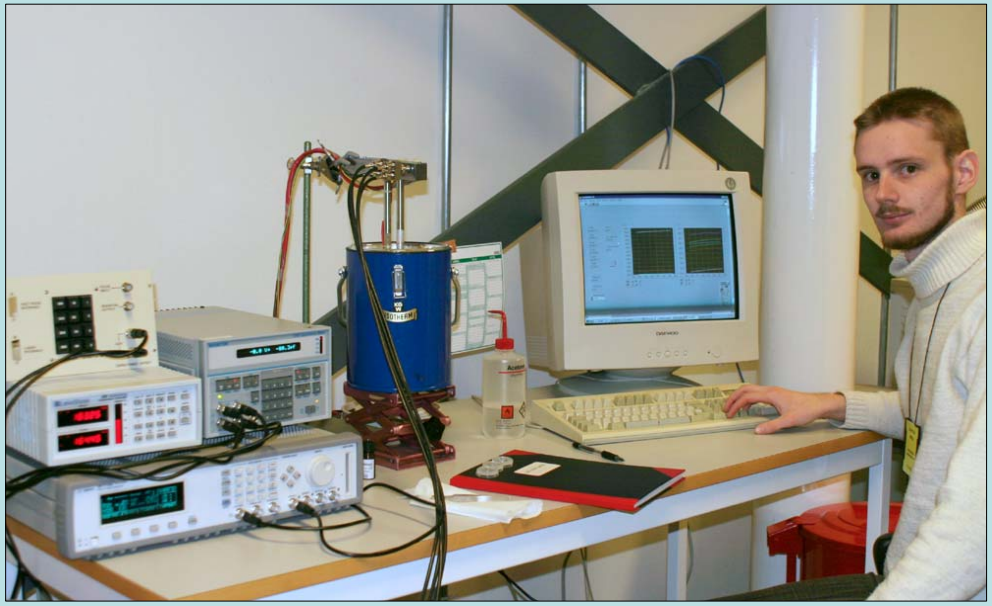
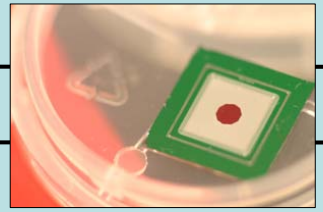
Results from my master thesis work:

Admittance spectroscopy study of point defects and nano-clusters in irradiated high-purity silicon



Klaus Magnus Johansen, University of Oslo

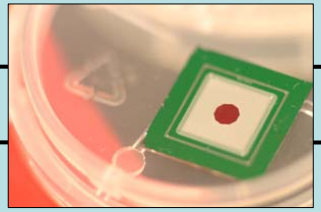
Supervisors: Joachim Grillenberger,
Edouard Monakhov and Bengt Svensson



Results from my master thesis work:

Admittance spectroscopy study of point defects and nano-clusters in irradiated high-purity silicon

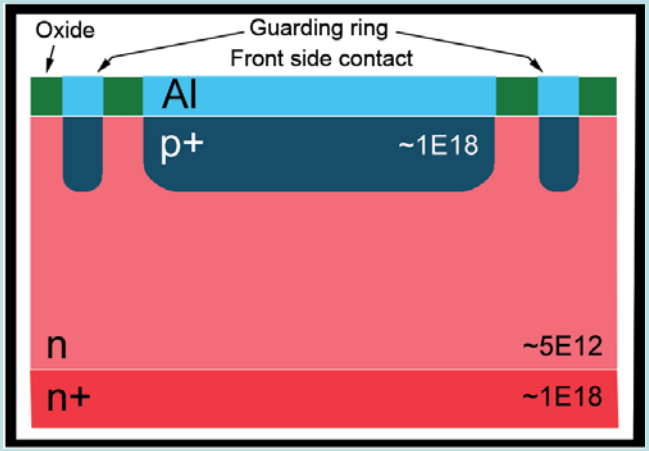
The aim of the project is to identify the defect structure responsible of type inversion in proton irradiated DOFZ-Si detectors



The detector:

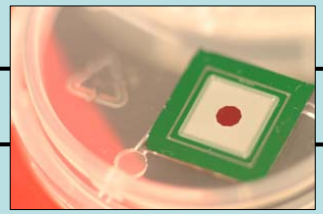
DOFZ – Si material

- produced by SINTEF
- 300 µm thick
- p+ n n+ diode structure
- guarding ring and optical window



Irradiated with 24 GeV protons at CERN IRRAD 1 PS-T7 beam line:

Sample number	Irradiation dose [protons/cm^2]	Expected type
1/76	none	n
4/5	7.55E12	n^-
1/17	7.55E12	n^-
1/16	9.04E13	p
1/13	6.5E14	p



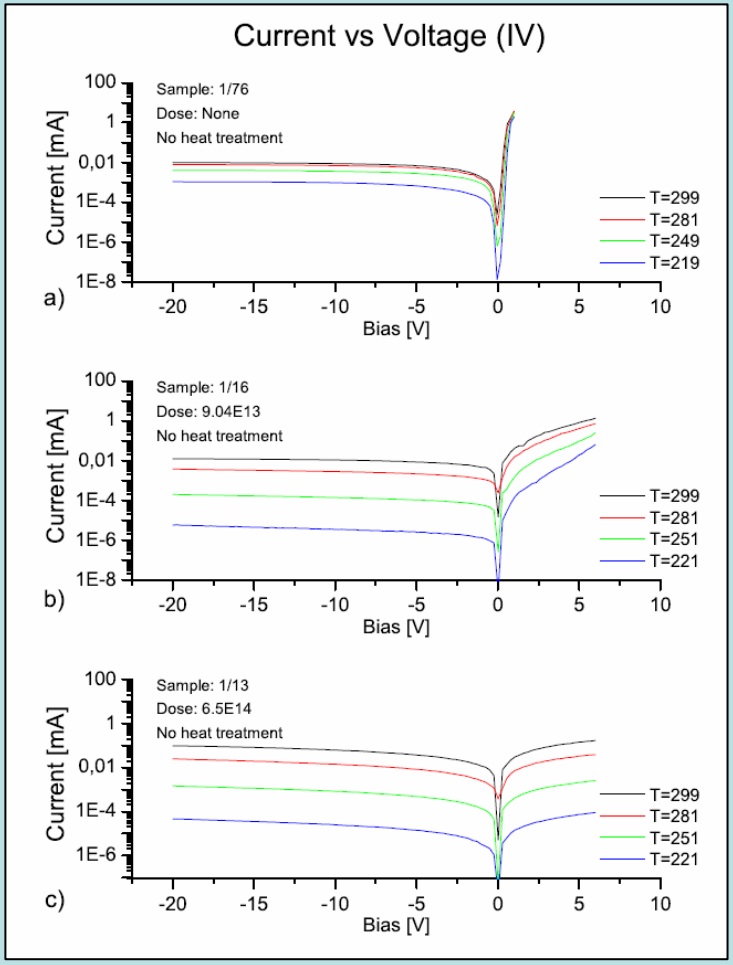
Results

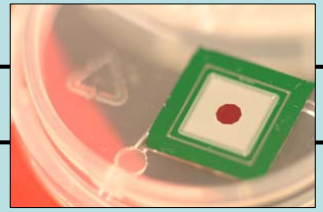
IV – IT– Adspec. – CV.

Proton irradiation induces:

- a decrease in forward current
  - increased recombination
- an increase of reverse current
  - increased generation
- a stronger temperature dependency
  - indicating a deep level.

Increasing dose



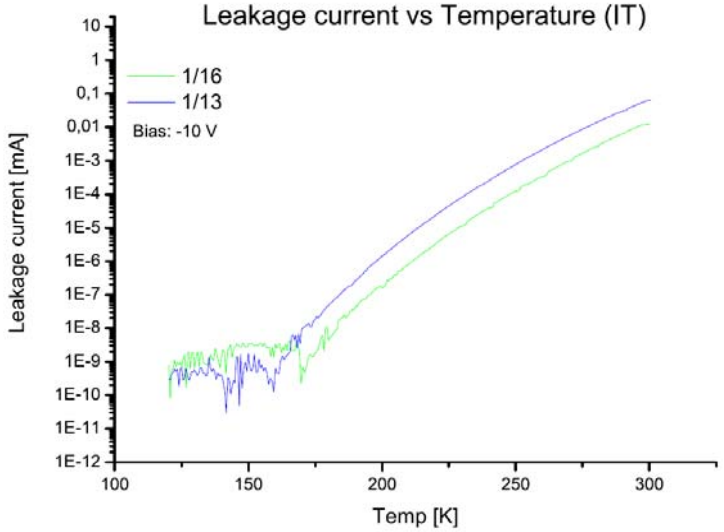


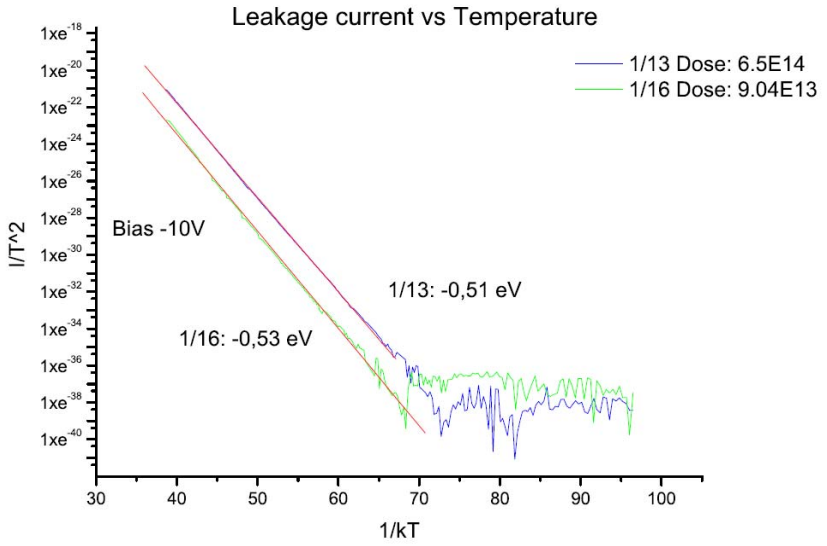
Results

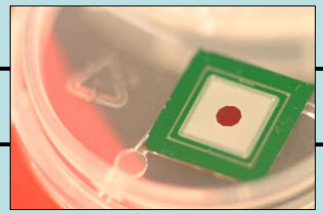
IV – **IT**– Adspec. – CV.

The current in reverse bias (-10 V) is dominated by the generation current

$$I_g \sim N_t \frac{\varepsilon_n \varepsilon_p}{\varepsilon_n + \varepsilon_p} \qquad \varepsilon_n^t = \sigma_a^t \langle \upsilon_n \rangle N_c \, exp\left(-\frac{\Delta H_t^c}{k_B T}\right) \qquad \varepsilon_p^t = \sigma_a^t \langle \upsilon_p \rangle N_v \, exp\left(-\frac{\Delta H_t^v}{k_B T}\right)$$





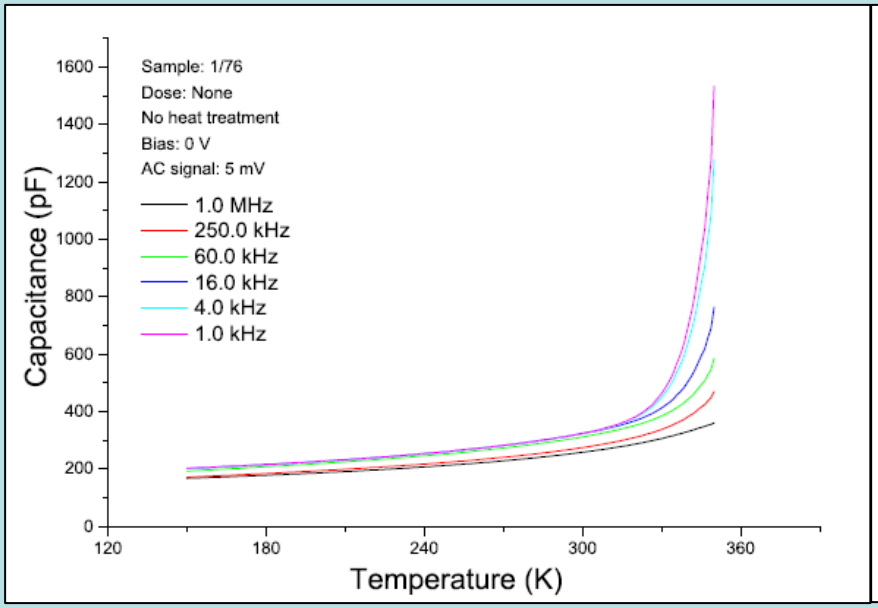


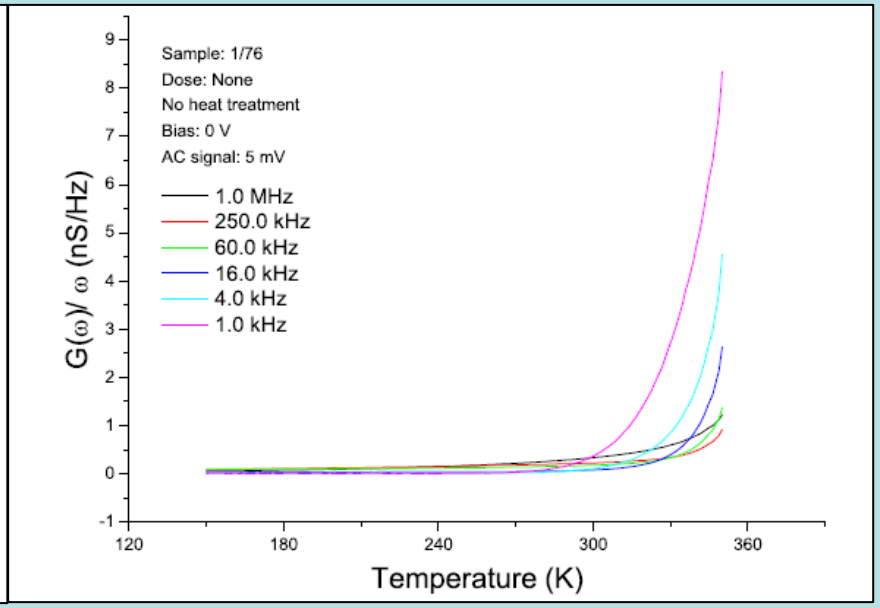
Results

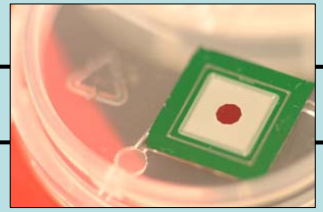
IV – IT – **Adspec.** – CV

Non-irradiated sample

- No indication of deep levels observed.
- Measured at 0 V bias and 5 mV AC-signal amplitude





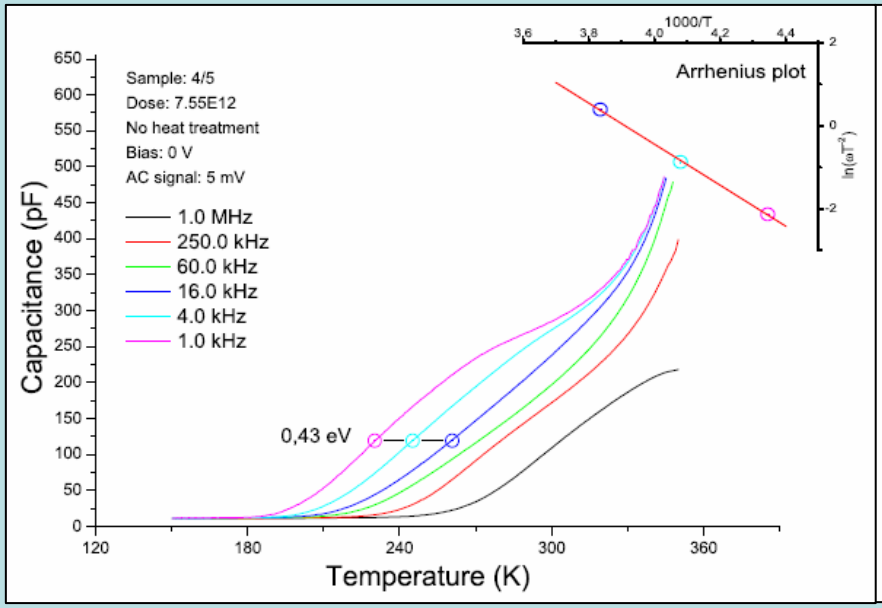


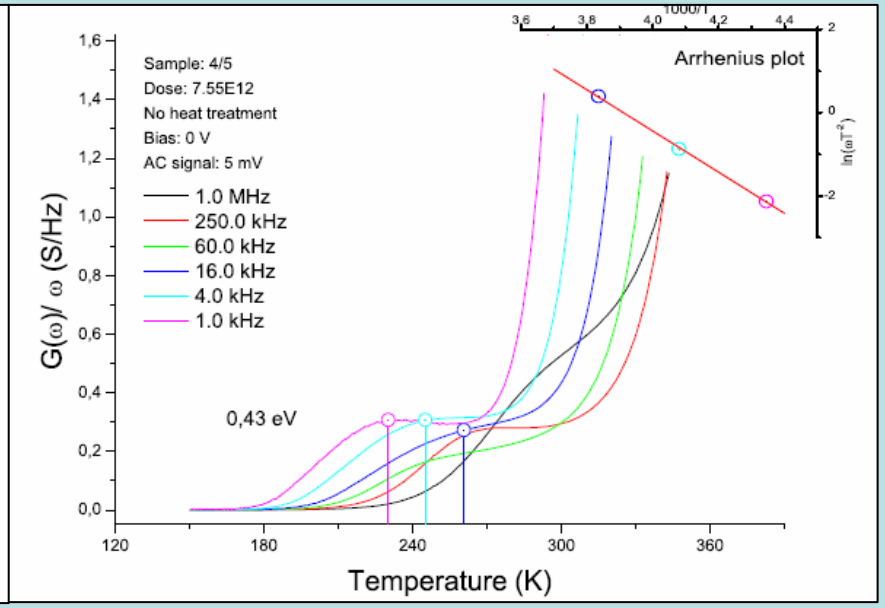
Results

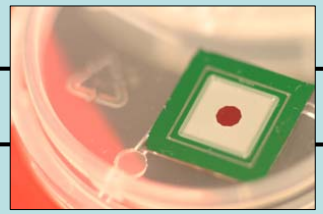
IV – IT – **Adspec.** – CV

Dose: 7.55E12 protons cm^{-2}

- Estimated activation energy: 0.43 eV
- Measured at 0 V bias and 5 mV AC-signal amplitude





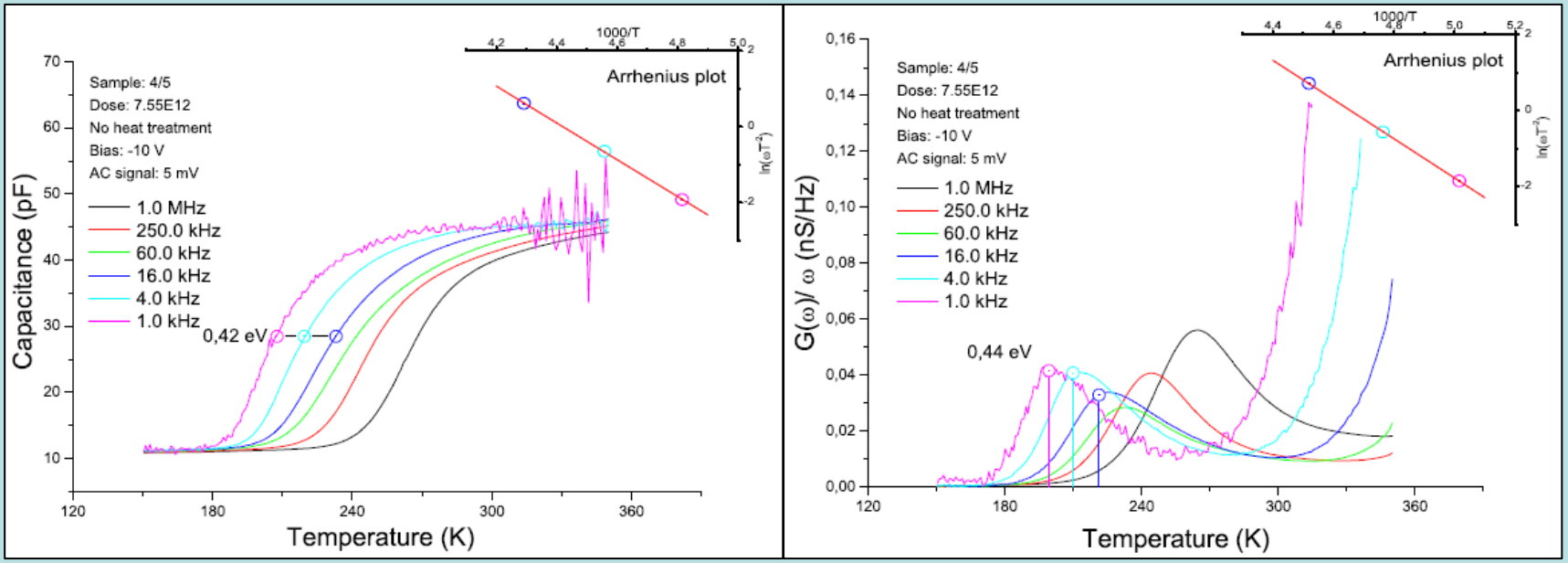


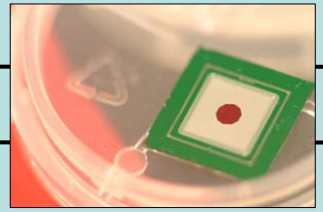
Results

IV – IT – **Adspec.** – CV

Dose: 7.55E12 protons cm^{-2}

- Estimated activation energy: 0.43 ± 0.01 eV
- Measured at -10 V bias and 5 mV AC-signal amplitude



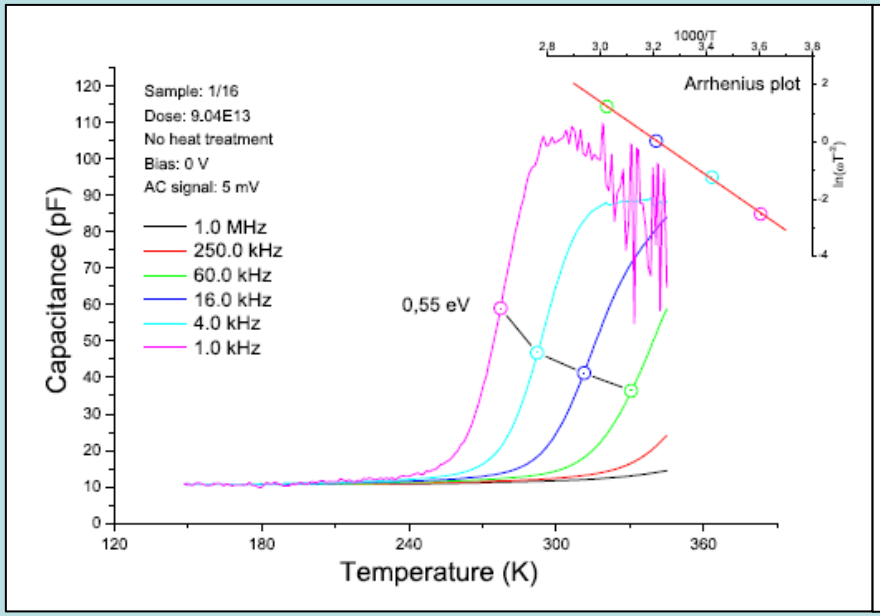


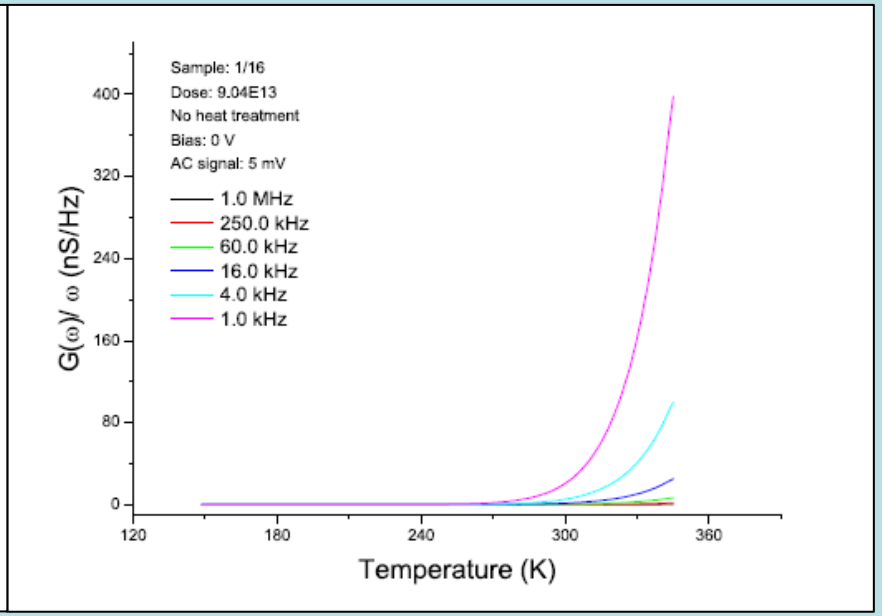
Results

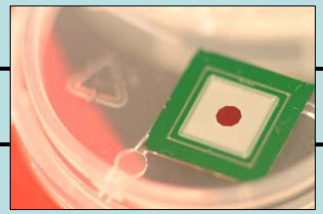
IV – IT – **Adspec.** – CV

Dose: 9.05E13 protons cm^{-2}

- Estimated activation energy: 0.55 ± 0.04 eV
- Measured at 0 V bias and 5 mV AC-signal amplitude





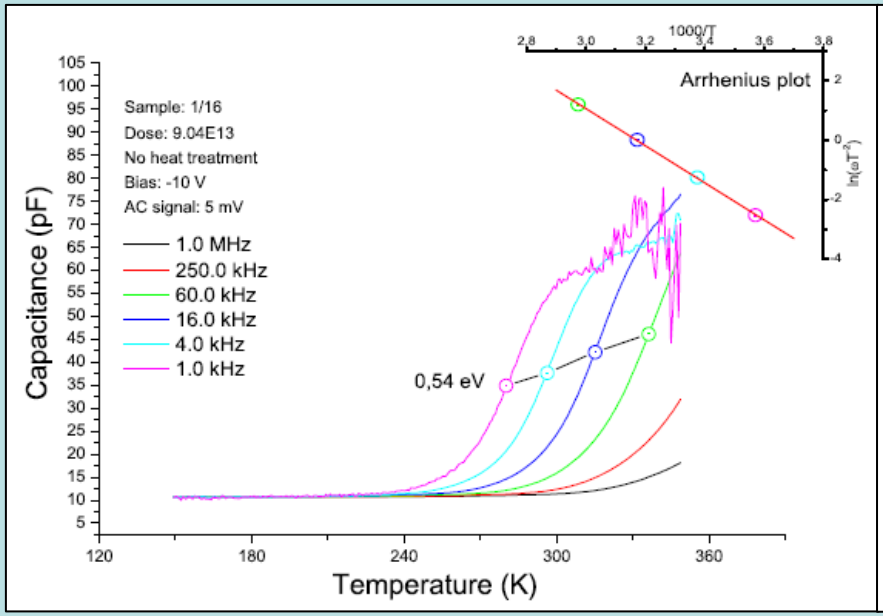


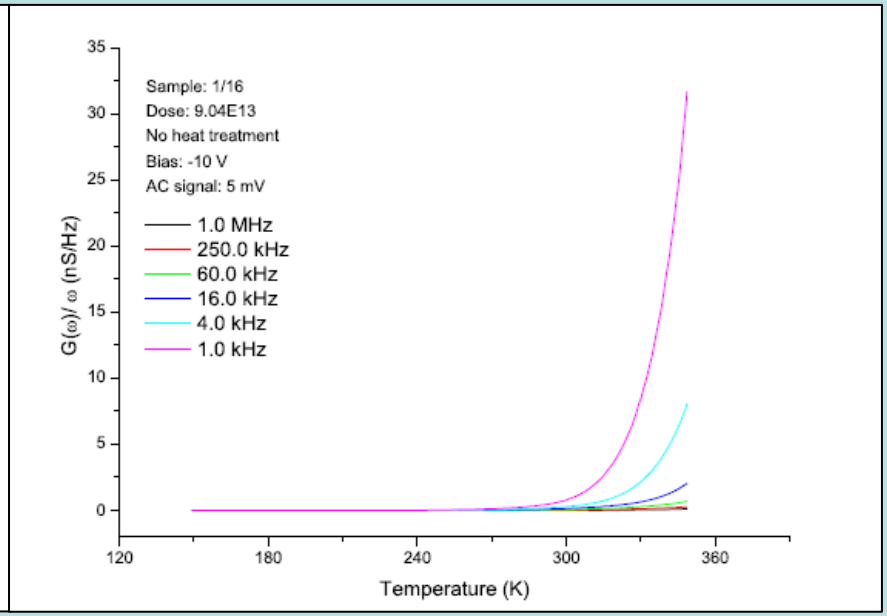
Results

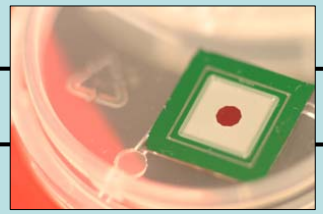
IV – IT – **Adspec.** – CV

Dose: 9.05E13 protons cm^{-2}

- Estimated activation energy: 0.55 ± 0.04 eV
- Measured at -10 V bias and 5 mV AC-signal amplitude





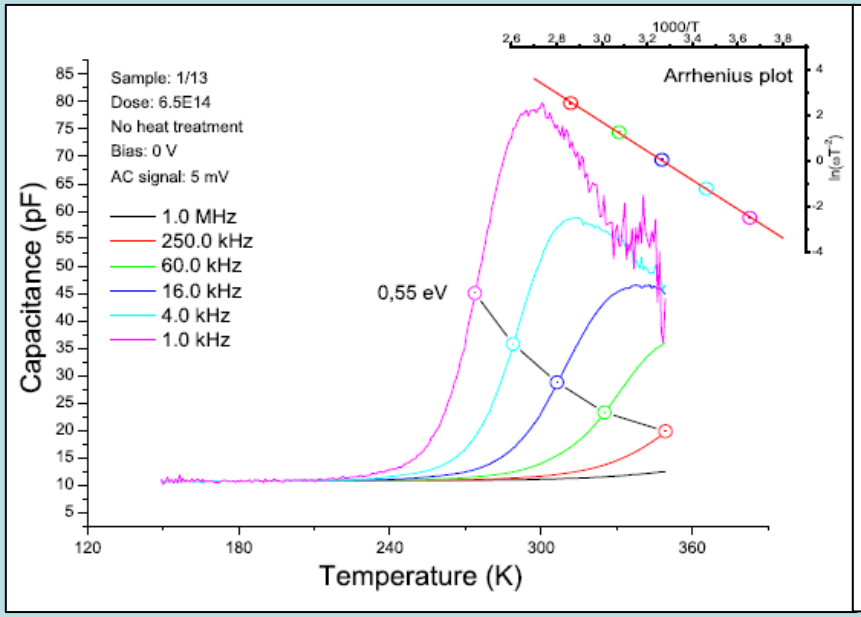


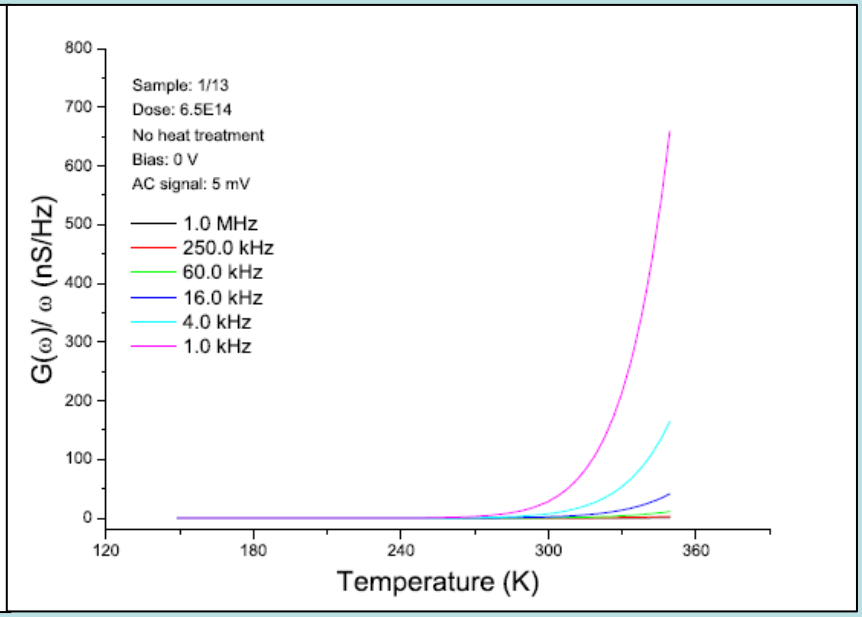
Results

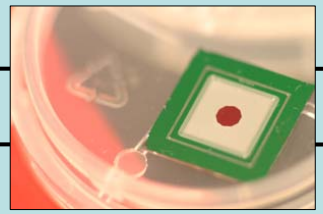
IV – IT – **Adspec.** – CV

Dose: 6.5E14 protons cm^{-2}

- Estimated activation energy 0.55 ± 0.04 eV
- Measured at 0 V bias and 5 mV AC-signal amplitude





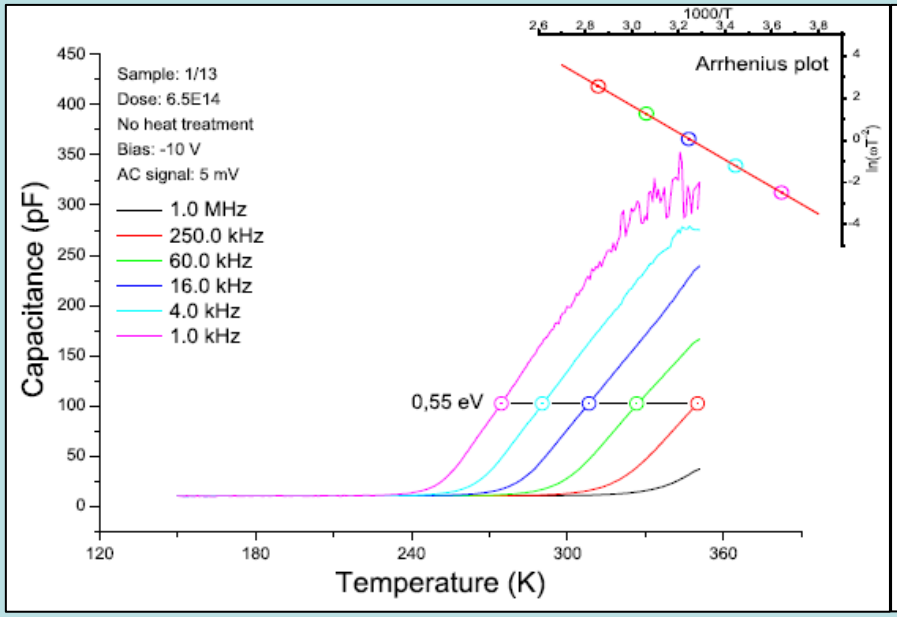


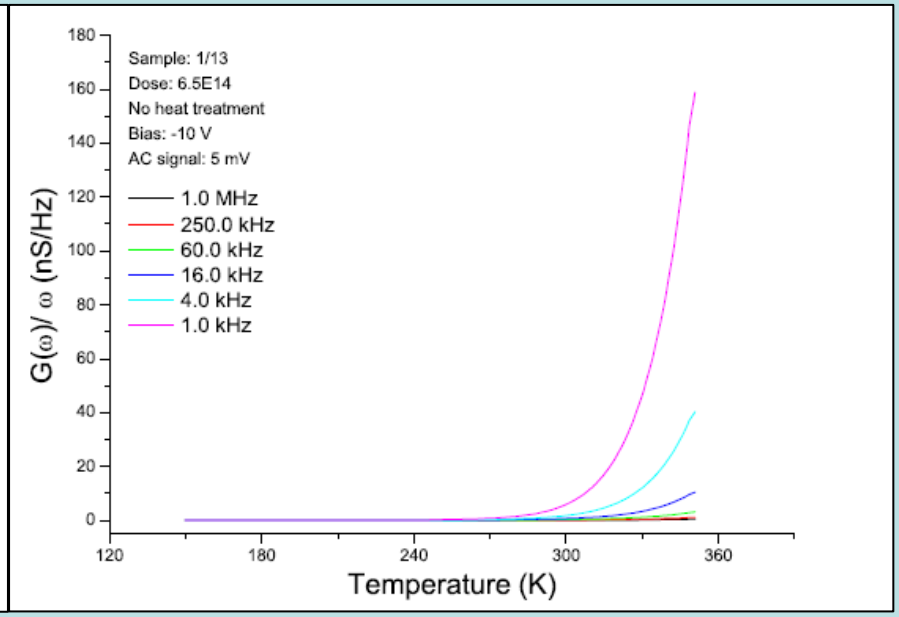
Results

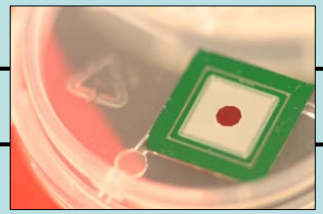
IV – IT – **Adspec.** – CV

Dose: 6.5E14 protons cm^{-2}

- Estimated activation energy 0.55 ± 0.04 eV
- Measured at -10 V bias and 5 mV AC-signal amplitude





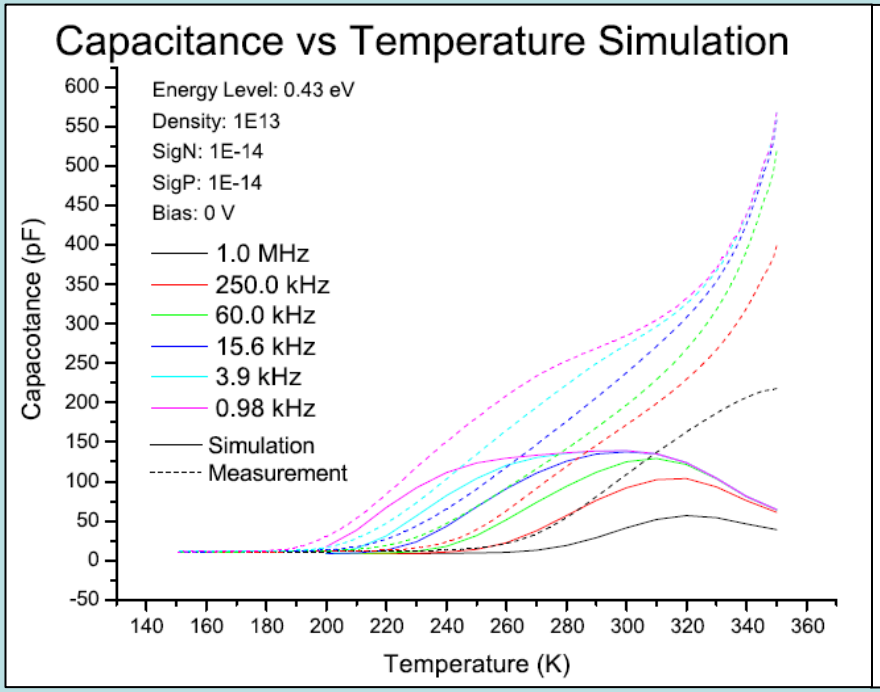


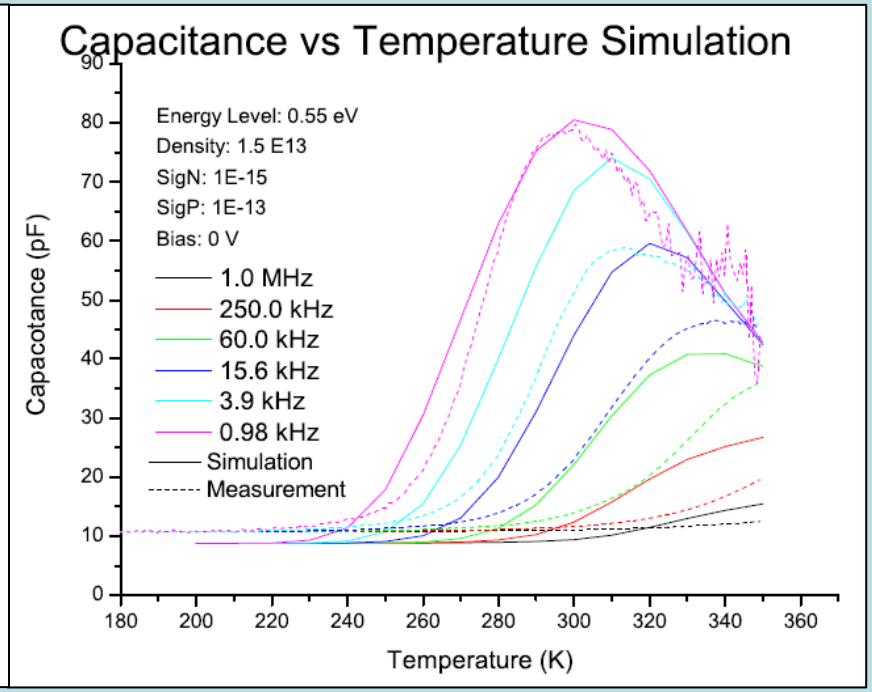
Results

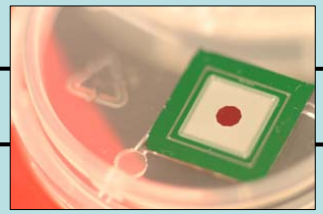
IV – IT – **Adspec.** – CV

Silvaco TCAD simulation of the two levels found

Not exact fits, but good enough?





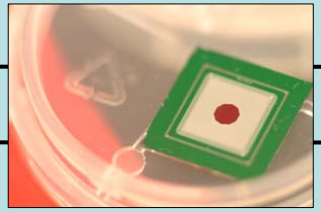


Results

IV – IT – **Adspec.** – CV

Summary of the estimated activation energies and capture cross sections at 0 V bias:

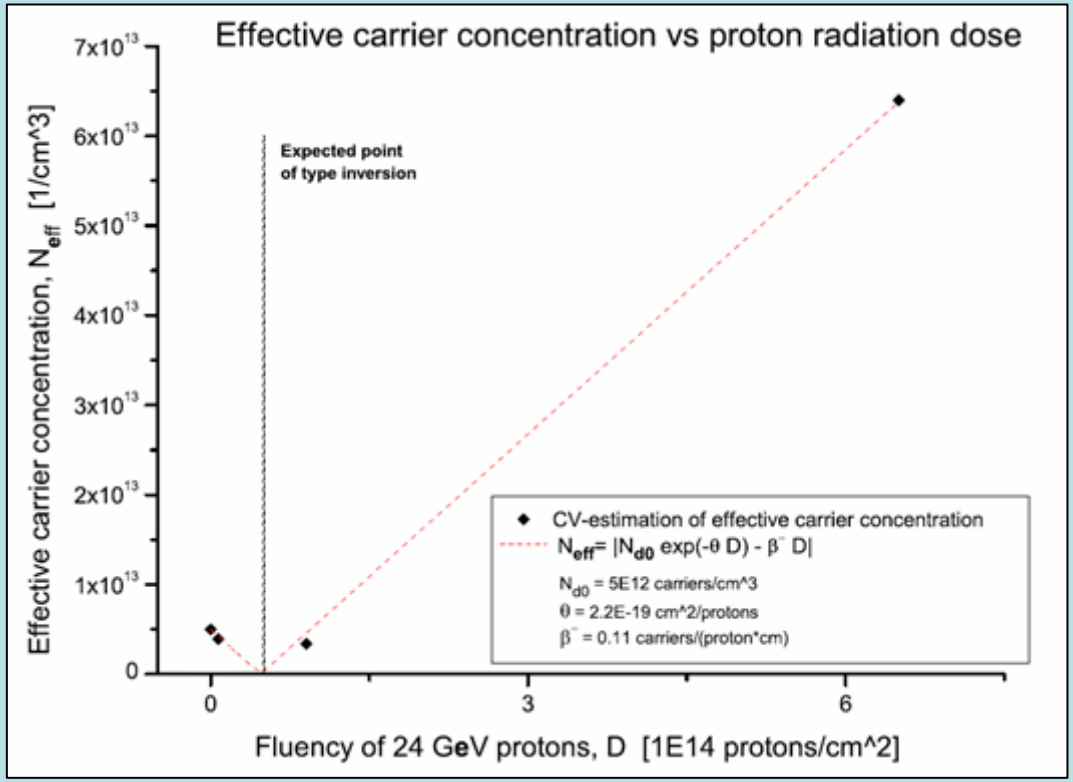
Dose [cm^{-2}]	Activation energy [eV]	Capture cross section [cm^2]
Control	No deep level	-
7.55E12	0.43 ± 0.02	6.2E-15
9.04E13	0.55 ± 0.04	2.2E-14
6.5E14	0.55 ± 0.04	2.7E-14



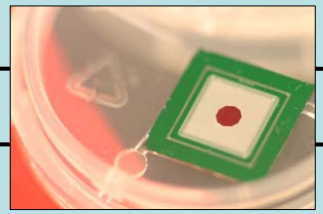
Results

IV – IT– Adspec. – **CV**

CV - effective carrier concentration estimation fits with



* Z. Li, E. Verbitskaya, E. Fretwurst, J. Kierstead, V. Eremin, I. Ilyashenko, R. Röder, and C. Wilburn. Nuclear Instruments and methods in Physics Research A, (514):2537, 2003.

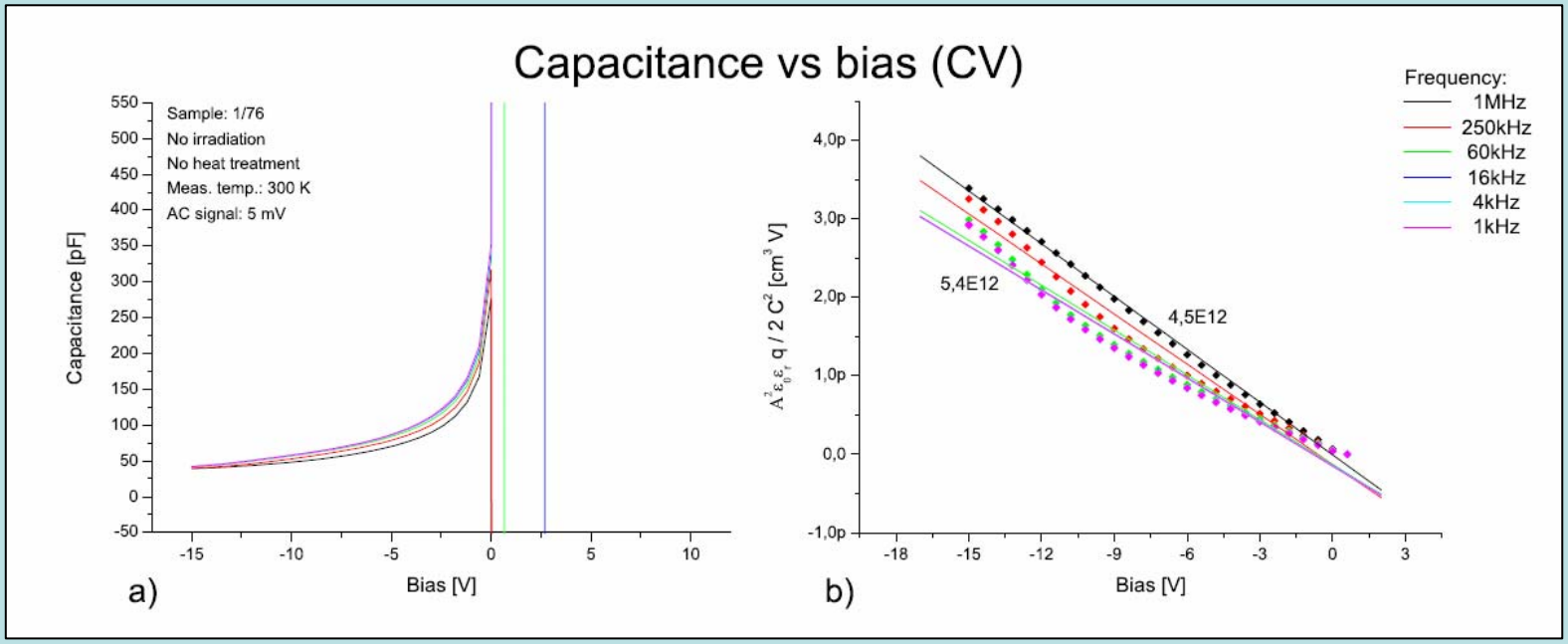


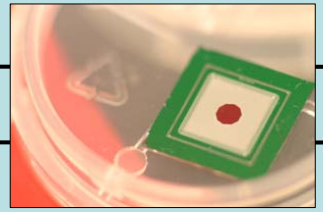
Results

IV – IT– Adspec. – **CV**

Non-irradiated sample

Estimated carrier concentration ~5E12 cm^{-3}



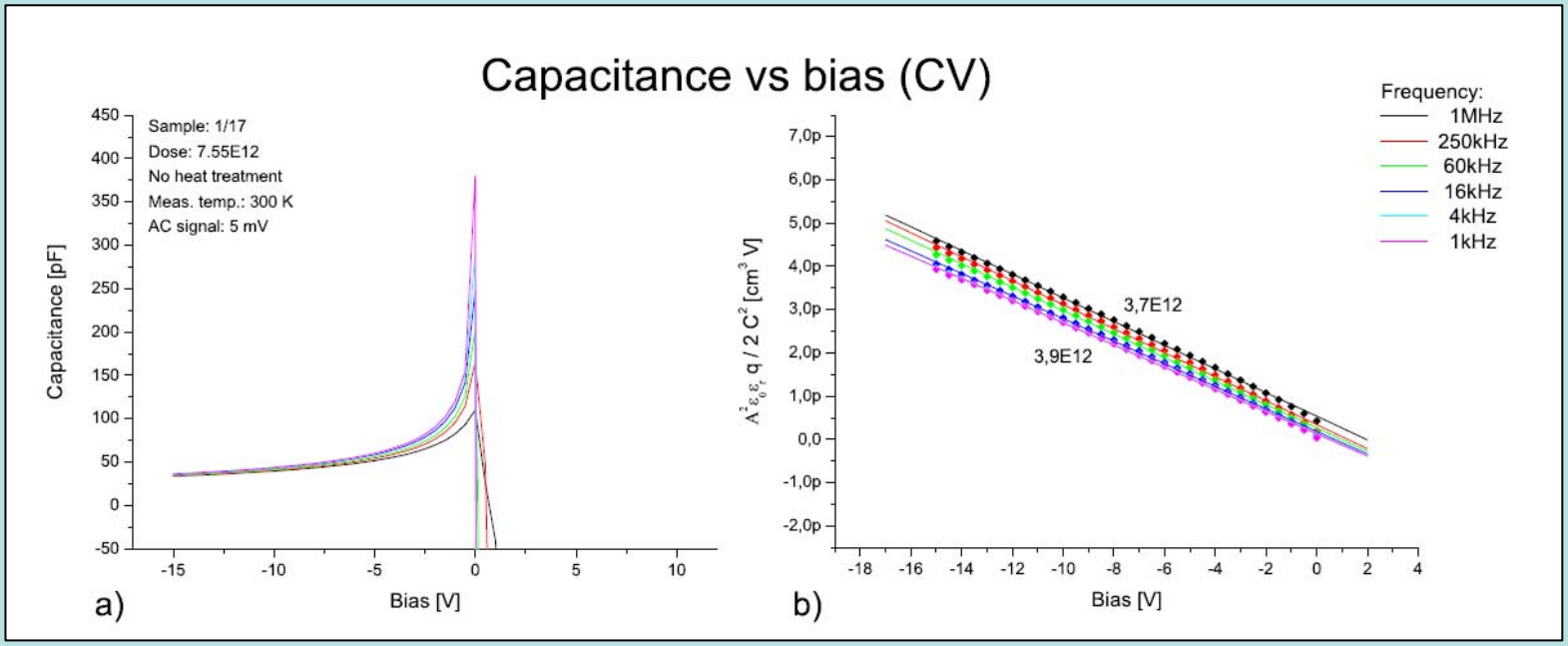


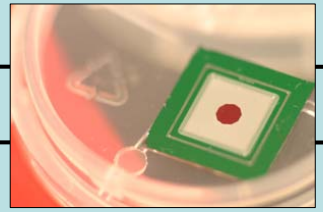
Results

IV – IT– Adspec. – **CV**

7.55E12 protons cm^{-2}

Estimated carrier concentration ~3.8E12 cm^{-3}



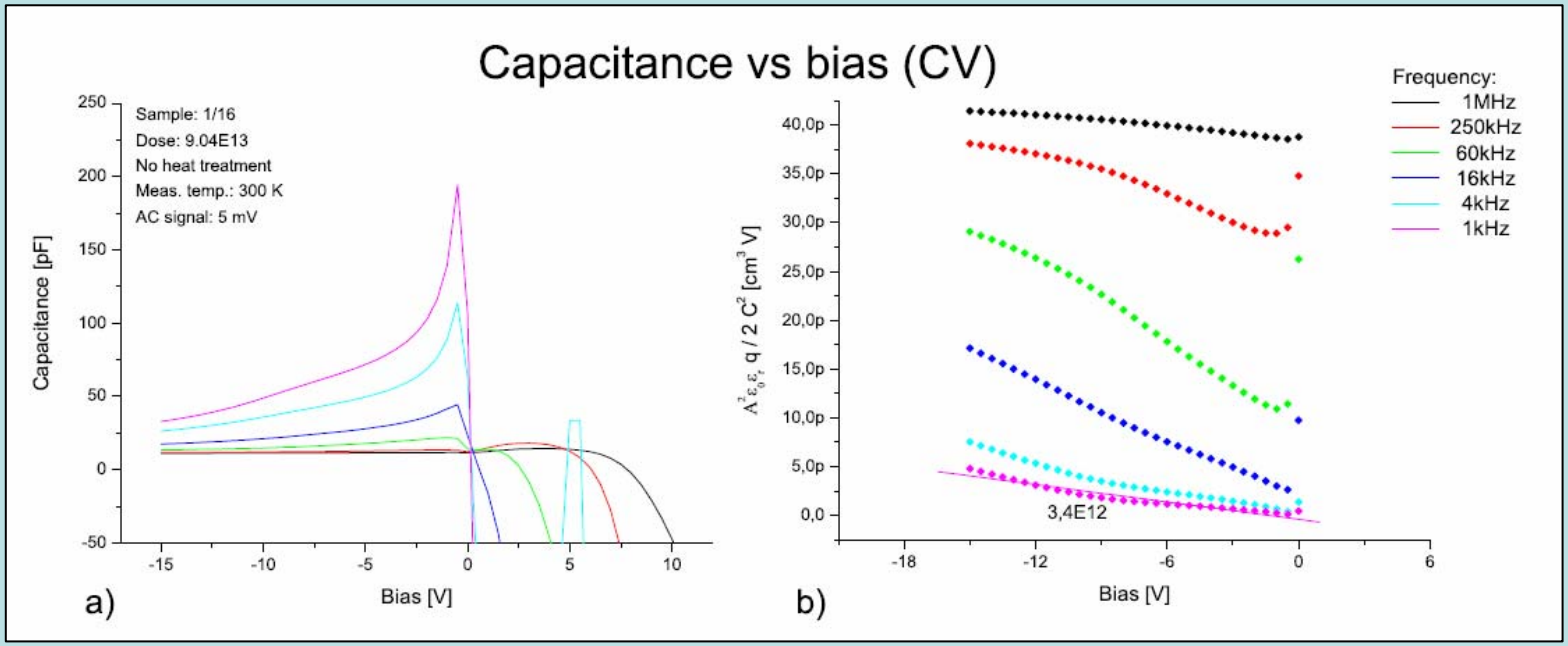


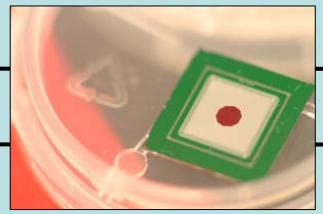
Results

IV – IT– Adspec. – **CV**

9.04E13 protons cm^{-2}

Estimated carrier concentration ~3.4E12 cm^{-3}



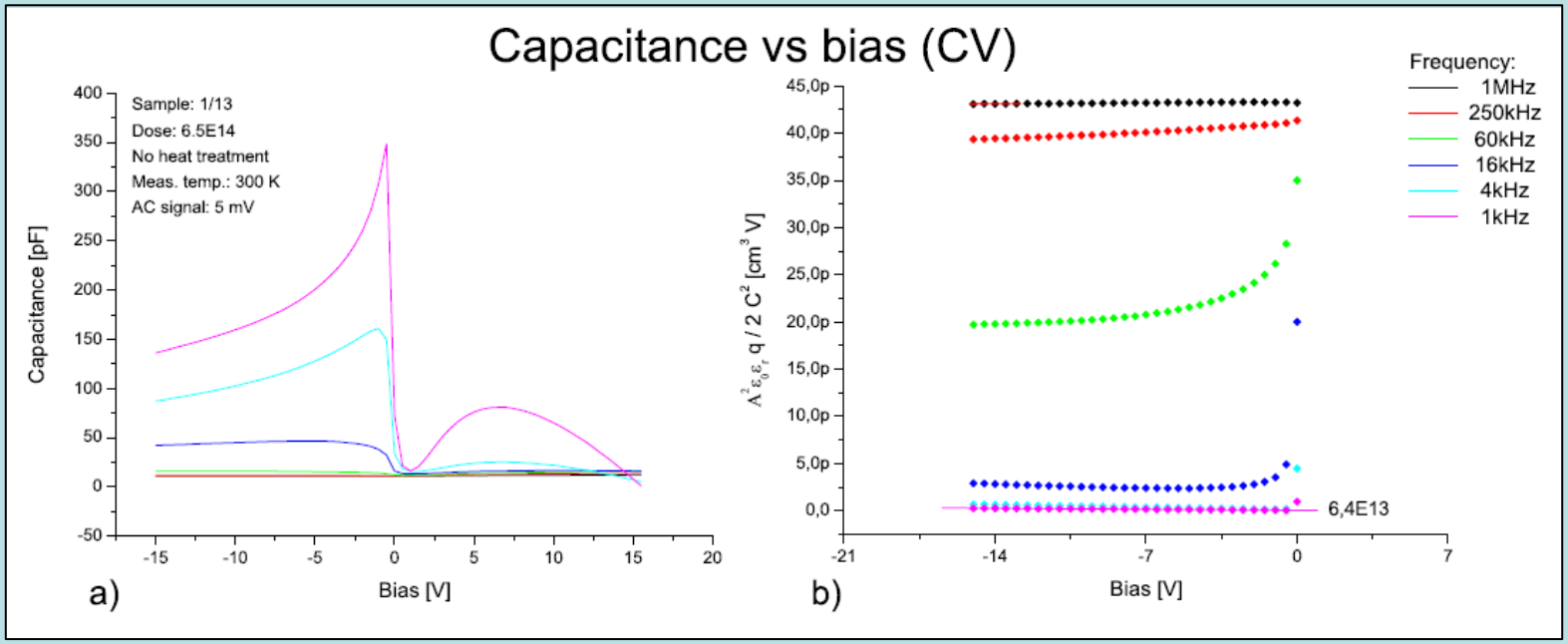


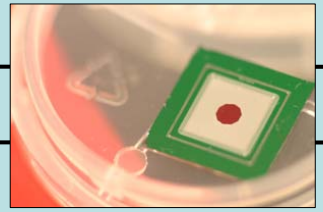
Results

IV – IT– Adspec. – **CV**

6.5E14 protons cm^{-2}

Estimated carrier concentration ~6.4E13 cm^{-3}

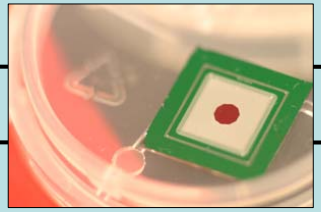


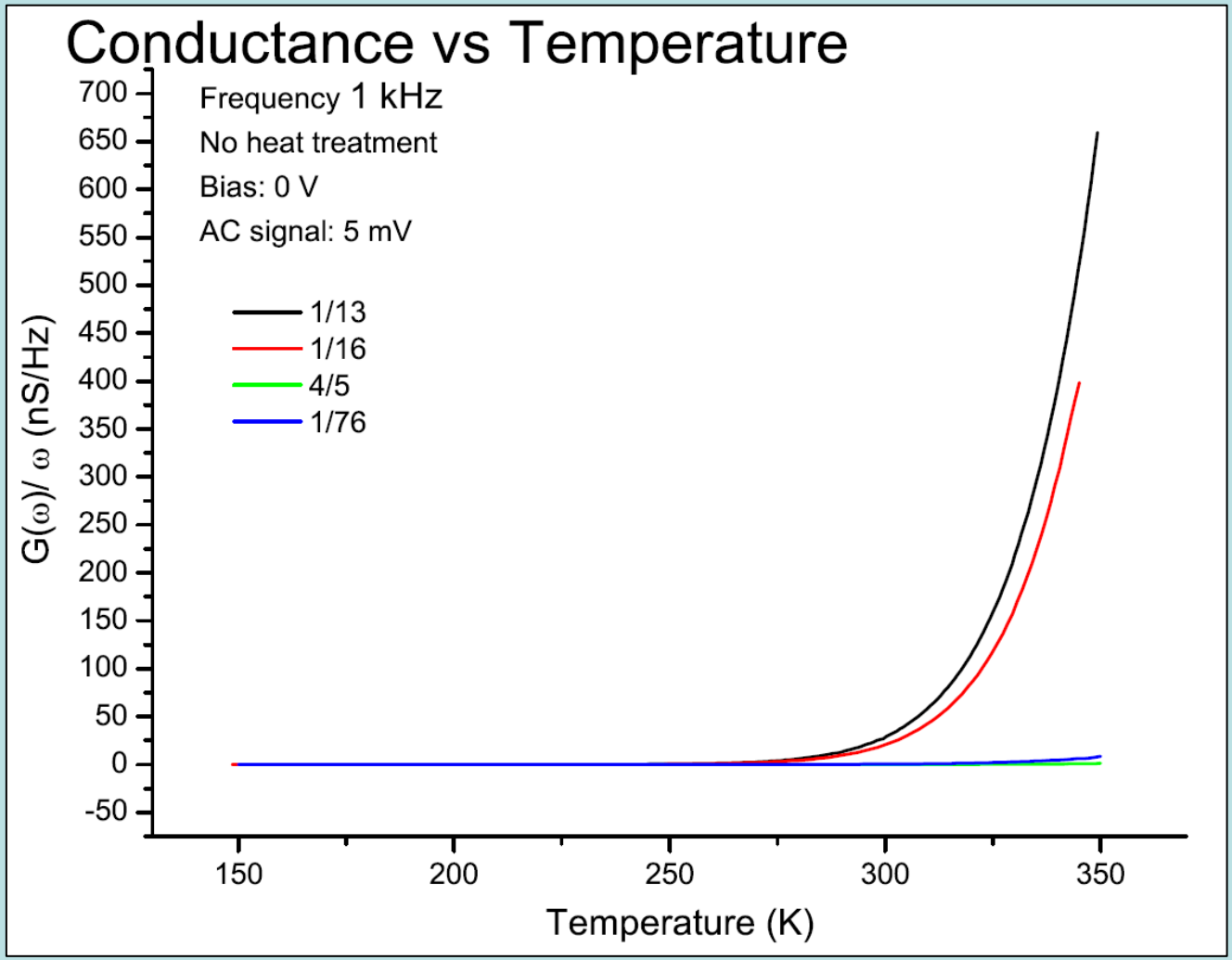


Conclusion

- IV-measurements show a clear degradation of the diode with irradiation dose, attributed to mid band gap generation- and recombination-centers.
- Two levels are found by admittance spectroscopy:
  - 0.43 eV level, fits with a V_2 response
  - 0.55 eV level, might be the I center[1]
- CV-measurements confirm that the two high doses type inverts the samples while the lowest dose does not, as expected.
- More measurements are needed to confirm the findings and to establish the growth rate of the 0.55 eV level.

[1] I. Pintilie, E. Fretwurst, G. Lindström, and J. Stahl. Applied Physics Letters, 82(13):21692171, March 2003.




Conductance vs Temperature
Frequency 1 kHz
No heat treatment
Bias: 0 V
AC signal: 5 mV
1/13
1/16
4/5
1/76
G(ω)/ ω (nS/Hz)
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
-50
150
200
250
300
350
Temperature (K)