

Temperature and frequency dependent CV measurements of highly irradiated ATLAS strip detectors and diodes for impedance spectroscopy

Albert-Ludwigs-Universität Freiburg



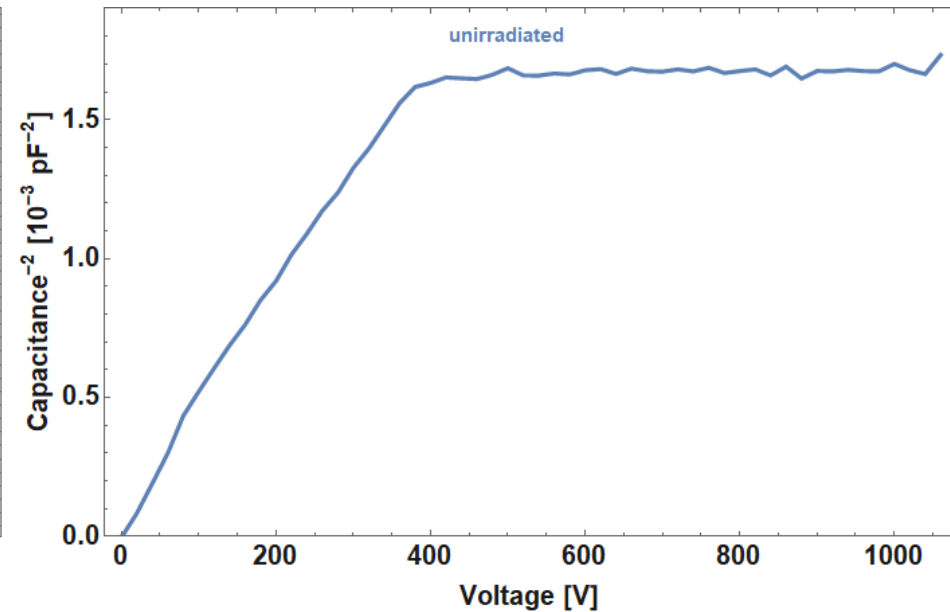
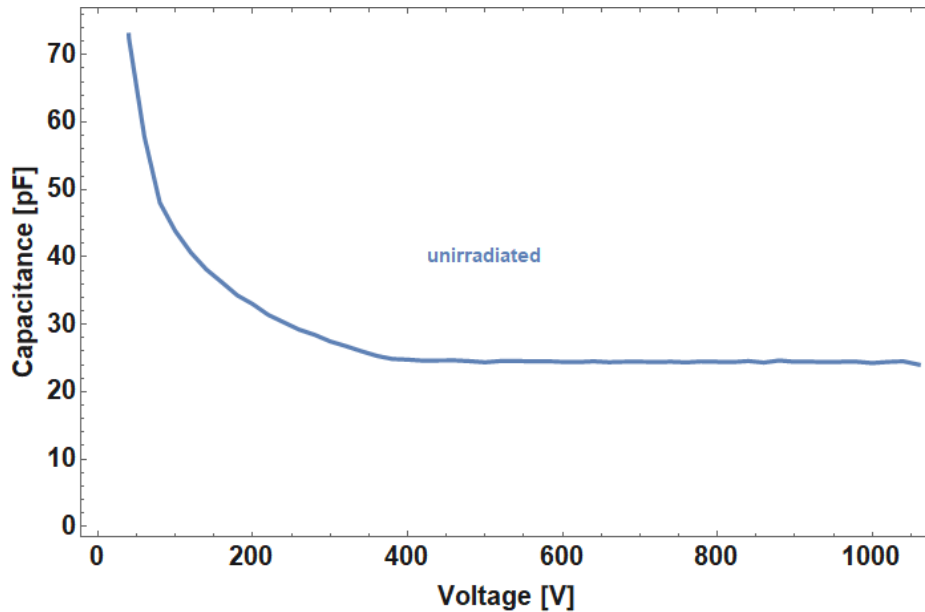
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Sven Mägdefessel

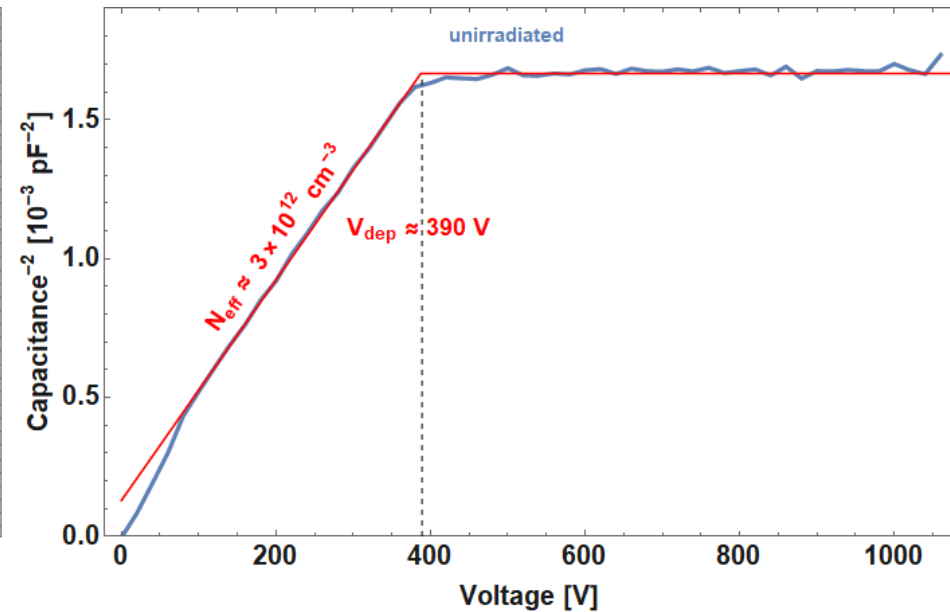
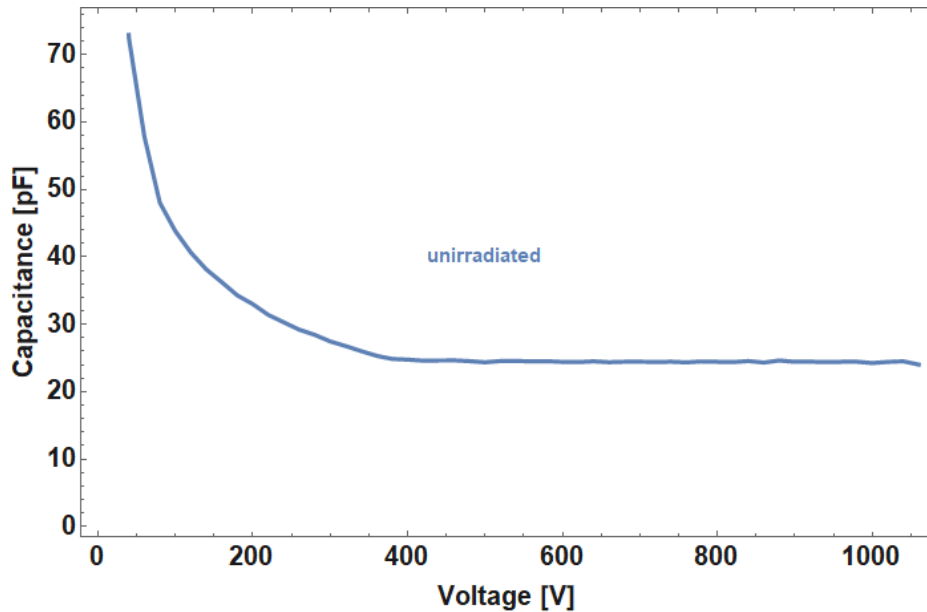
Riccardo Mori, Liv-Wiik Fuchs, Ulrich Parzefall

14th „Trento“ Workshop on Advanced Radiation Detectors

- ▶ Capacitance vs. Voltage (CV) measurements well established for sensor characterisation
- ▶ Provide doping level and depletion voltage

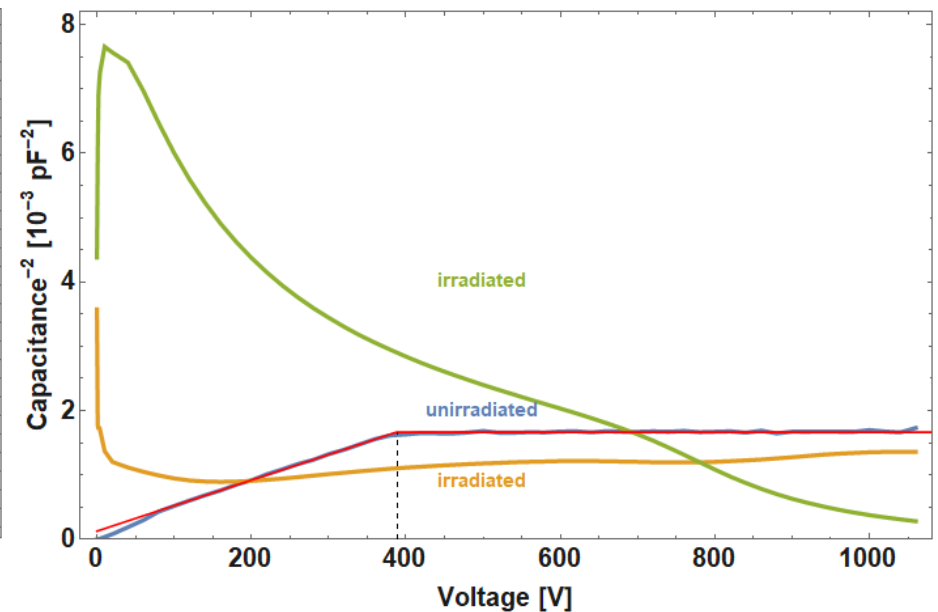
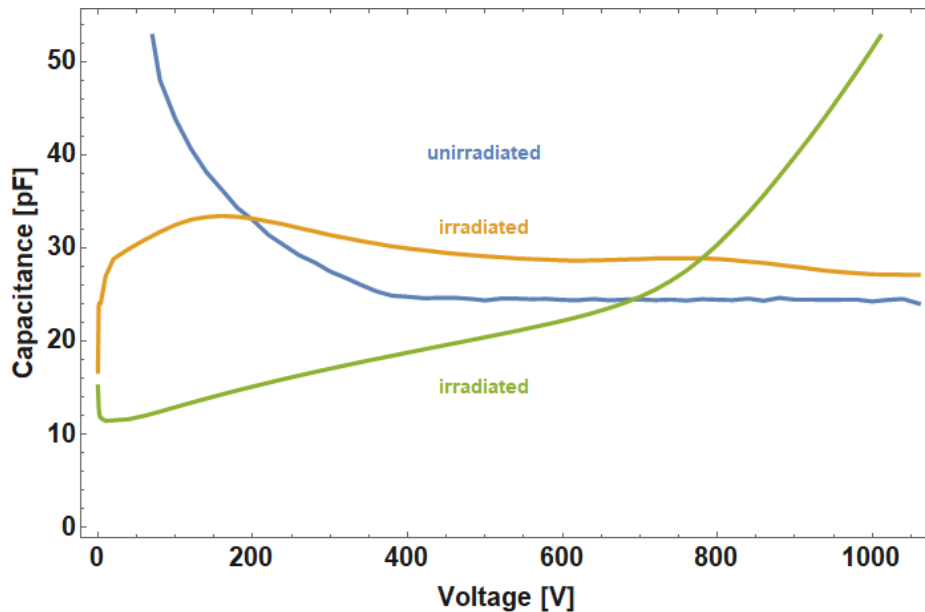


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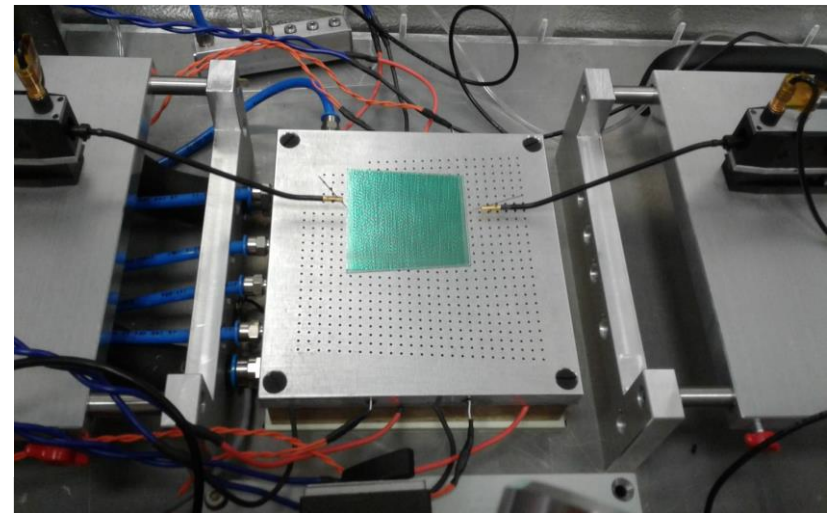
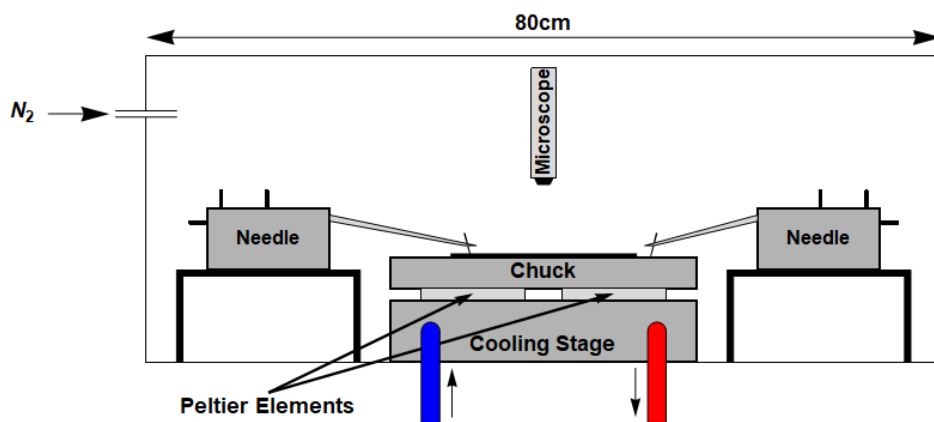
- ▶ Capacitance vs. Voltage (CV) measurements well established for sensor characterisation
- ▶ Provide doping level and depletion voltage

→ Several problems for irradiated devices



- ▶ Measure highly irradiated sensors
 - ▶ Compare diodes, strip detectors and 3D detectors
 - ▶ Understand frequency behaviour
 - ▶ Investigate temperature behaviour
 - ▶ Check whether reliable doping level or depletion voltage determination possible
- ▶ Also establish setup usable for preproduction and production quality assurance for the ATLAS ITK upgrade

- ▶ Designed & assembled setup for measuring IV and CV:
 - ▶ Combination of chiller and peltier elements
 - ▶ Contacting sensor via needles
 - ▶ Elimination of humidity by nitrogen flushed glove box
 - ▶ Temperatures down to -45°C
 - ▶ Frequency range of LCR for capacitance measurement (20 Hz – 1 MHz)
 - ▶ Sensors up to 8" size

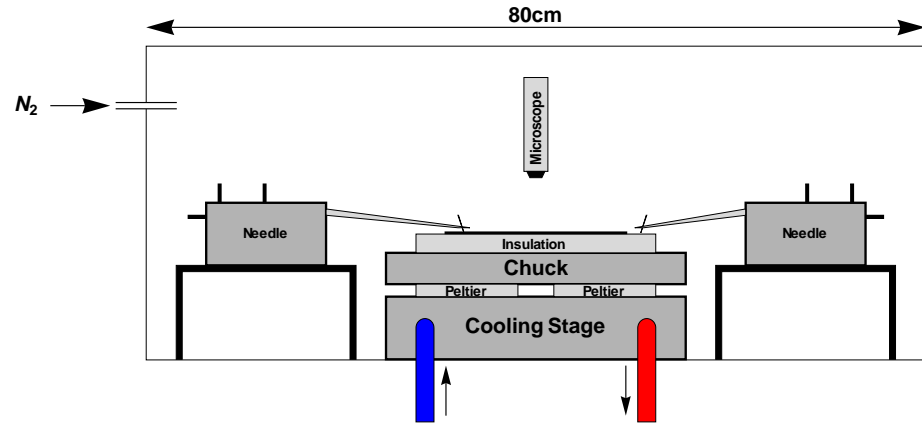


- ▶ Several technical improvements to suppress electronic coupling

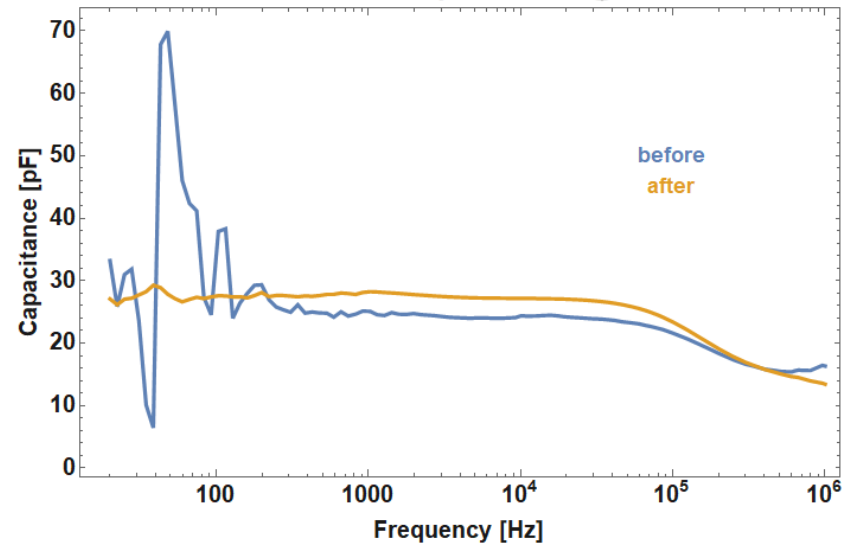
- ▶ Electromagnetic shielding
- ▶ Insulation layer
- ▶ Constant peltier current
- ▶ Eliminating ground loops

- ▶ Result in

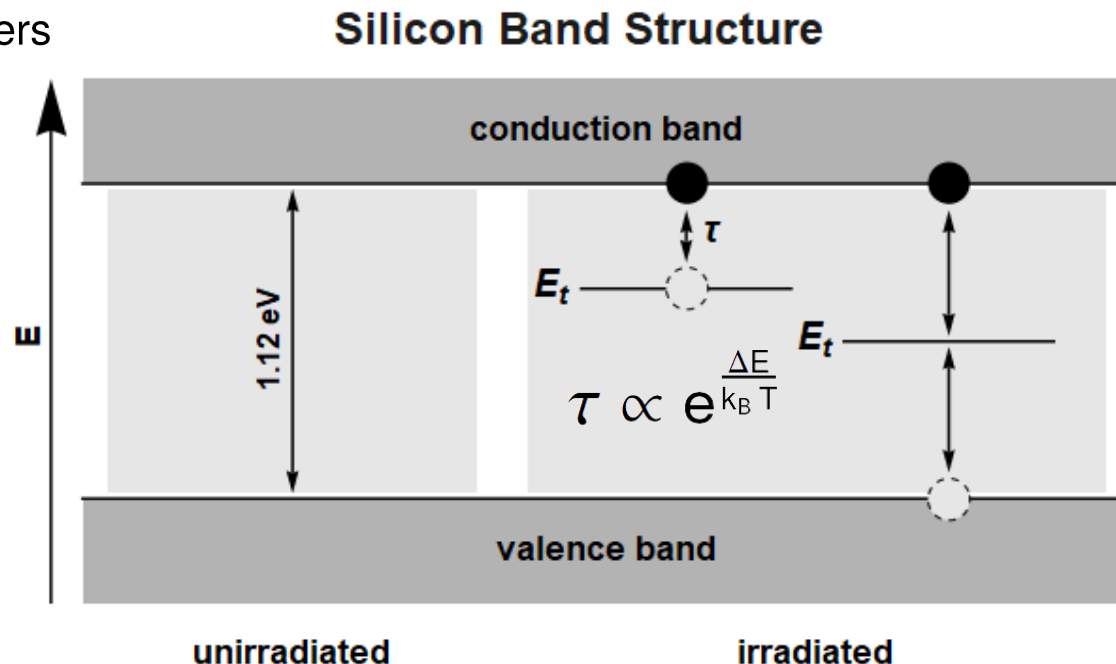
- ▶ Stable low and mid frequency performance
- ▶ High frequency drop will be discussed later



Unirradiated Strip Detector @ -20°C

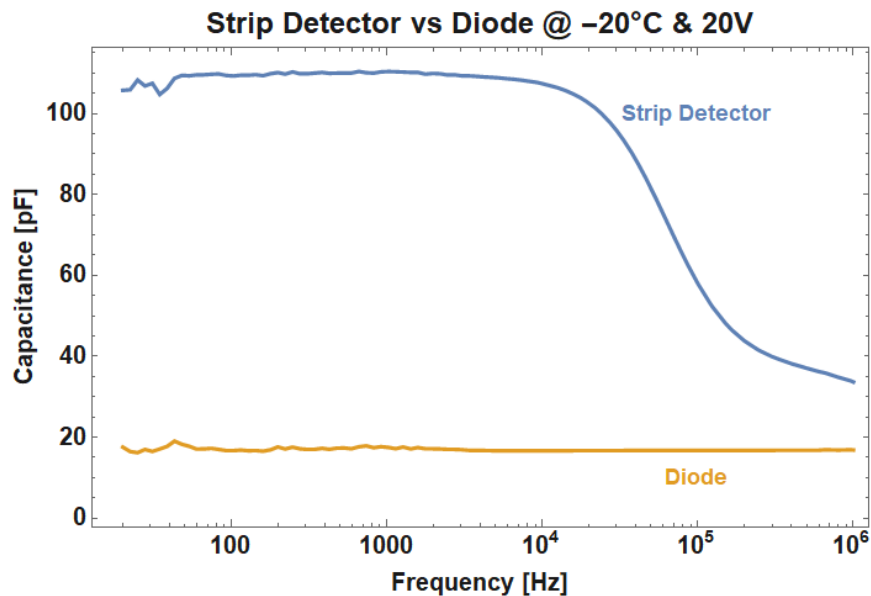


- ▶ Production of lattice defects (trap levels) by impinging irradiation:
 - ▶ Vacancies
 - ▶ Interstitial atoms
 - ▶ Clusters



- ▶ Maximum contribution of E_t if capture time τ matches measurement frequency f
- ▶ Minimum contribution if $f \ll \tau^{-1}$ (→ low frequencies desired)

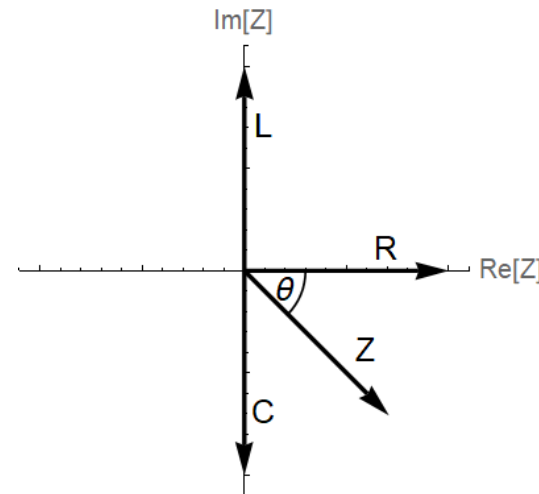
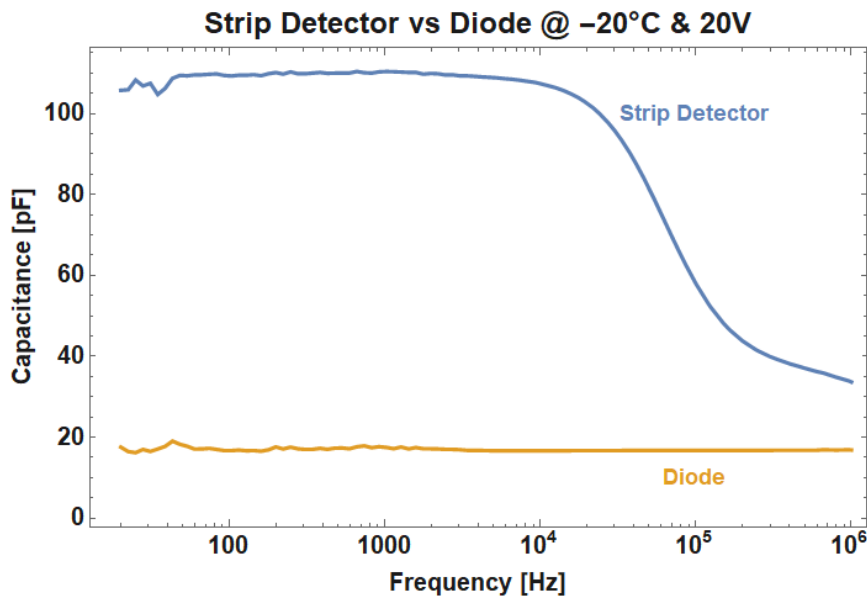
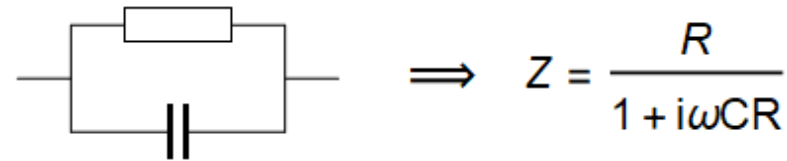
- ▶ Comparison of unirradiated Diode and Strip Detector:
 - ▶ Diode does not show high frequency drop
 - ▶ Are the strips and bias resistors responsible?



Reason of the High Frequency Deviation

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- ▶ Calculation of the phase θ of the impedance:

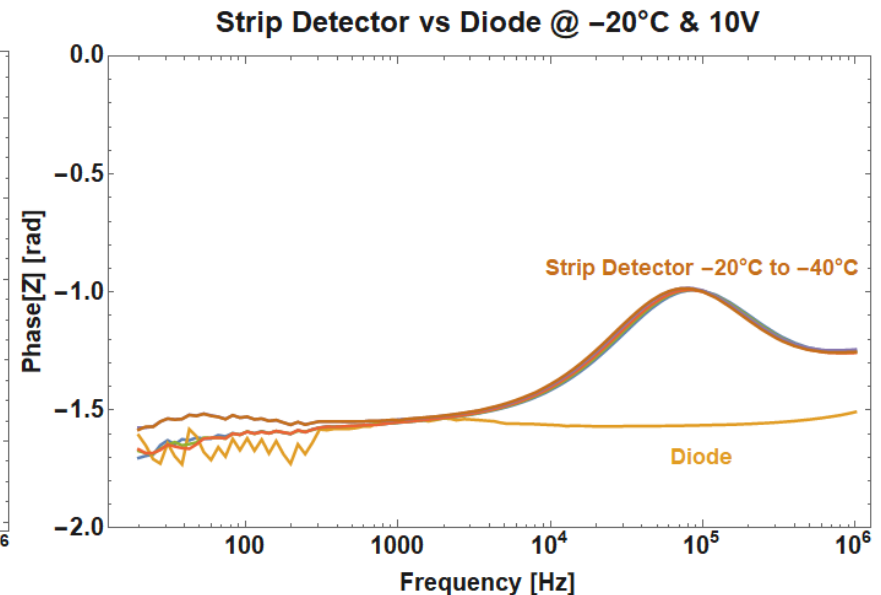
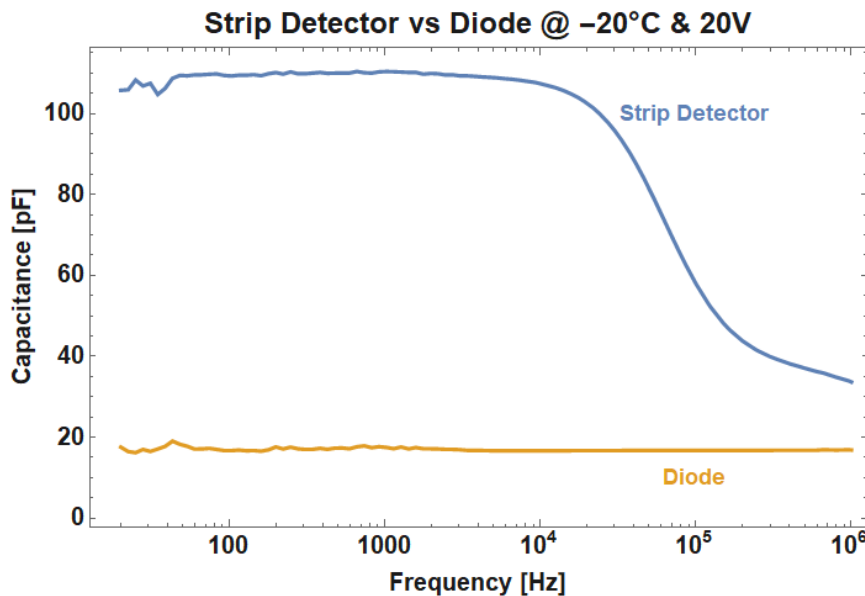
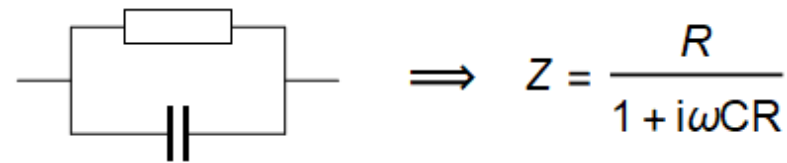


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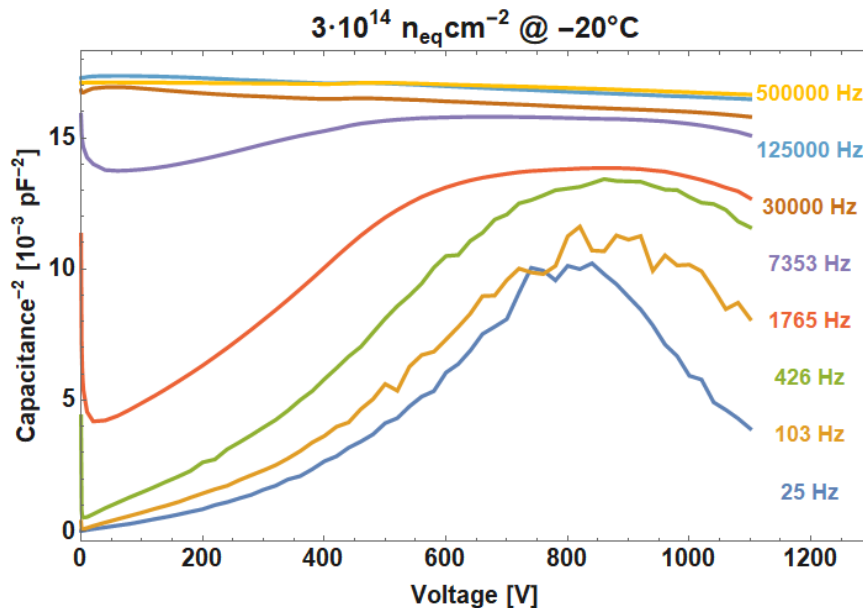
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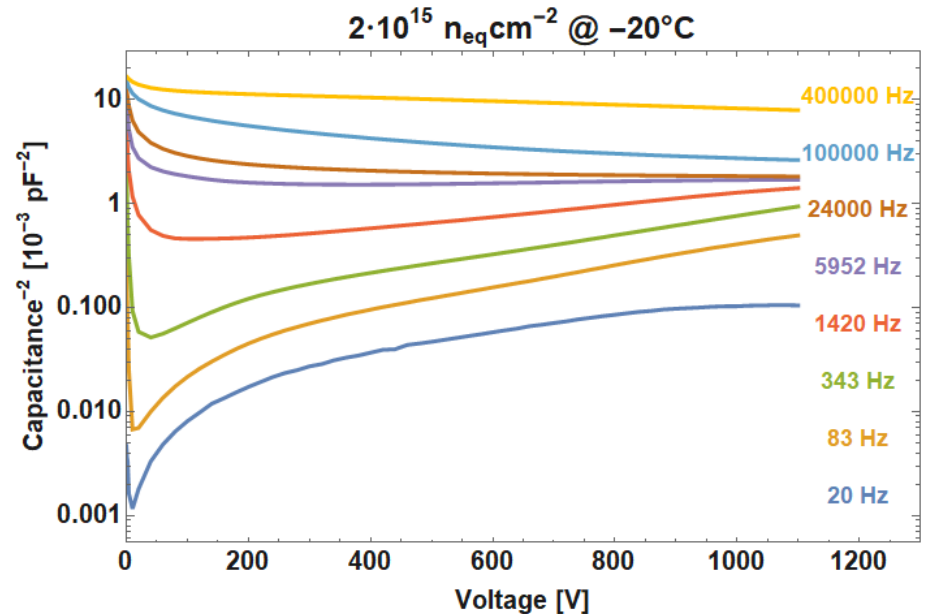
Effect of Radiation Damage on Capacitance



- ▶ Diode (NitroStrip)
 - ▶ Expected increase only at low frequencies
 - ▶ At high frequencies no voltage dependence

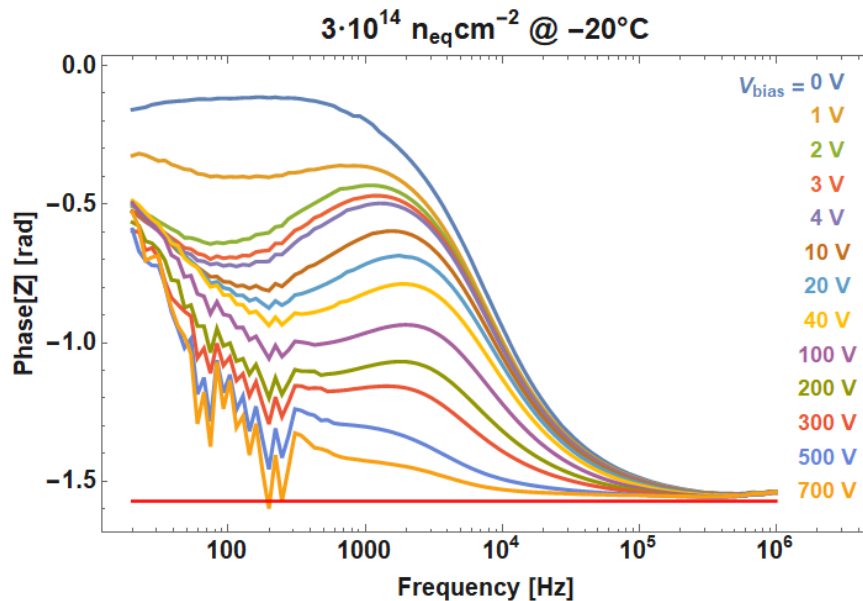


- ▶ Strip Detector (ATLAS12 mini)
 - ▶ Larger frequency dependence
 - ▶ Increase also only at low frequencies
 - ▶ CV measurements not sufficient anymore



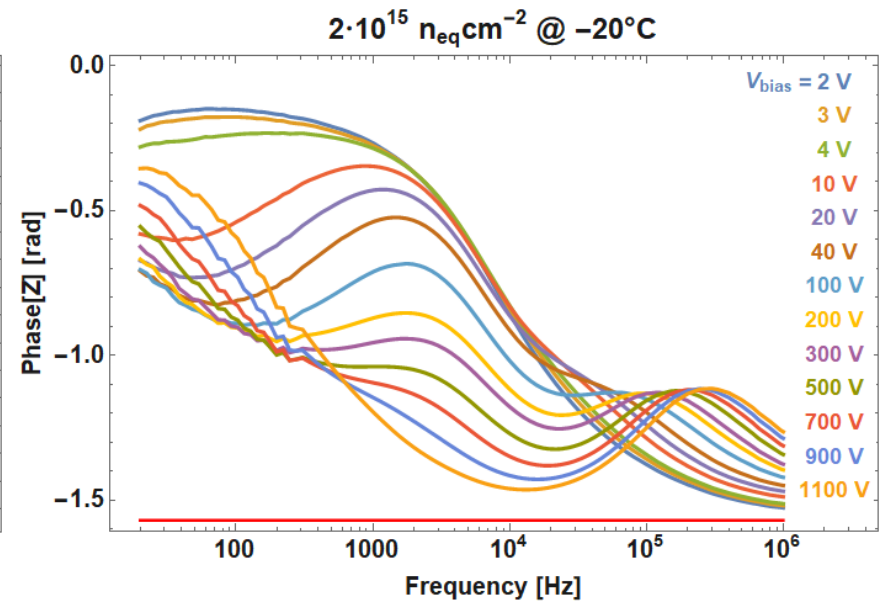
▶ Diode

- ▶ Decreasing resistive behaviour with increasing voltage in low frequency range
- ▶ Peak of resistive behaviour around 1kHz
 - Active defect



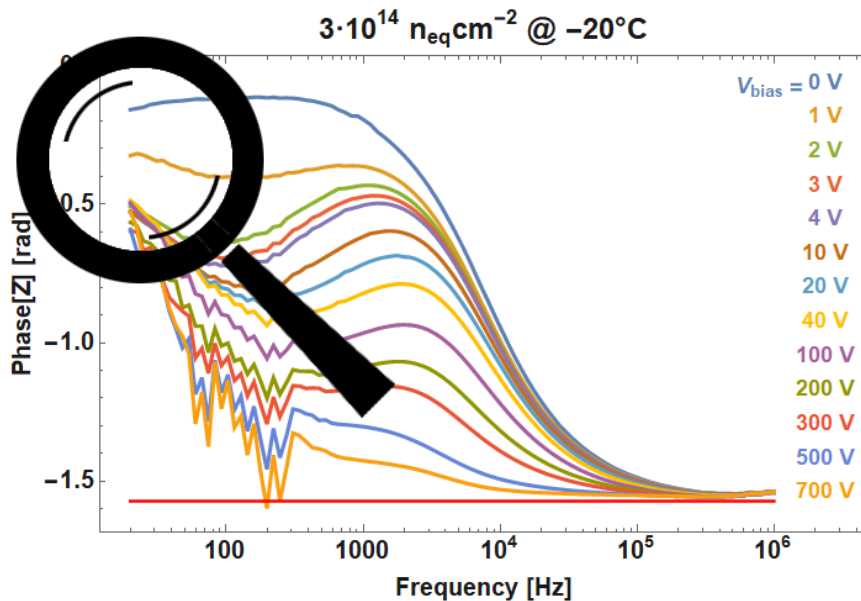
▶ Strip Detector

- ▶ Similar behaviour in low frequency range
- ▶ Additional peak in high frequency range
 - Only due to strips?



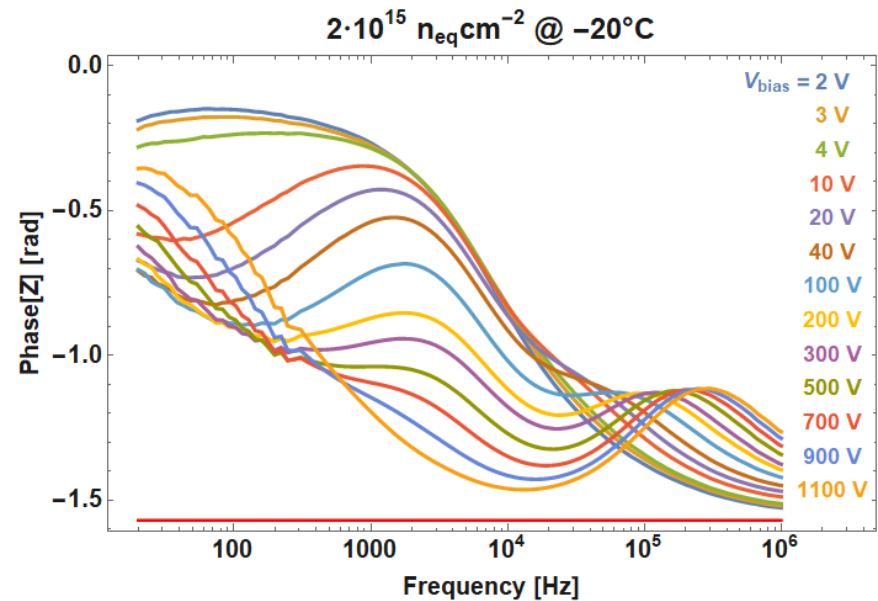
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▶ Strip Detector

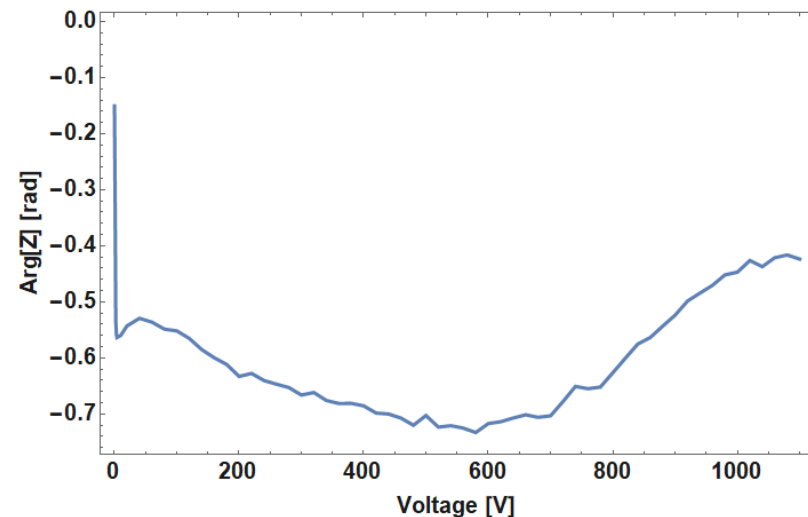
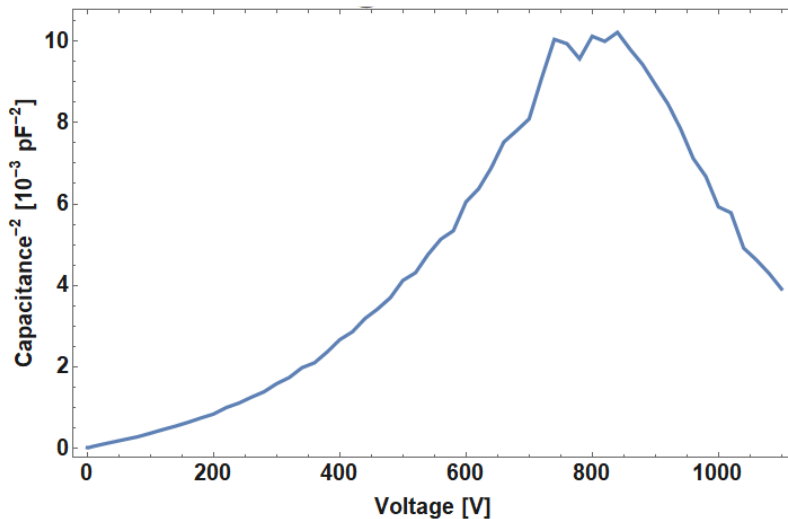
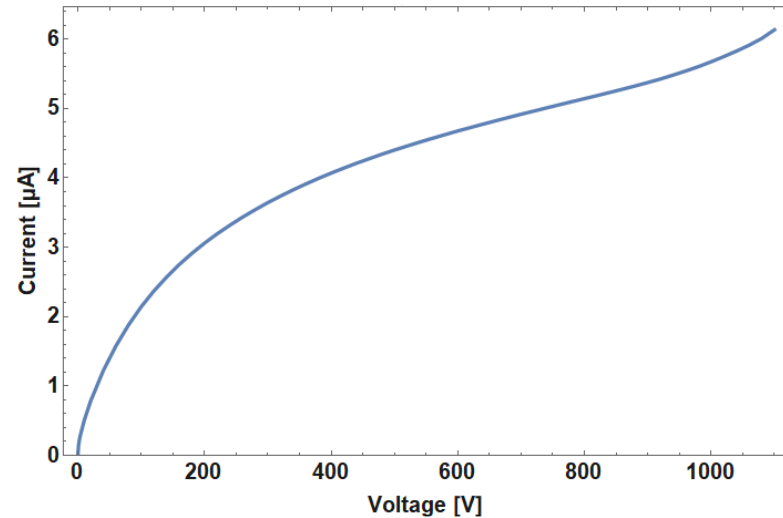
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Comparison of IV, CV and Phase



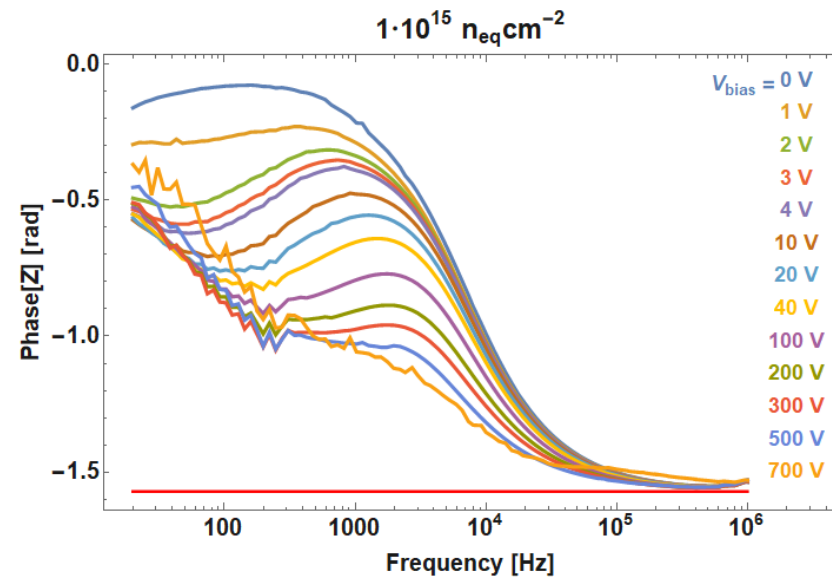
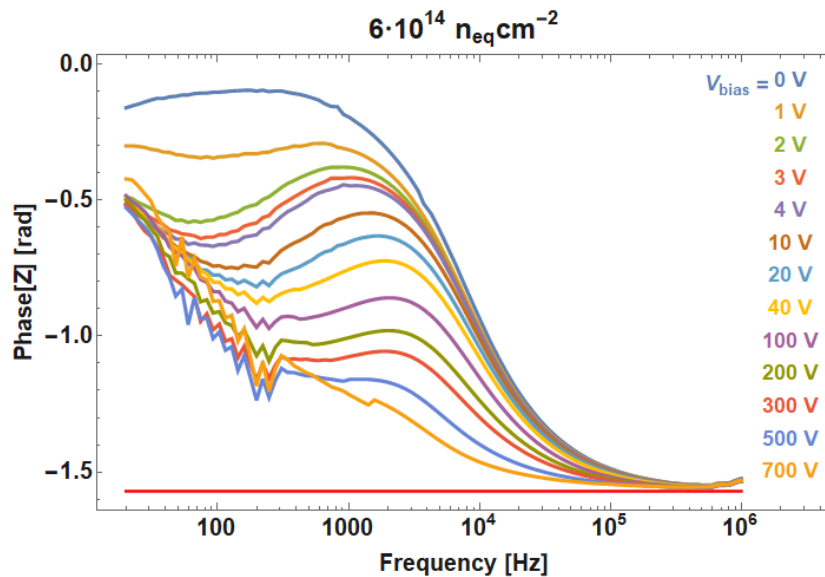
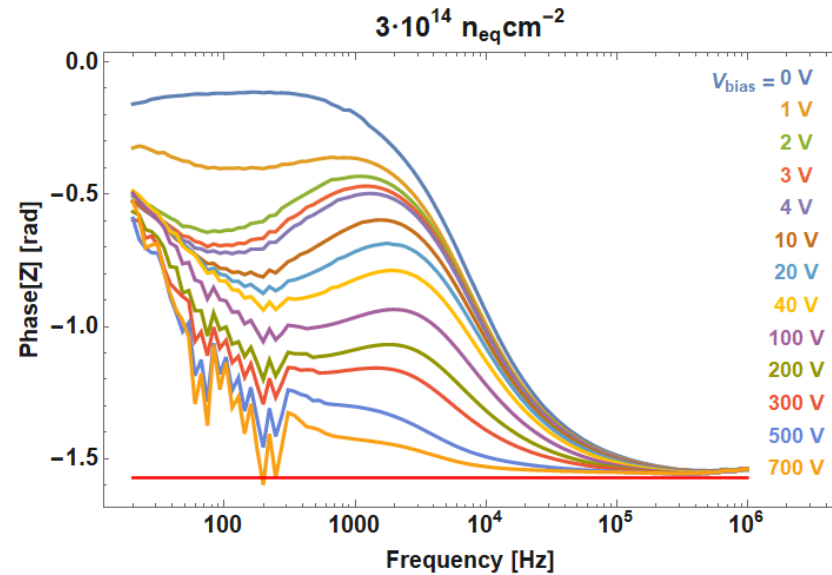
- ▶ Measured at -20°C & 25Hz
- ▶ Capacitance increases above 700V
- ▶ Coincides with turnover point of IV
- ▶ Phase also shows increasing resistive behaviour at this voltage



Effect of Fluence on Phase

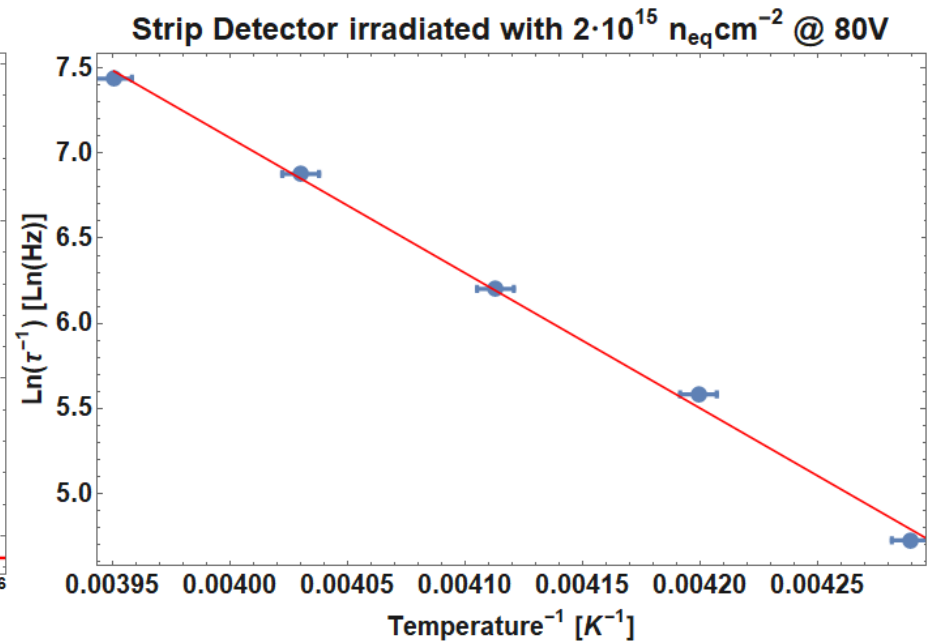
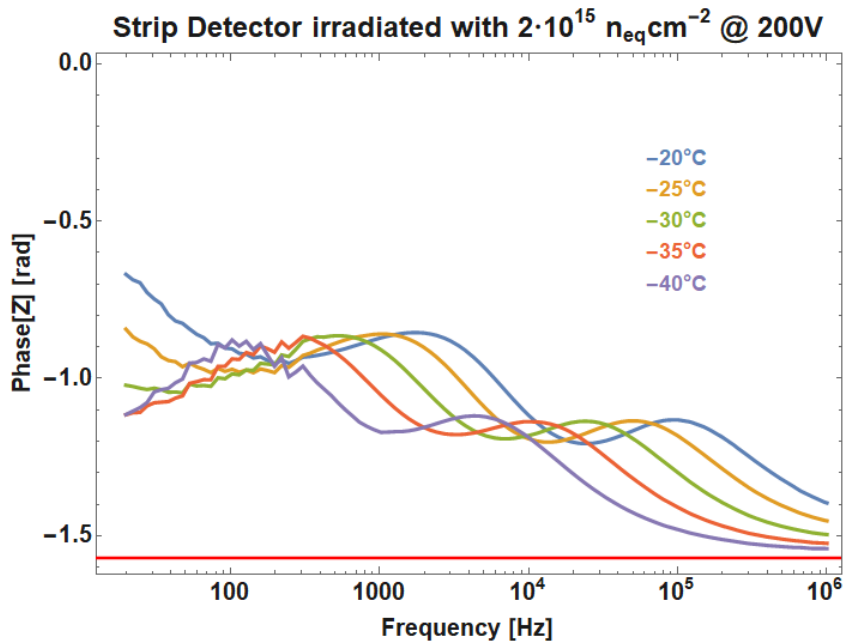


- ▶ Diodes measured at -20°C
- ▶ In low frequency range:
 - ▶ The higher the fluence the more resistive
- ▶ The higher the frequency the less fluence and voltage dependence

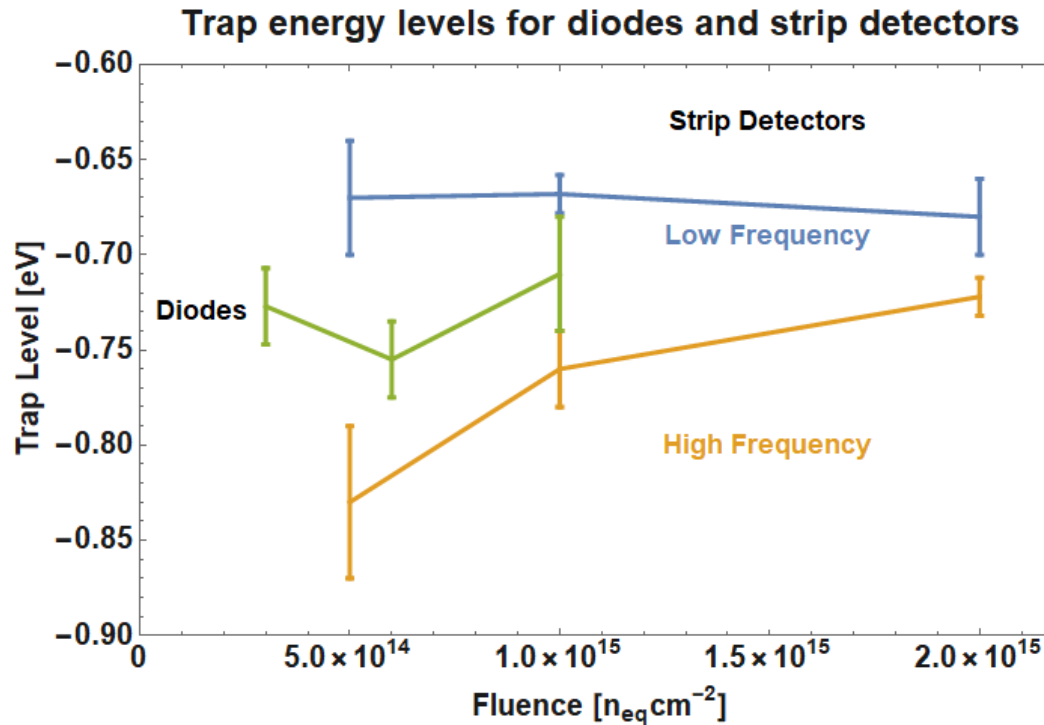


- ▶ Varying the temperature shows:
 - ▶ Slowing down of carrier capture
 - ▶ High frequency peak shifts
 - ▶ Caused by traps and interaction with defects

$$\tau \propto e^{\frac{\Delta E}{k_B T}}$$

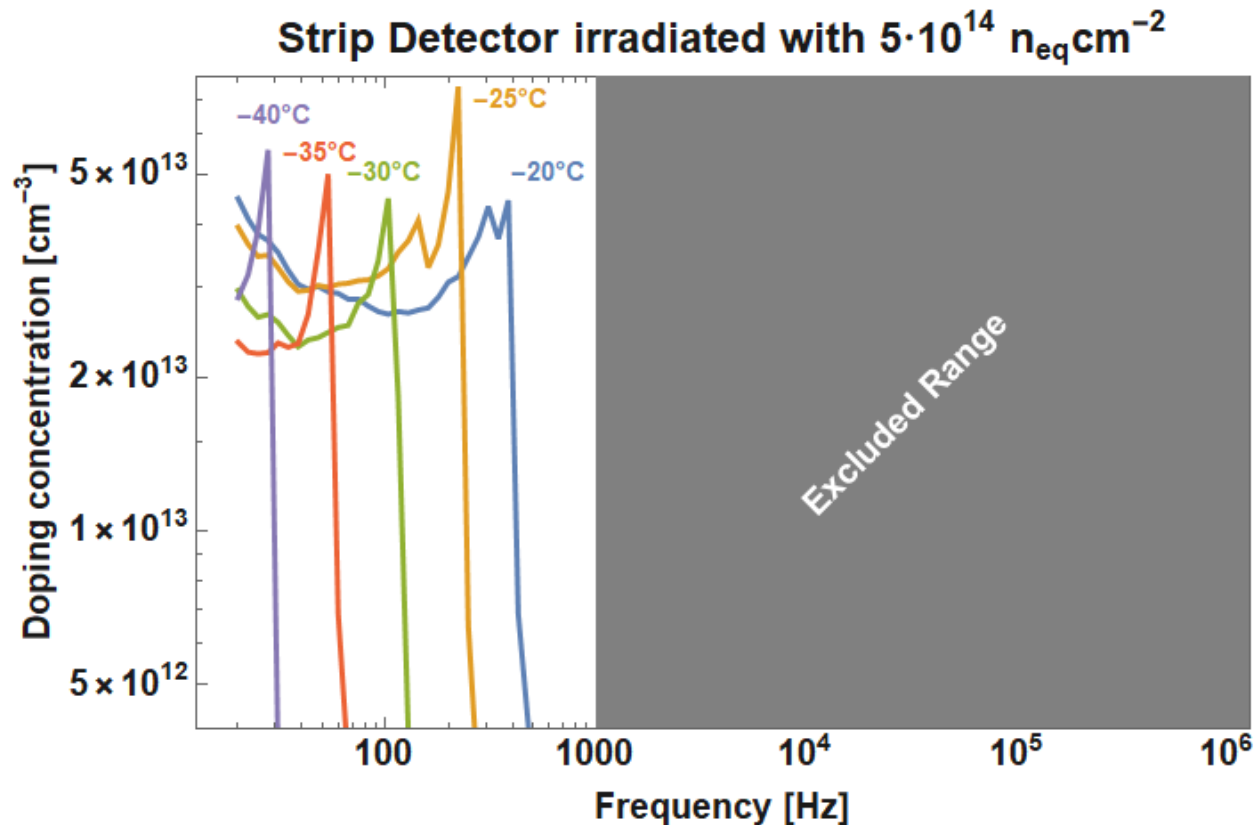


Comparison of Trap Energy Levels for Different Fluences



- ▶ Different energy levels for low and high frequency peak
 - ▶ Different defects contributing
- ▶ No fluence dependence for low frequency peak
- ▶ Fluence dependence for high frequency peak

- ▶ Doping fit only converges in low frequency range
- ▶ Same temperature dependence as phase
- ▶ Values consistent with expectation



- ▶ Strong frequency dependence
 - ▶ For strip detectors compared to diodes at high frequencies
 - ▶ Allows determination of effective energy depth of trap levels

- ▶ Temperature dependent high frequency behavior for strip detectors
- ▶ Measurement of full depletion capacitance at high frequencies for irradiated devices

- ▶ Ability to measure doping concentration of highly irradiated sensors with low frequencies (the lower the better)

- ▶ Outlook:
 - ▶ Finalize 3D measurements
 - ▶ Investigate annealing
 - ▶ Compare to simulations
 - ▶ Compare with TSC measurements



Backup

- ▶ Current vs. Voltage (IV)
 - ▶ No breakdown for unirradiated strip detector
 - ▶ Linear increase for irradiated strip detector

- ▶ Capacitance vs. Voltage (CV)
 - ▶ Measurement via LCR oscillating circuit with selectable frequency
 - ▶ Quadratic inverse depiction enables determination of doping concentration and depletion voltage

