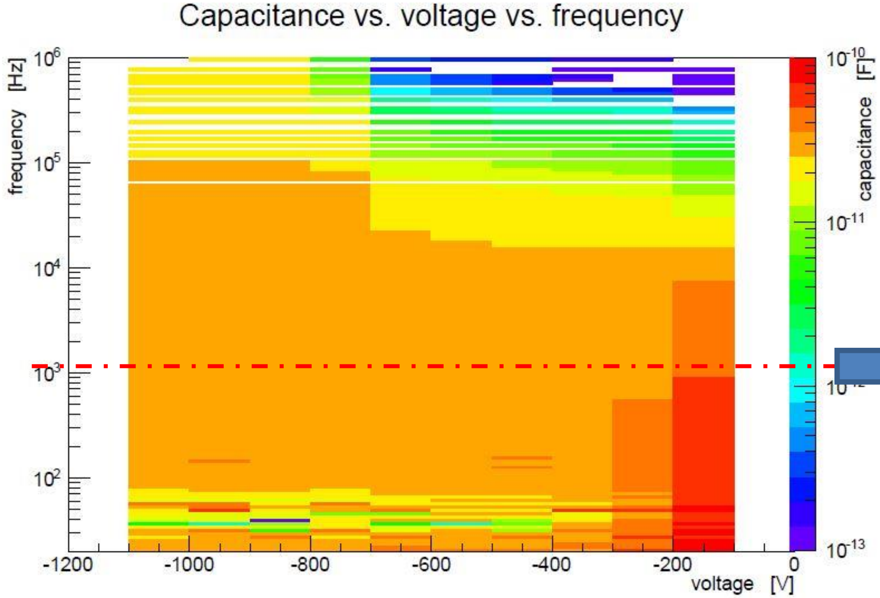
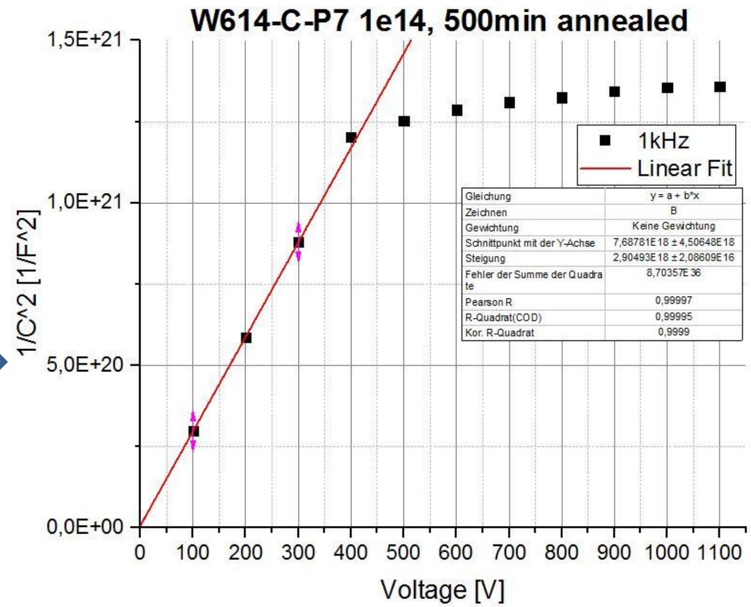
- Effective doping concentration (Neff) analysis:

Sensor: W614-C-P17, 1e14 , 500min annealed:



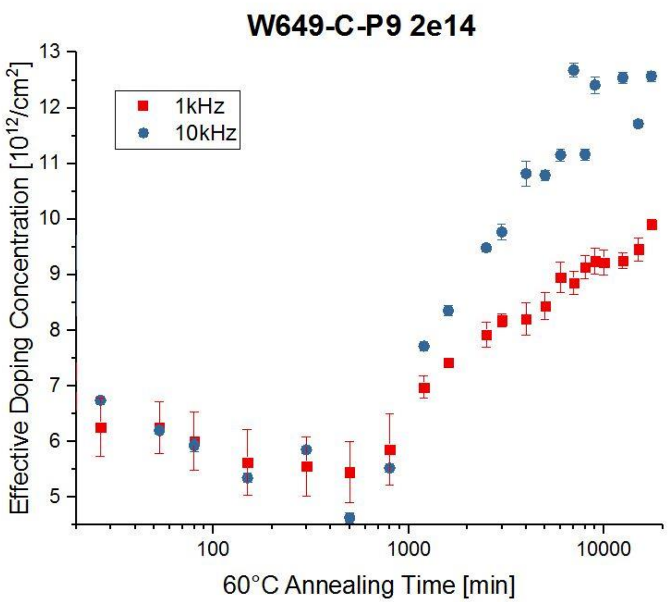


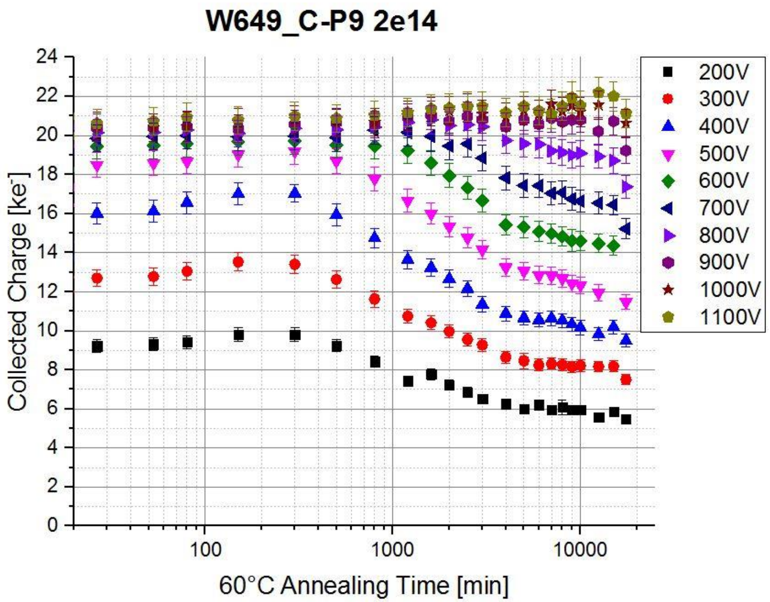
$$\frac{1}{C^2} = \frac{1}{A^2}\frac{2V}{\varepsilon q N_{eff}}$$

- 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.

Correlation between charge collection and effective doping concentration

- Results: 2e14 N_eq/cm2





- 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).
- Sensor lives through very long annealing times -> but fluence too low for Charge Multiplication. We are still annealing it……

Effective doping concentration and damage parameter

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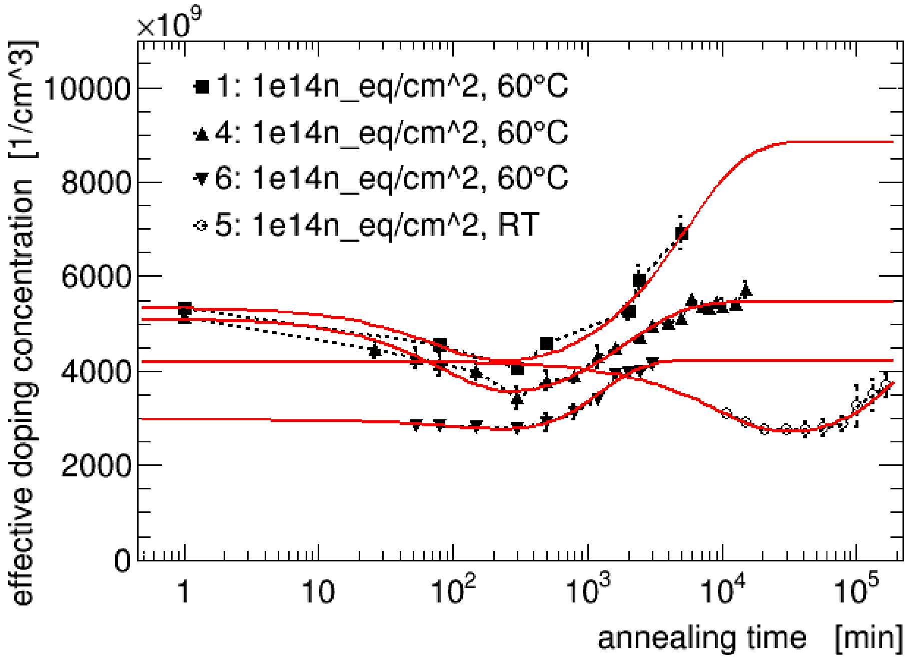
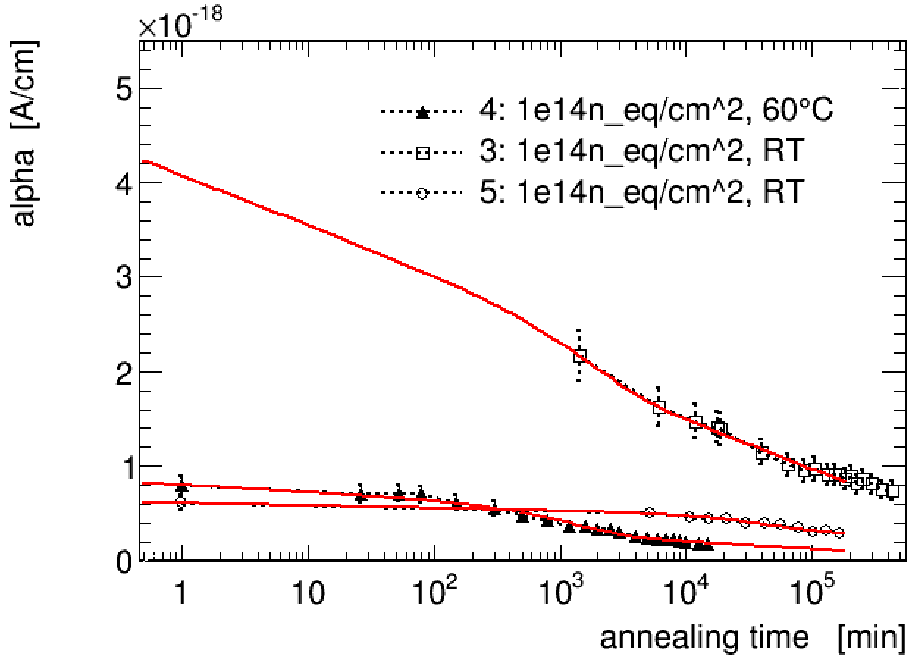
- Results: 1e14 N_eq/cm2



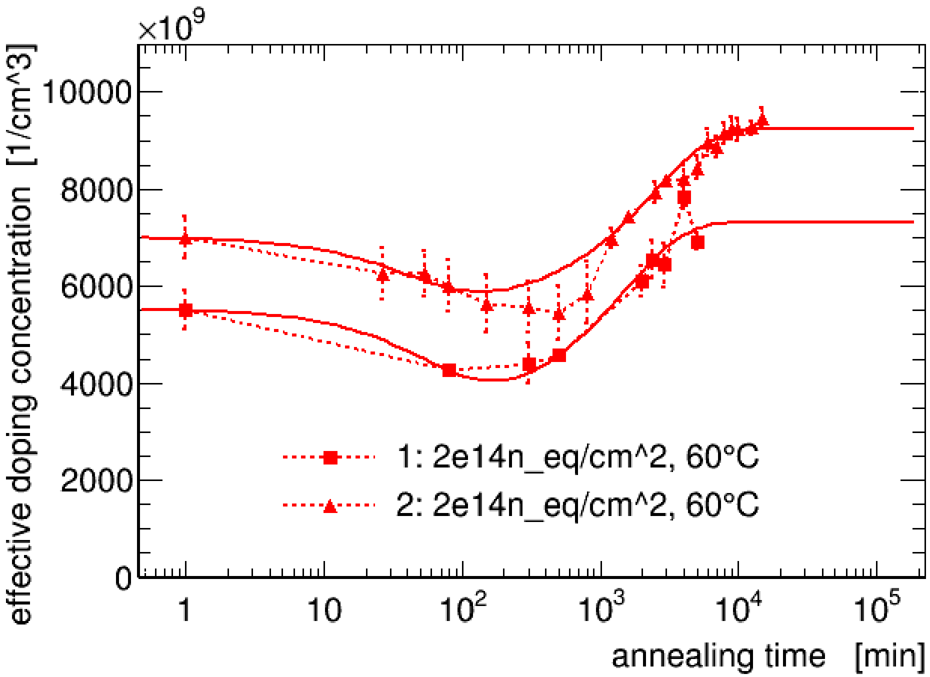


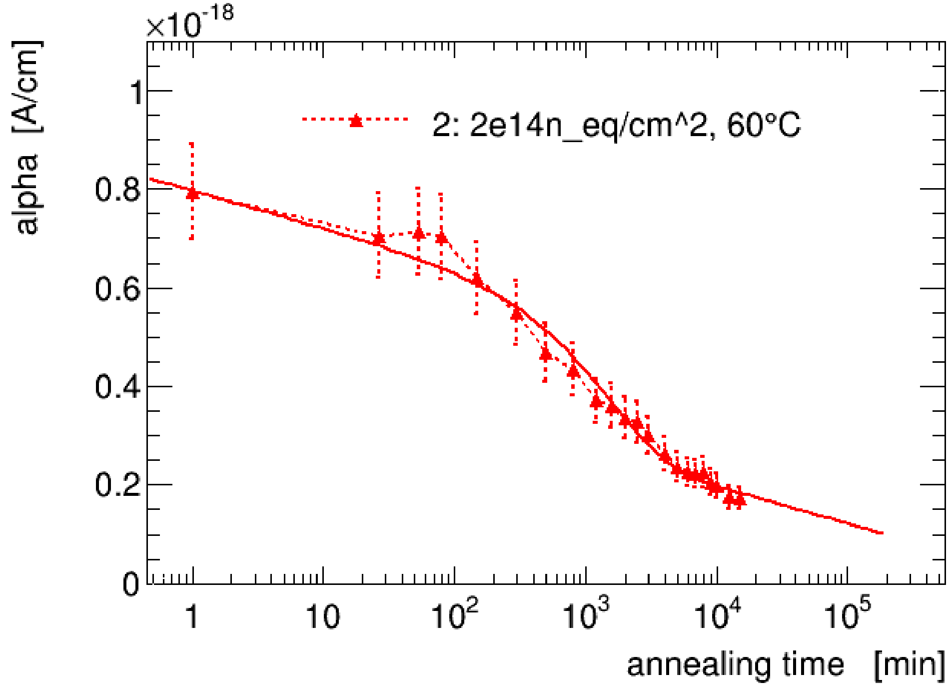
leakage current normalized to a temperature of 0°C

- Neff values well in the expected range:
  - at this fluence capacitance measurements are (at 1kHz) are still ok! (Capacitance is flat at low frequencies.)
- Hamburg model fits for Neff and alpha describe well the behavior.
- The beneficial annealing (minimum of Neff) appears to be 100 times slower at RT respect to 60°C….
- (sensor 3 showed larger current but similar annealing times.)

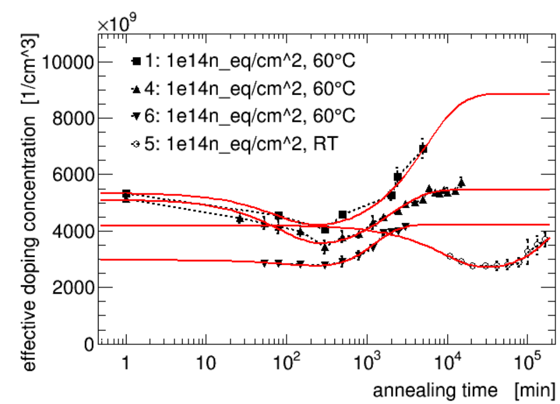
Effective doping concentration and damage parameter

- Results: 2e14 N_eq/cm2



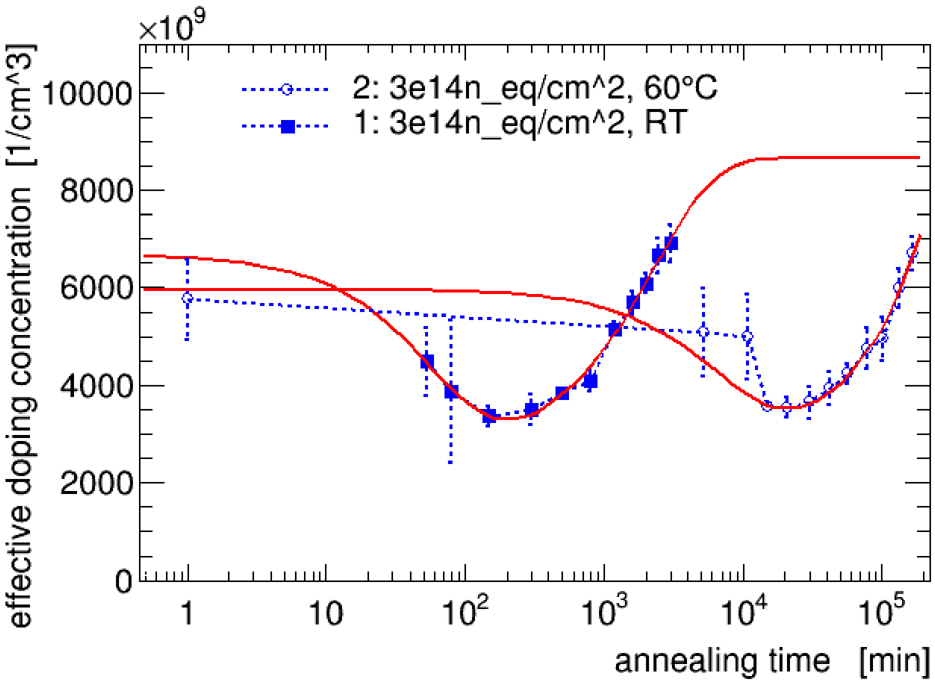


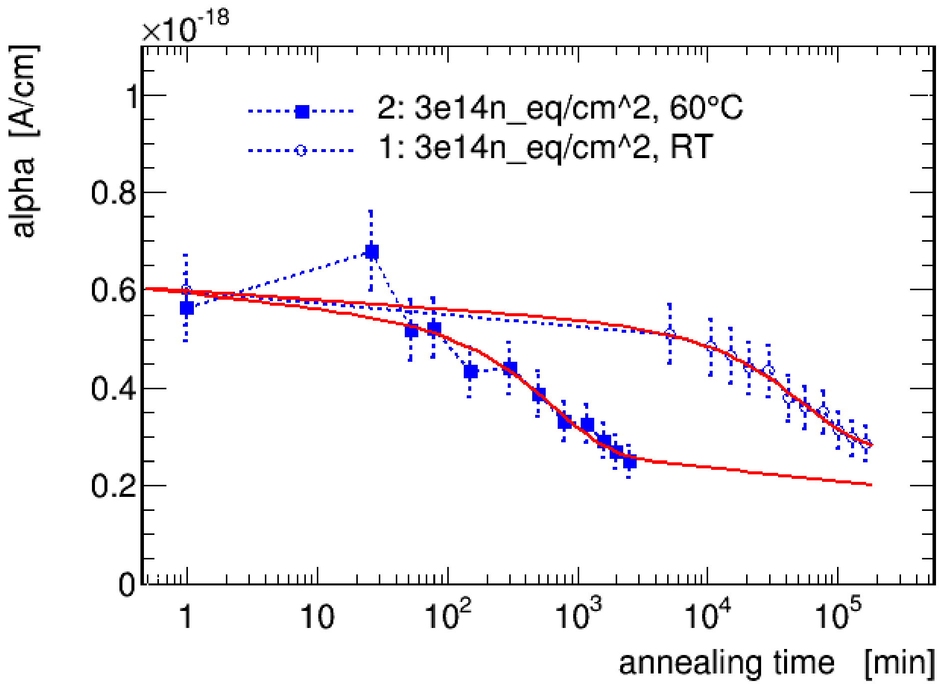
- Also at 2e14 $\frac{n_{eq}}{cm^2}$ the capacitane measurements are giving reasonale results.
- Annealing time constants are similar to the ones of 1e14 $\frac{n_{eq}}{cm^2}$.
- (Unfortunately we have only 60°C data for this fluence.)



Effective doping concentration and damage parameter

- Results: 3e14 N_eq/cm2



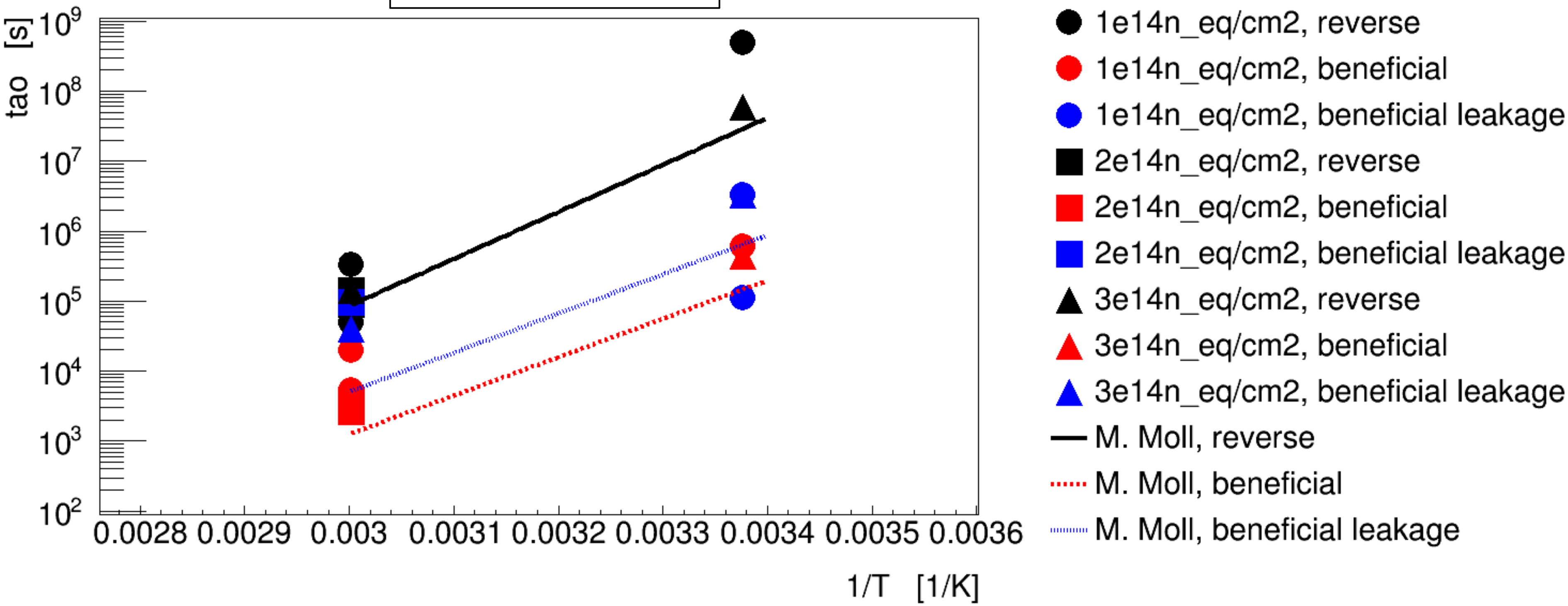


- Time constants and annealing behaviour is confirmed at 3e14 $\frac{n_{eq}}{cm^2}$.
- Larger errors:
  - Capacitance measurements start to loose accuracy already at this fluence.

Investigation of the time constants

- Result summary:

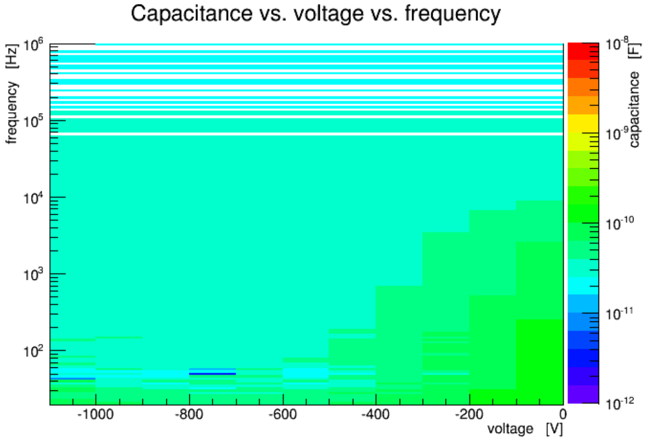
$$k, \frac{1}{\tau} = k e^{-\frac{E_a}{k_B T}}$$

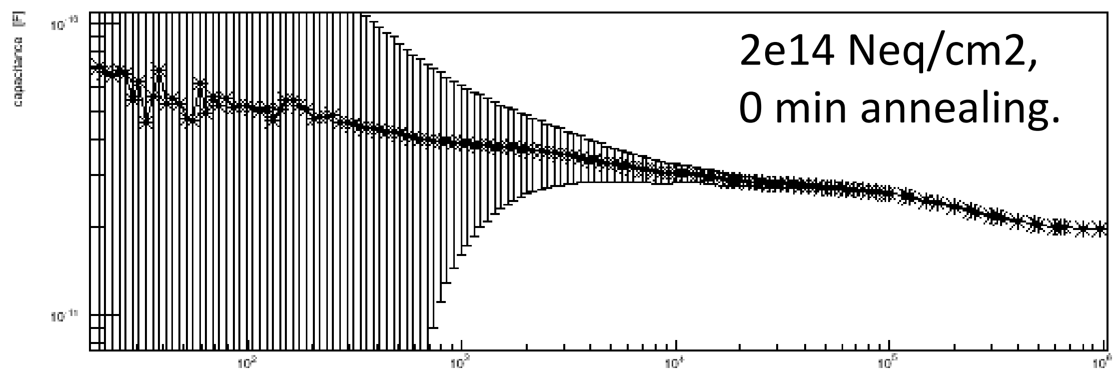


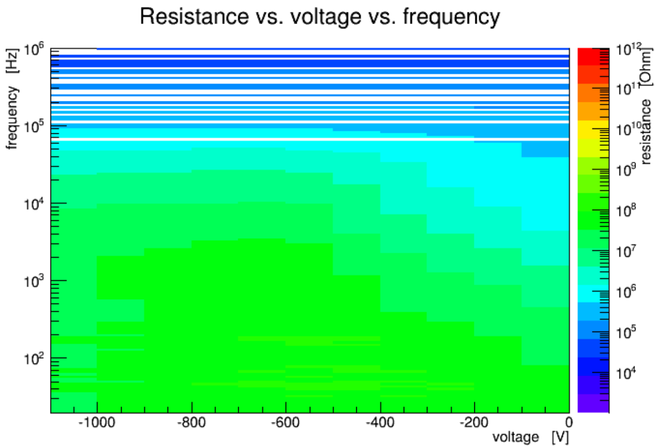
- ATLAS12 annealing generally slower.
- Some outliers for the reverse annealing (not saturating Neff): still difficult to attribute the discrepancy in the temperature factor to the activation energy (slope).
- Significant difference in the frequency factor (offset), especially for beneficial annealing:
  - ATLAS12 having a lower annealing frequency => lower than the phonon frequency for a single jump ~1e13 s^{-1}, maybe indicating a long range migration.

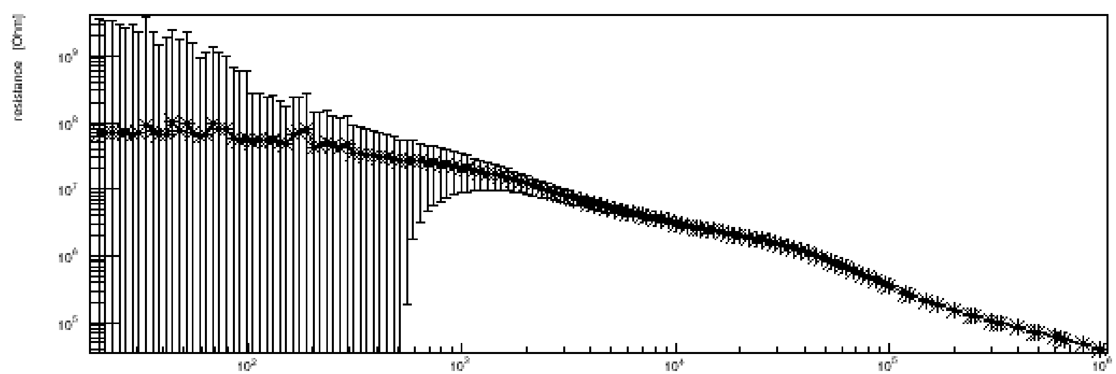
Impedance measurements: work in progress

- Discussion:
- 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….









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

Summary

- Discussion:

- The determined effective doping concentration fits in the expexted range and behaves like expected with increasing annealing time.

- The trend corresponds (inverted) to the trend of the collected charge.

- The discrapancies with previously studied (mainly n-type) sensors show that ATLAS12 sensors anneal generally slower; difference mainly in annealing frequency of the beneficial annealing.
    - A deeper understanding could come from defect spectroscopy.

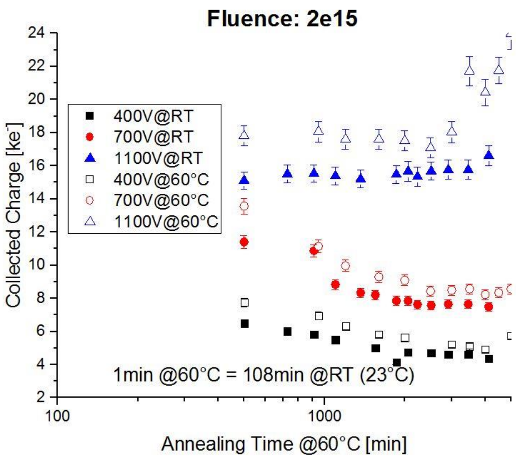
- ATLAS12 sensors can live through very long annealing times without charge multiplication or breakdown, if the fluences are not too high. We are still annealing them….

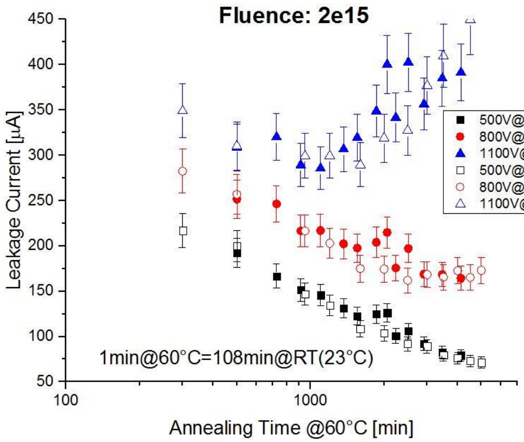
- In the future we want to use impedance/ capacitance measurements also to investigate defects more, especially how they change during annealing.

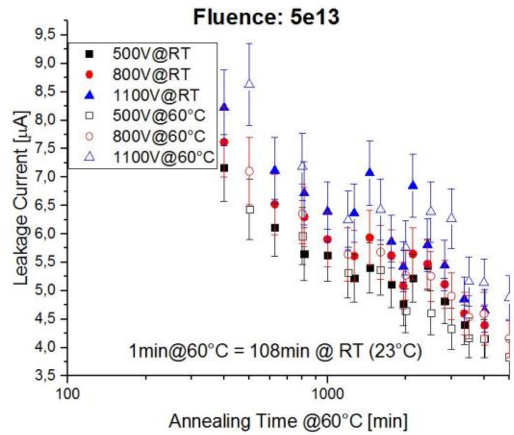
Thank you for your attention!

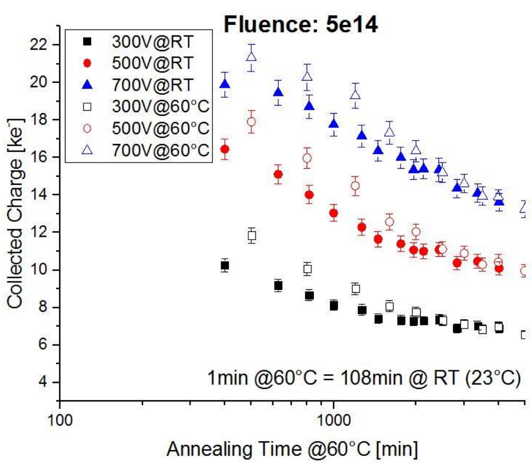
… and a special thanks to Riccardo Mori for a lot of time and effort!

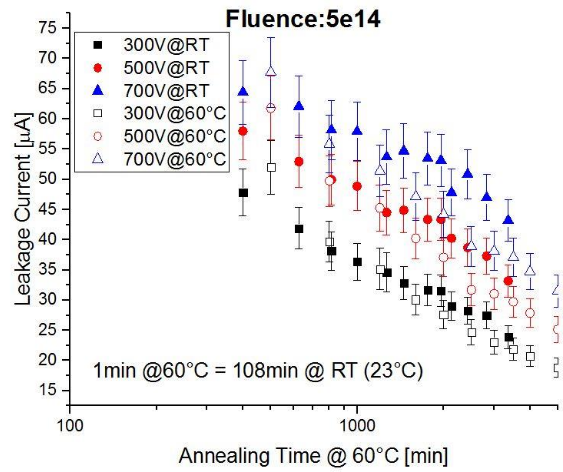
Backup: Factor

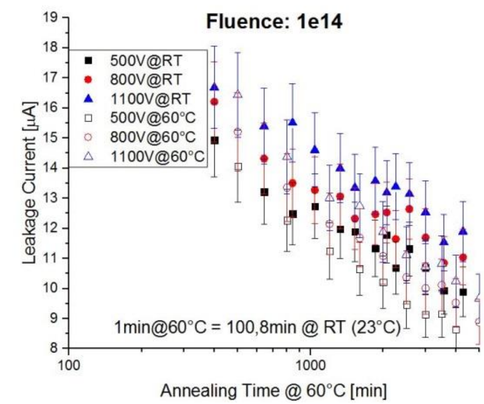




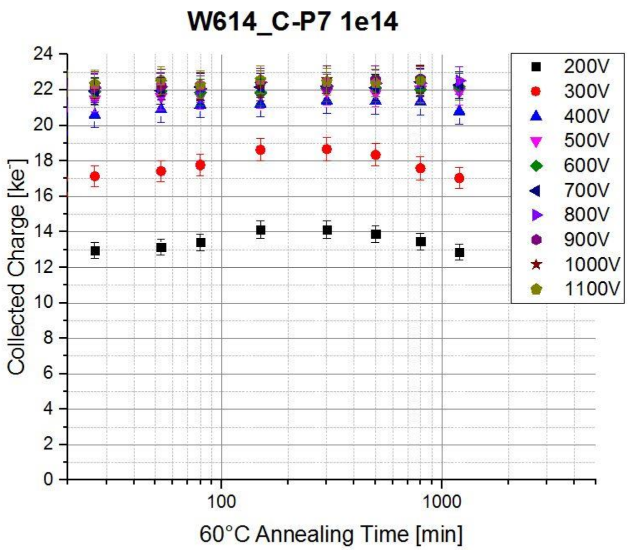


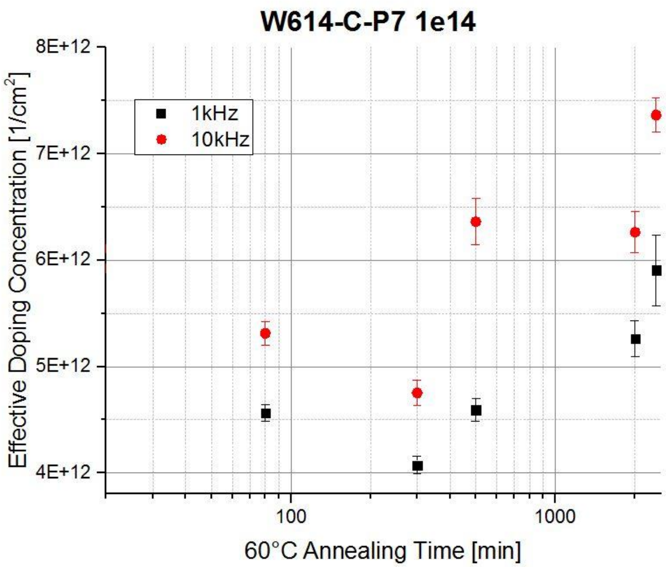


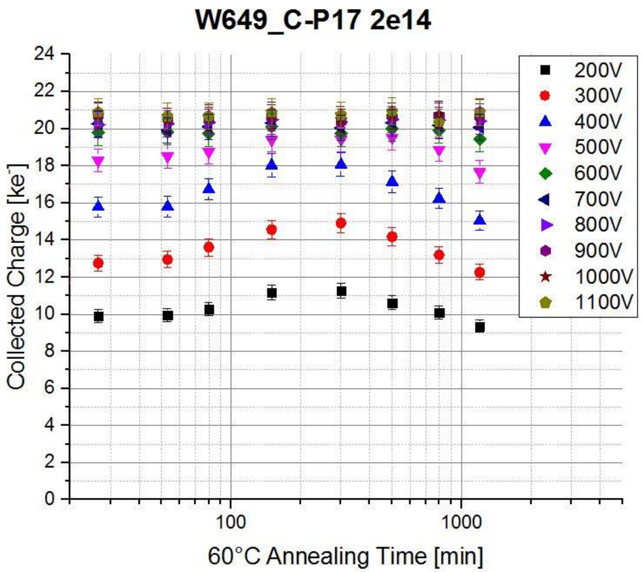


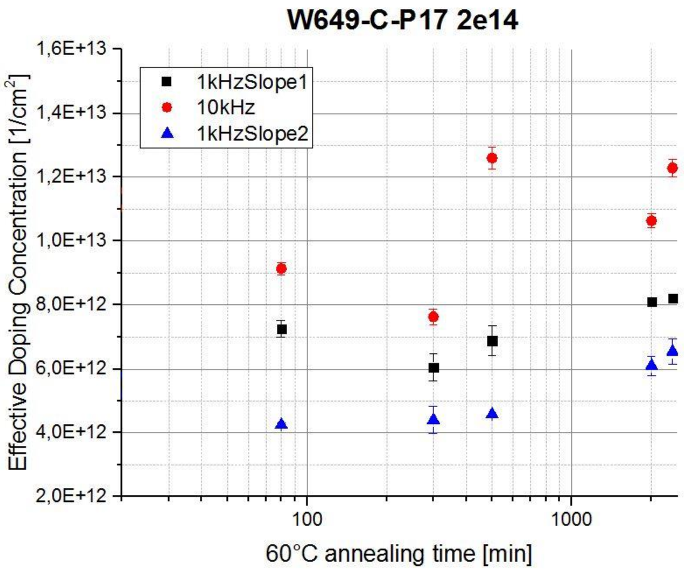


Backup: Effective doping concentration

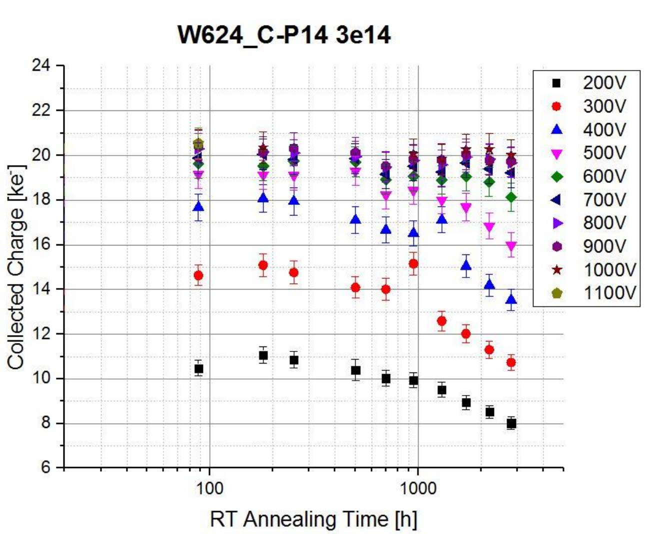


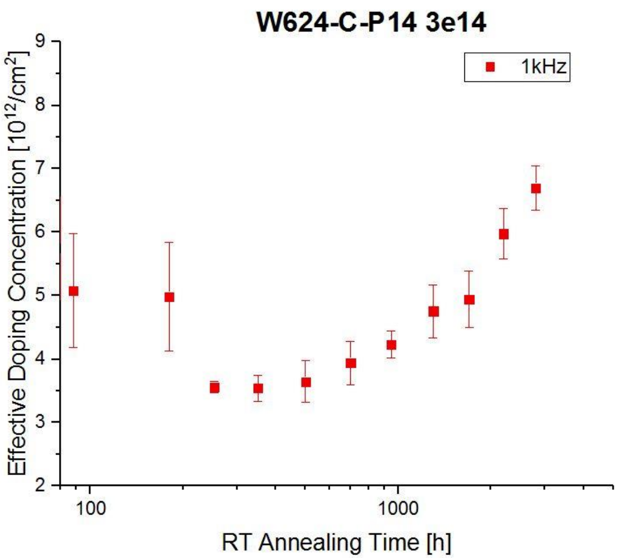


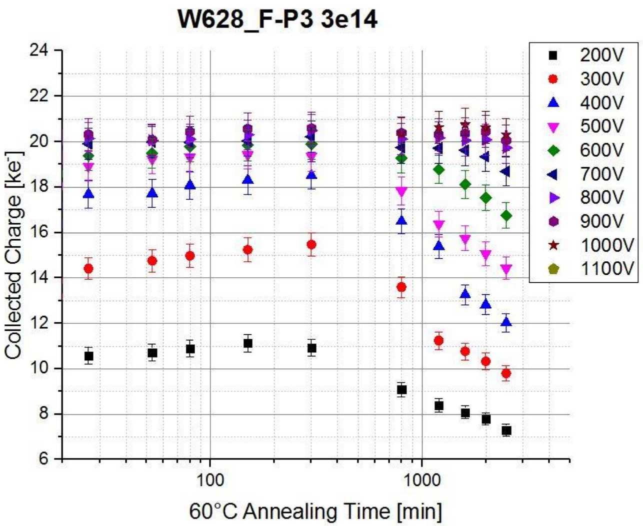


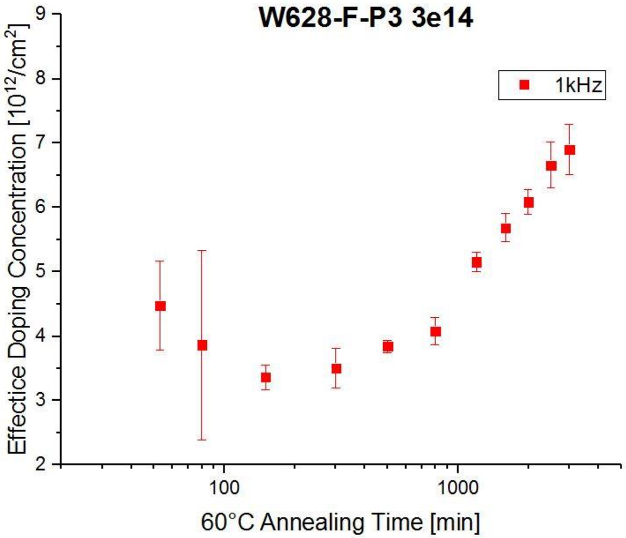


Backup: Effective doping concentration









Backup: Effective doping concentration