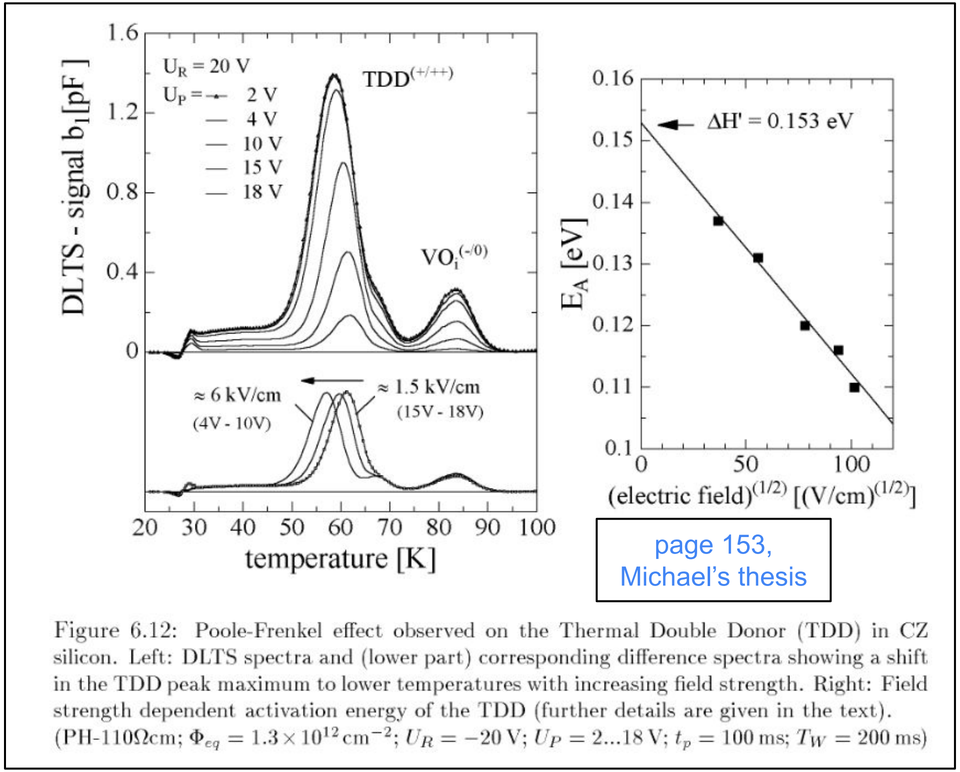
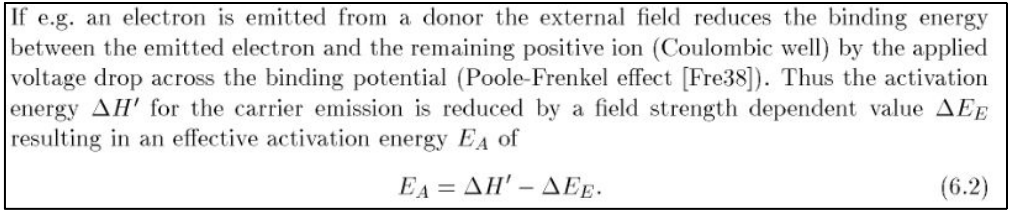
hunting for the x-defect, or… on the trail of Michael’s thesis



page 153, Michael’s thesis

Figure 6.12: Poole-Frenkel effect observed on the Thermal Double Donor (TDD) in CZ silicon. Left: DLTS spectra and (lower part) corresponding difference spectra showing a shift in the TDD peak maximum to lower temperatures with increasing field strength. Right: Field strength dependent activation energy of the TDD (further details are given in the text). (PH-110Ωcm; $\Phi_{eq} = 1.3 \times 10^{12}\,\mathrm{cm}^{-2}$; $U_R = -20$ V; $U_P = 2...18$ V; $t_p = 100$ ms; $T_W = 200$ ms)

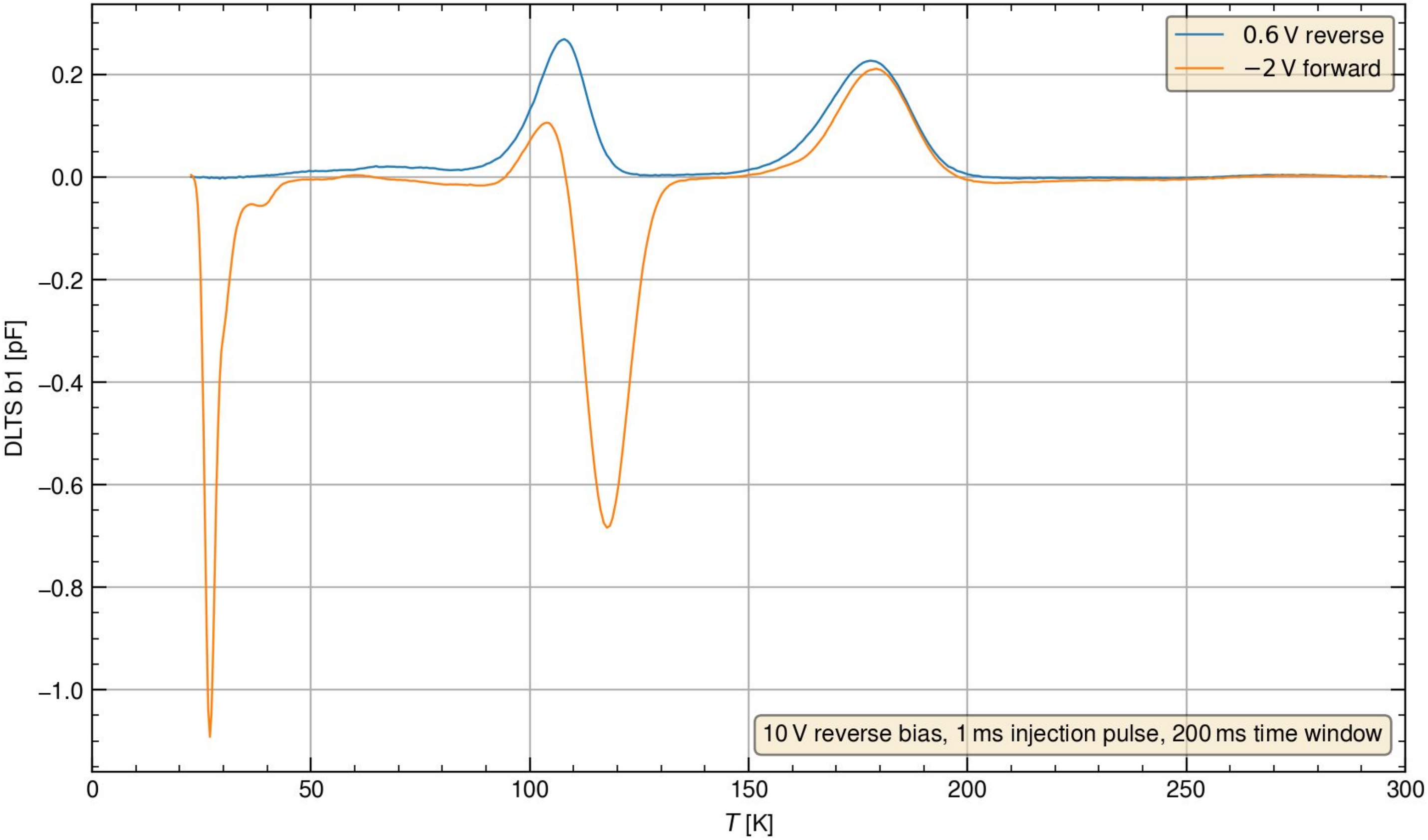

If e.g. an electron is emitted from a donor the external field reduces the binding energy between the emitted electron and the remaining positive ion (Coulombic well) by the applied voltage drop across the binding potential (Poole-Frenkel effect [Fre38]). Thus the activation energy $\Delta H'$ for the carrier emission is reduced by a field strength dependent value ΔE_E resulting in an effective activation energy E_A of

$$E_A = \Delta H' - \Delta E_E. \quad (6.2)$$

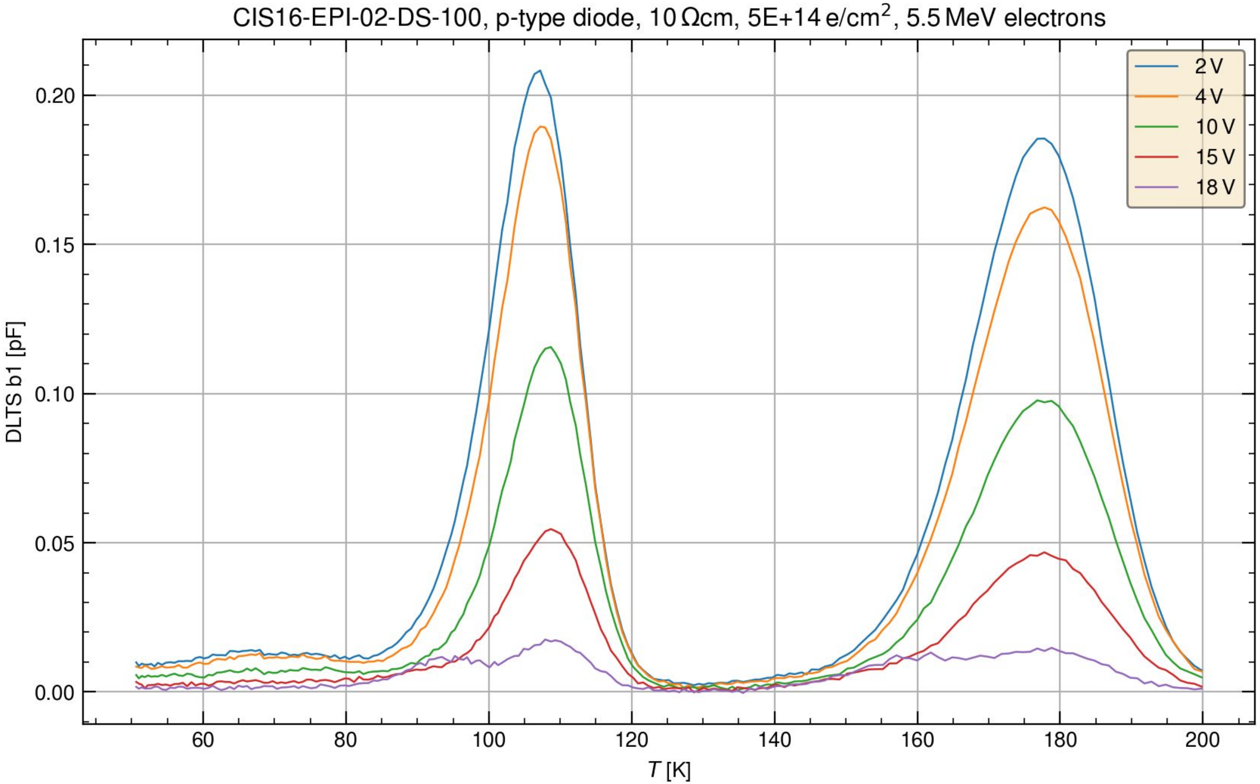
- investigate the x-defect
- Poole-Frenkel?
- 5E14 electron/cm2, 5.5 MeV (Minsk)
- p-type diode (CIS16-EPI-02-50-DS-100)
- 10Ωcm for strong electrical fields

- perform DLTS measurements with different pulse voltages
- spectra resulting from 2V pulse comes from defects sitting in the depth range between W(20V) and W(2V)
- subtract spectra from each other to get signal contribution only from defects in this specific depth range
- difference spectra are effectively spectra recorded for different field strengths
- get activation energy dependent on E-field strength
- obtain 0 field energy

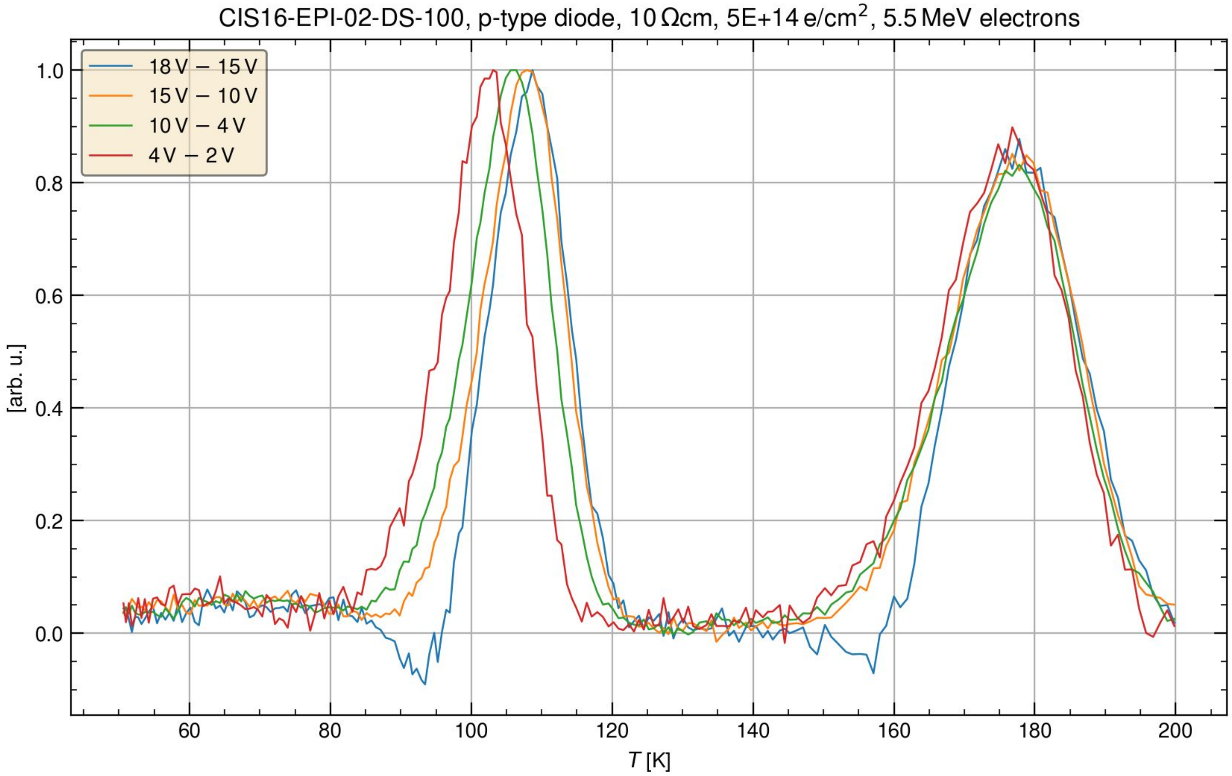
Standard DLTS measurement



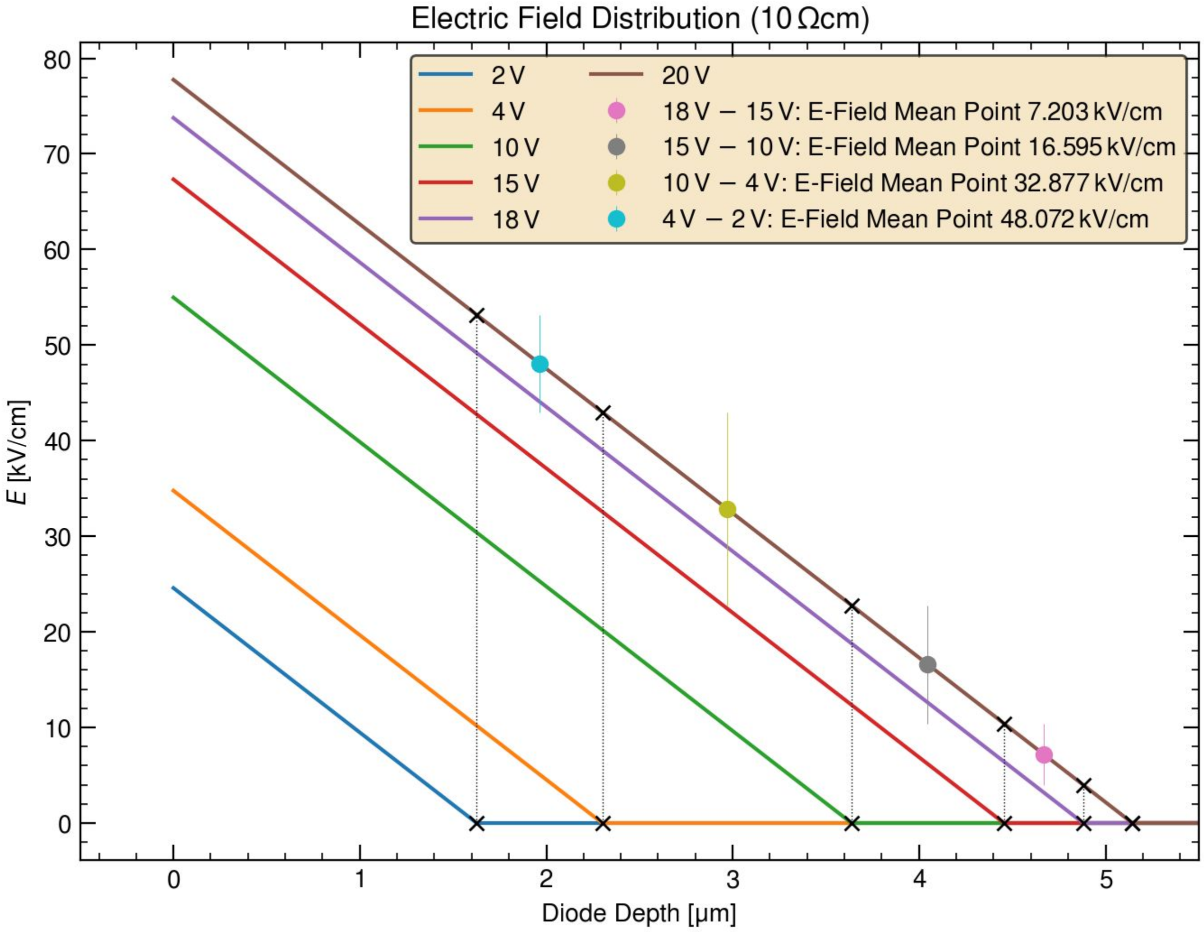
DLTS with different pulse voltages, 20V reverse



DLTS difference spectra



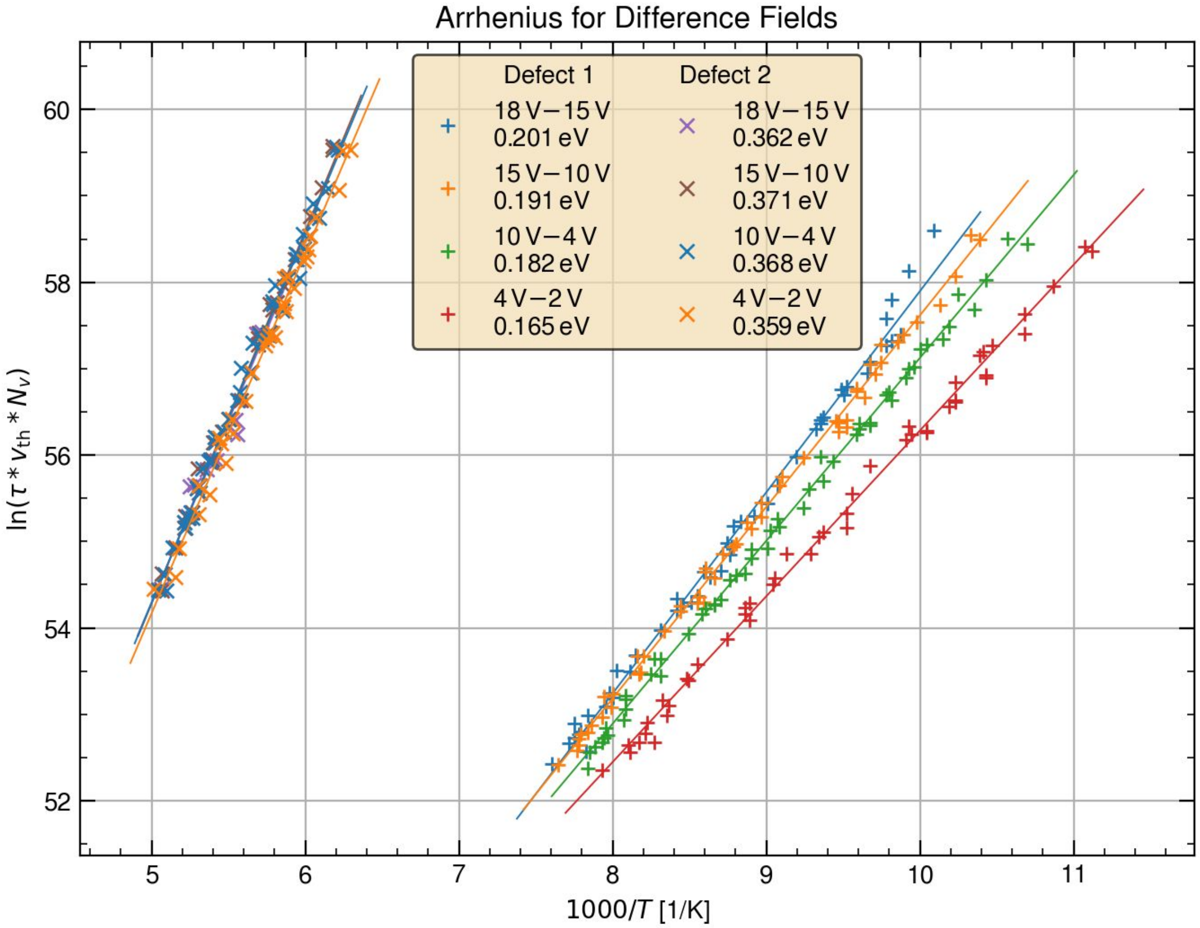
E-Field calculations



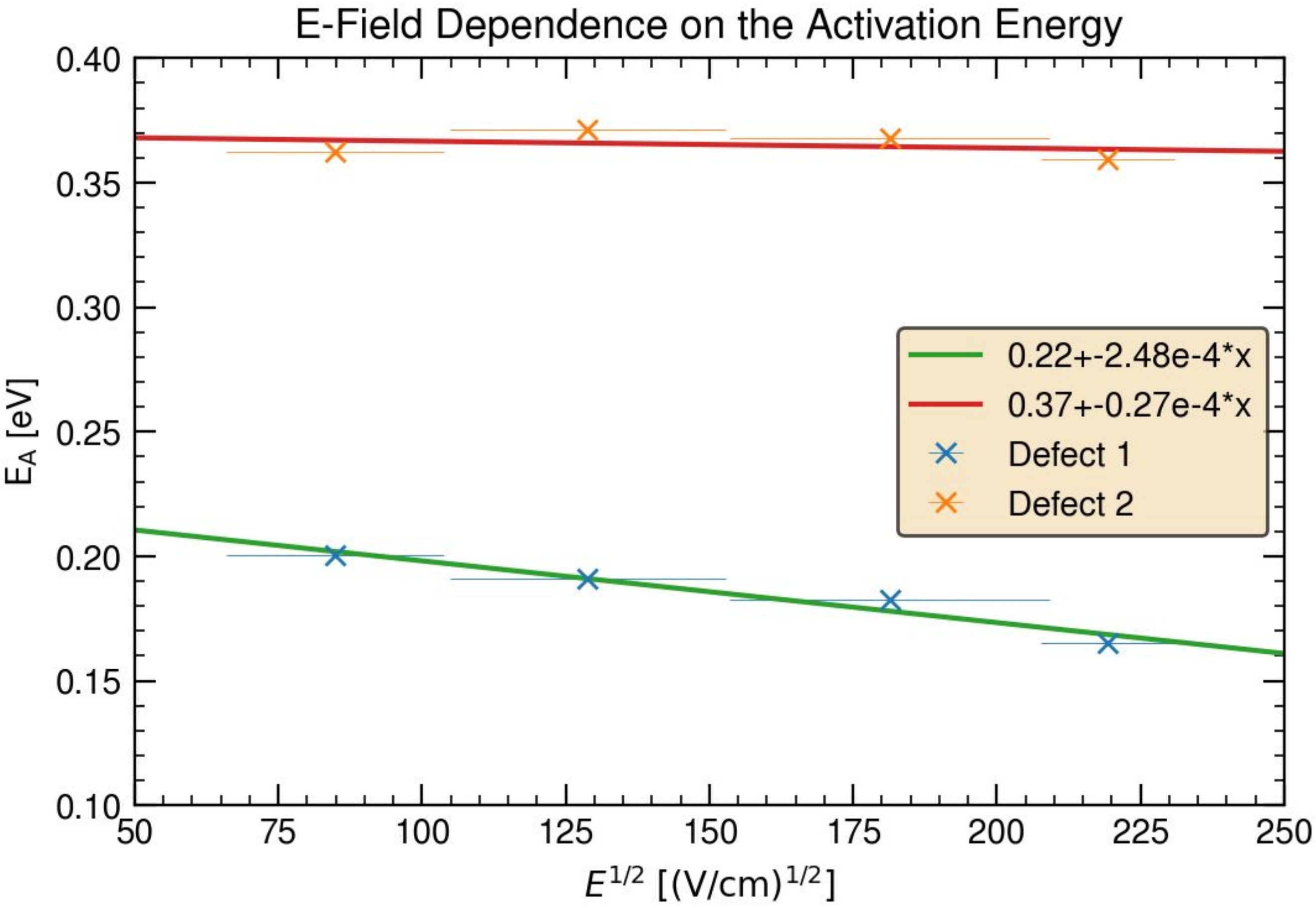
$$\mathcal{E}(x, V) = \frac{2V_{fd}}{d^2}(w(V) - x)$$

- Calculate depth of depletion for different biases
- Project onto E-Field curve of reverse bias (20V)
- Find areas of difference pulse voltages
- Calculate mean electric field value (on 20V curve)

Arrhenius Plots for difference DLTS measurements



Sqrt(E-Field) dependence?



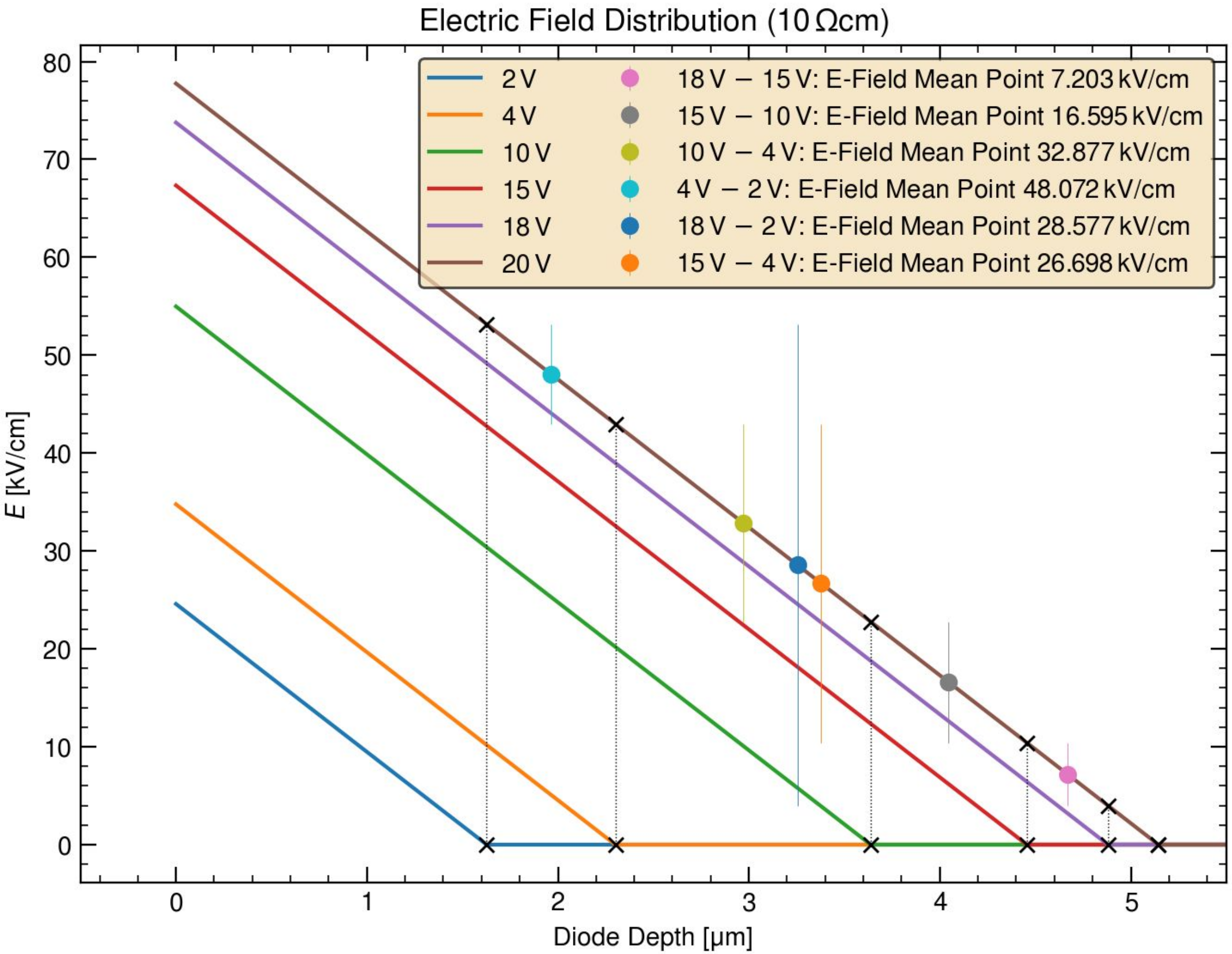
$$E_A = \Delta H' - \Delta E_E.$$

$$\Delta E_E = q_0\sqrt{\frac{q_0 E}{\pi\epsilon\epsilon_0}} = 2.2\times 10^{-4}\sqrt{E[V/cm]}\,eV.$$

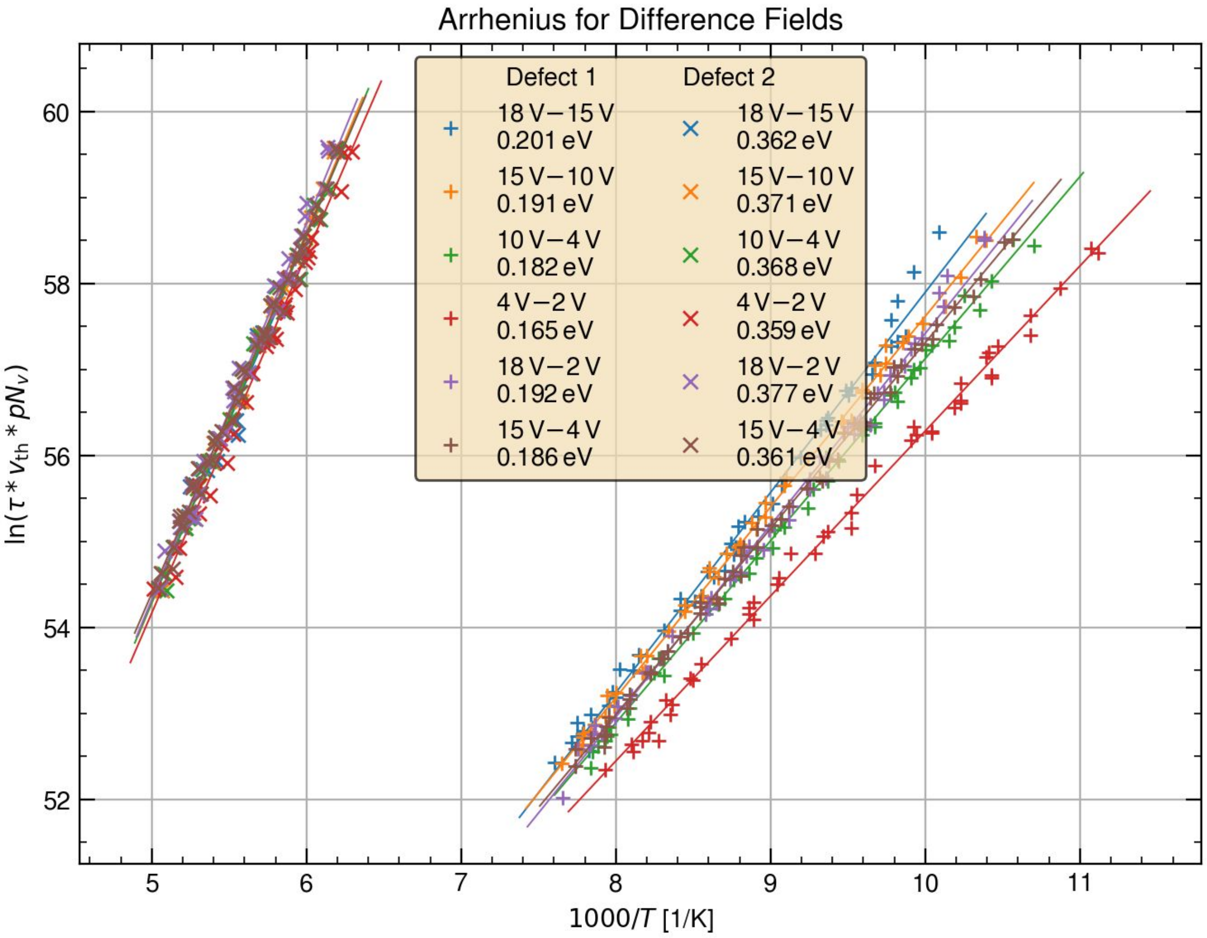
- X-Defect follows sqrt(E-Field) dependence
- Poole-Frenkel effect

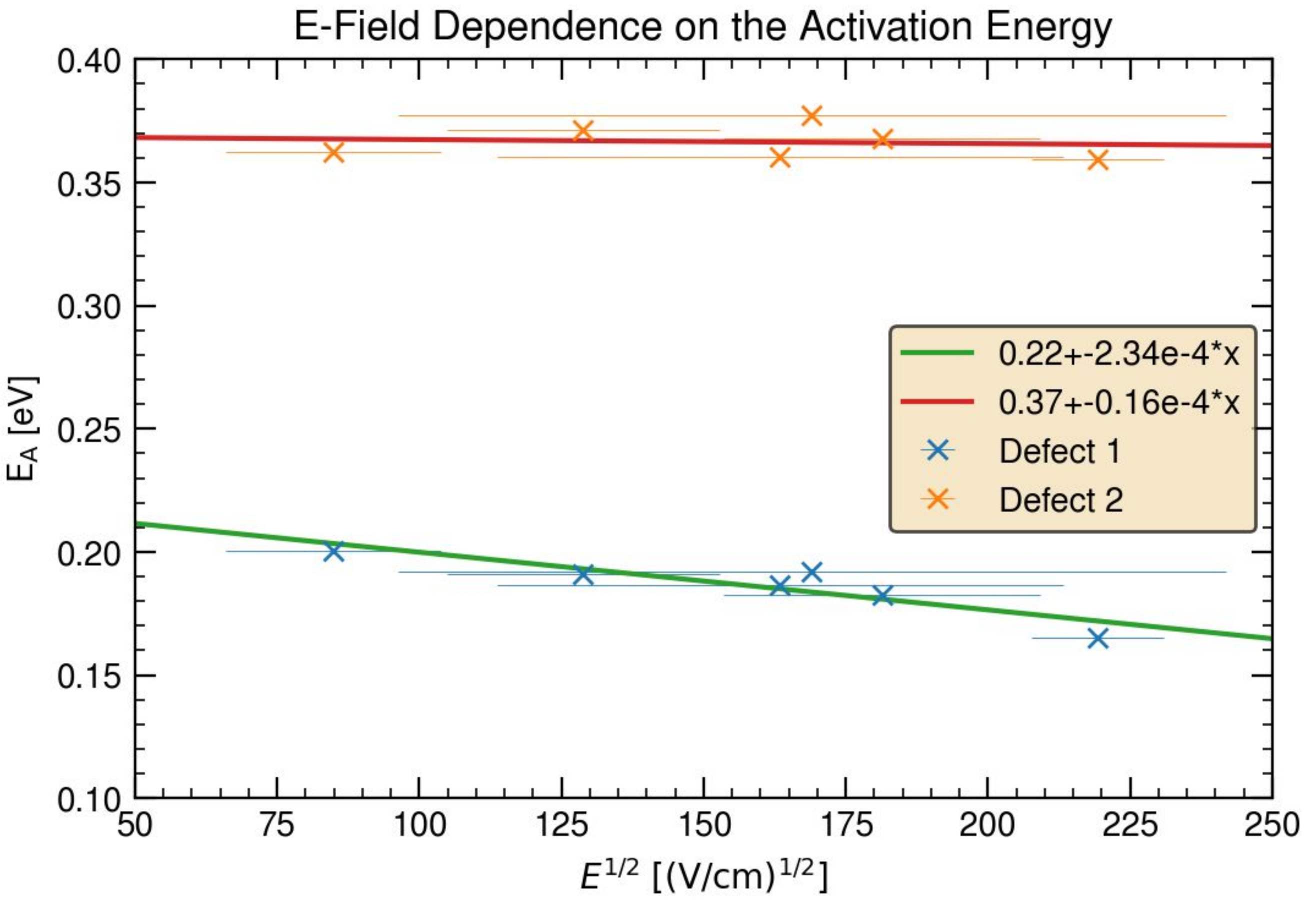
E-Field calculations

$$\mathcal{E}(x,V) = \frac{2V_{fd}}{d^2}(w(V) - x)$$



Arrhenius Plots for difference DLTS measurements



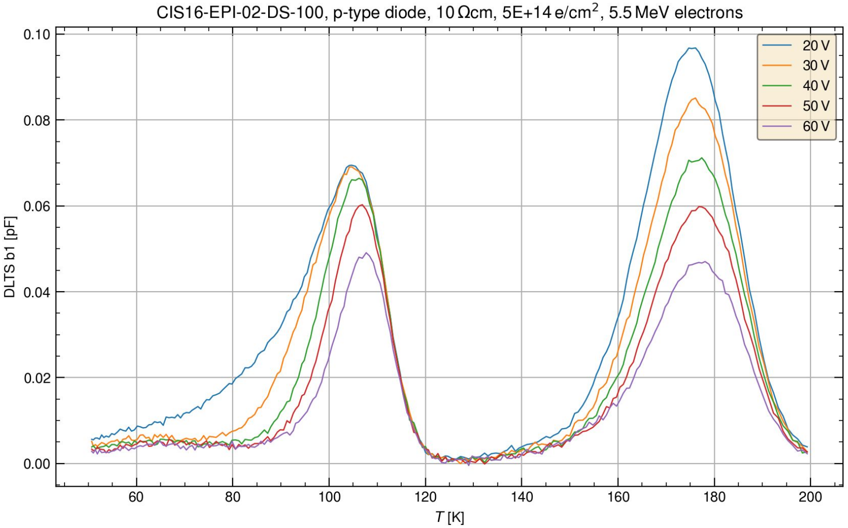


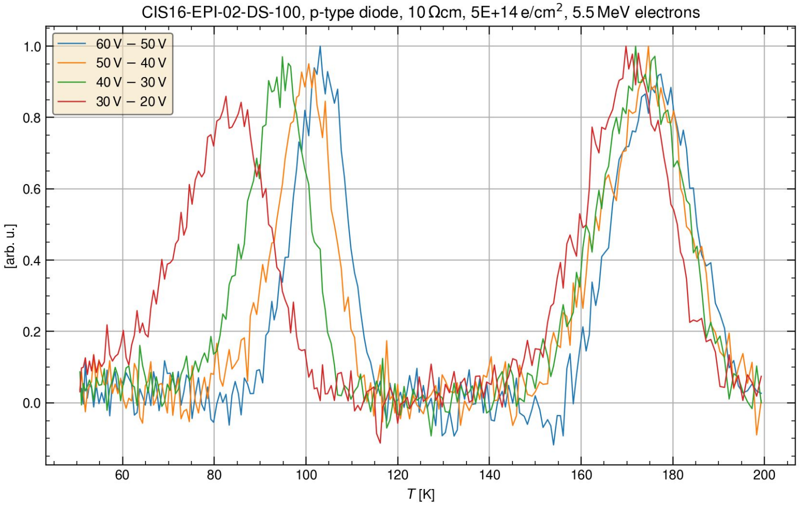
$$E_A = \Delta H' - \Delta E_E.$$

$$\Delta E_E = q_0\sqrt{\frac{q_0 E}{\pi\epsilon\epsilon_0}} = 2.2\times 10^{-4}\sqrt{E[V/cm]}eV.$$

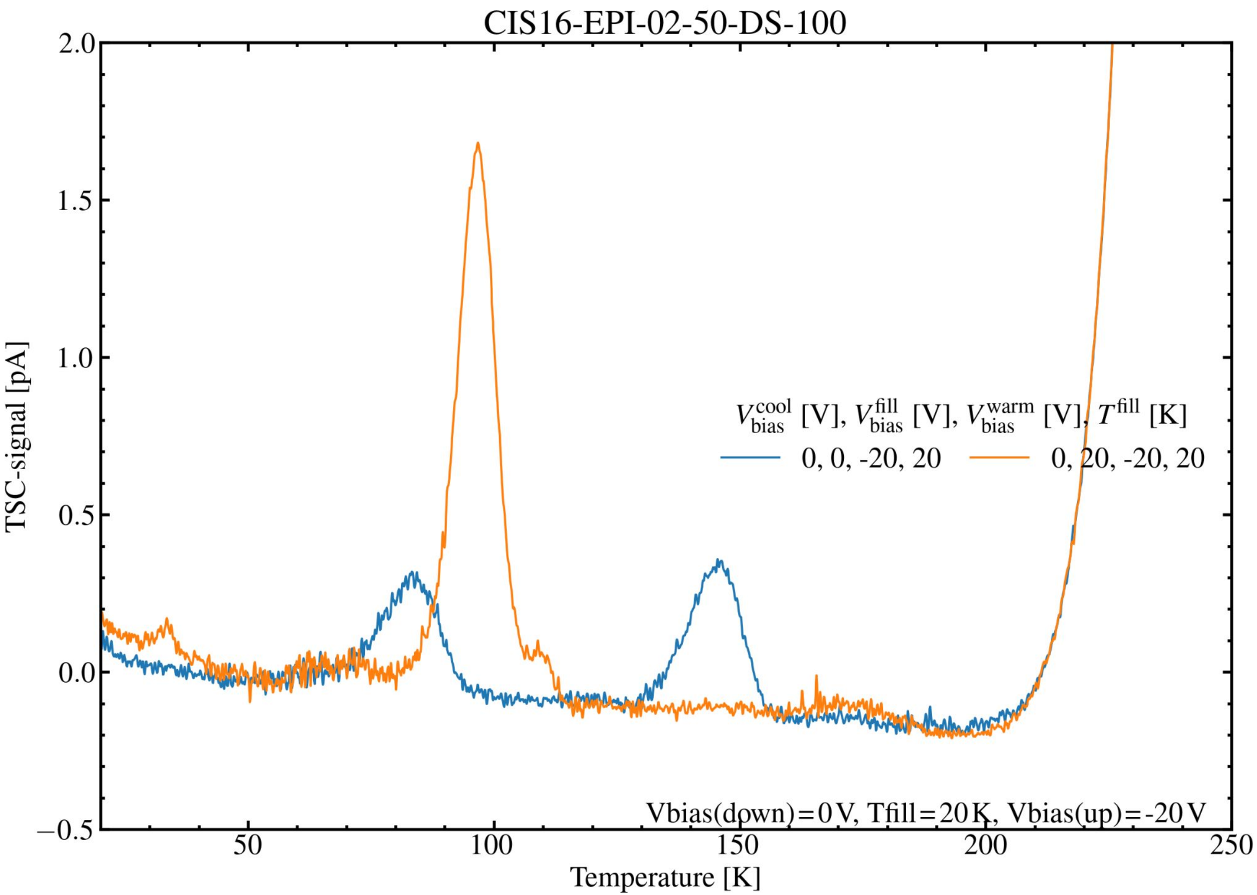
- X-Defect follows sqrt(E-Field) dependence
- Poole-Frenkel effect

the same exercise again with 100V reverse bias and higher pulse biases

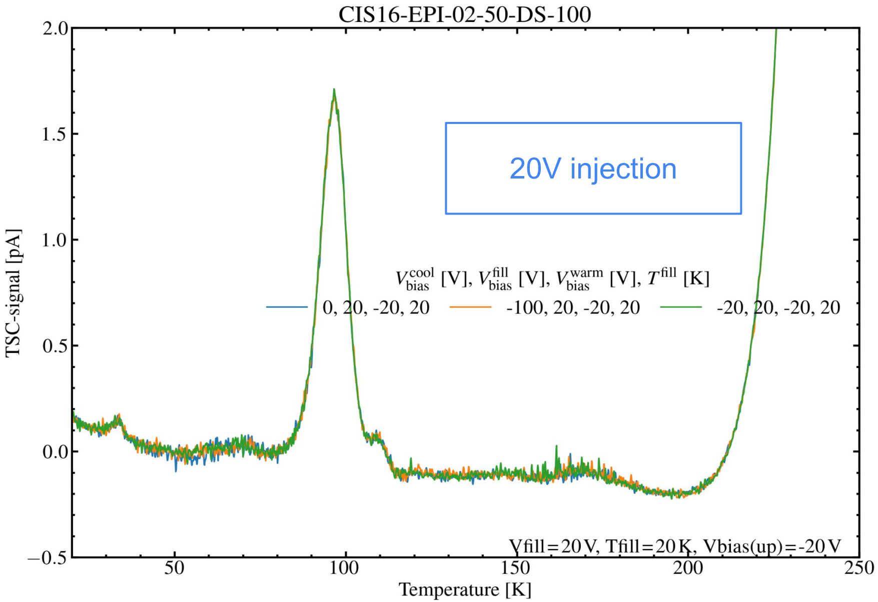


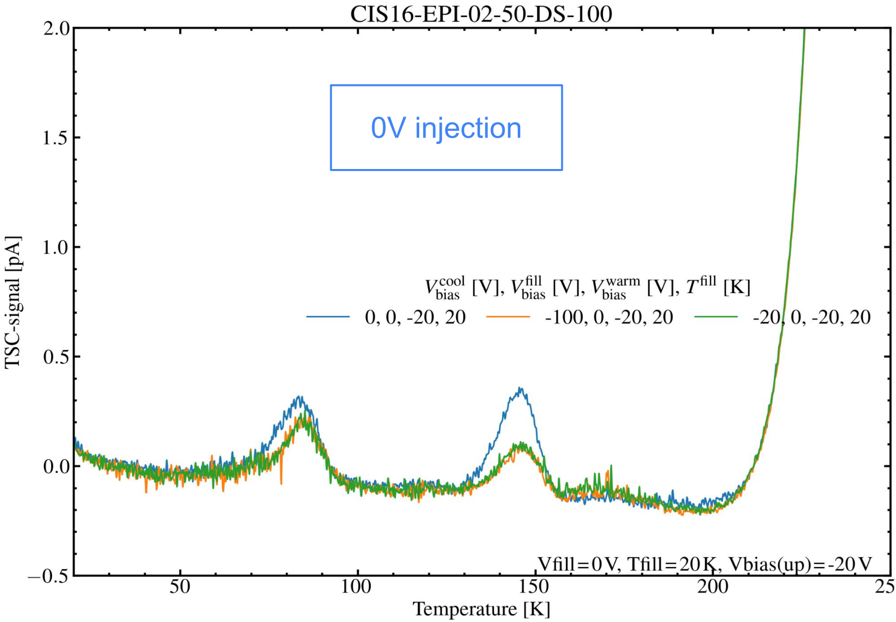


TSC measurements: cool down under 0V, warm up under -20V reverse

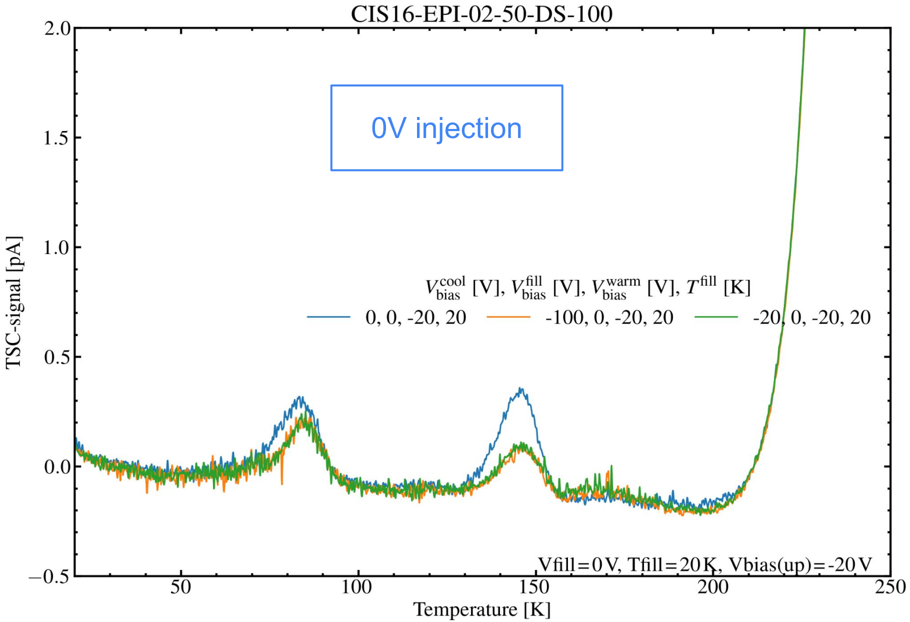


TSC: 0V cooling (comparing cooldown at 0, -100 and -20V) for Tfill 20K


20V injection

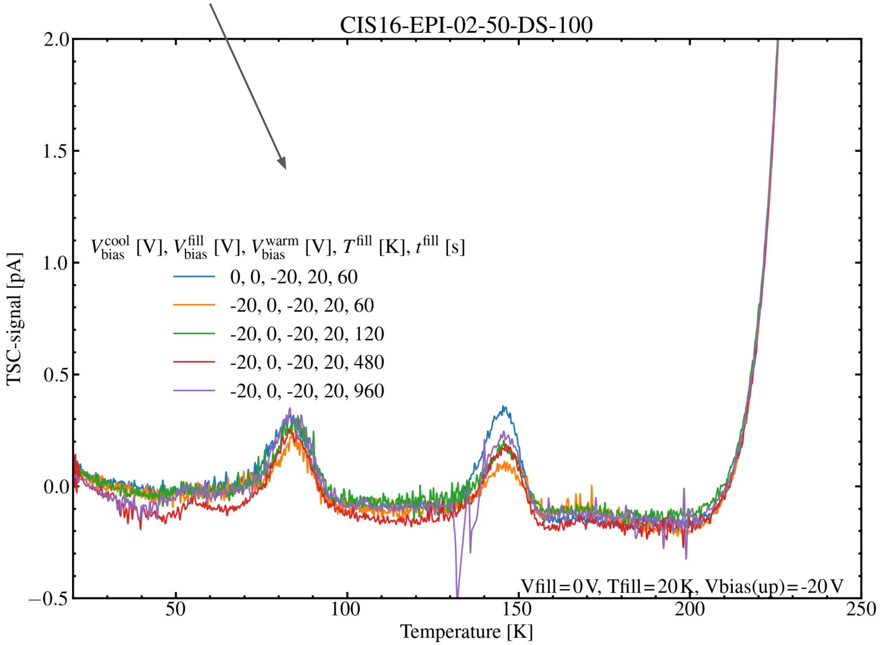

0V injection

TSC: -20V cooling, warm up -20V, injection 0V, Tfill 20K

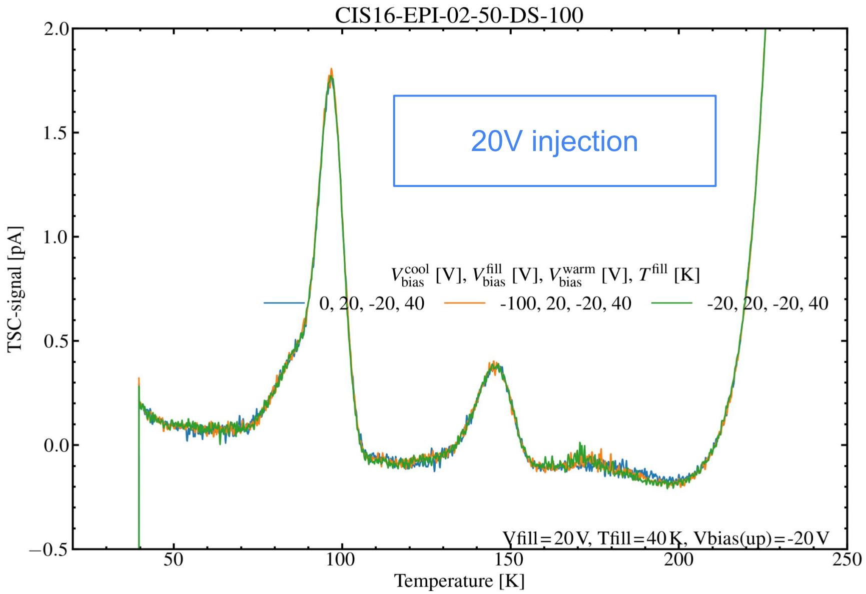


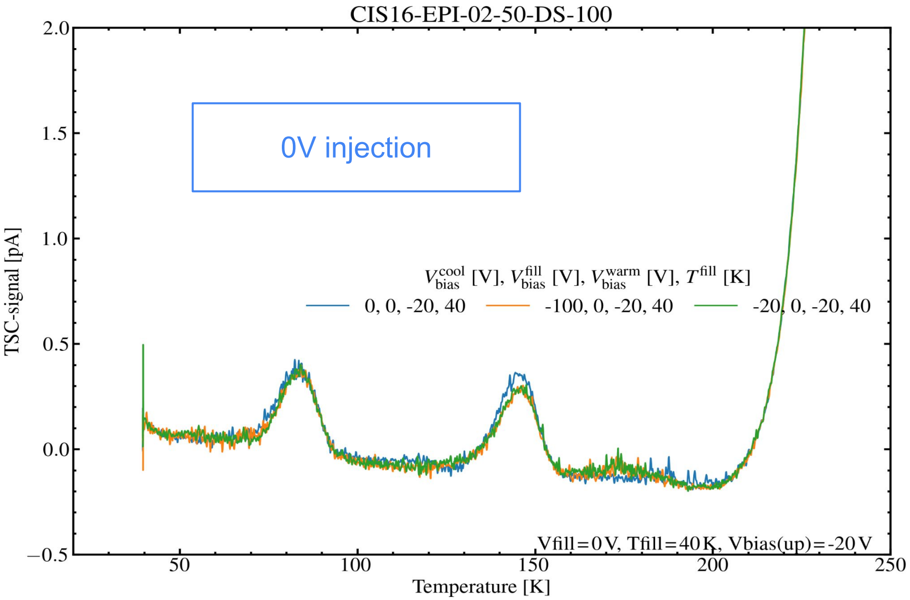
0V injection

- check for different tfill durations!
- see if we reach 0V cool down defect concentration

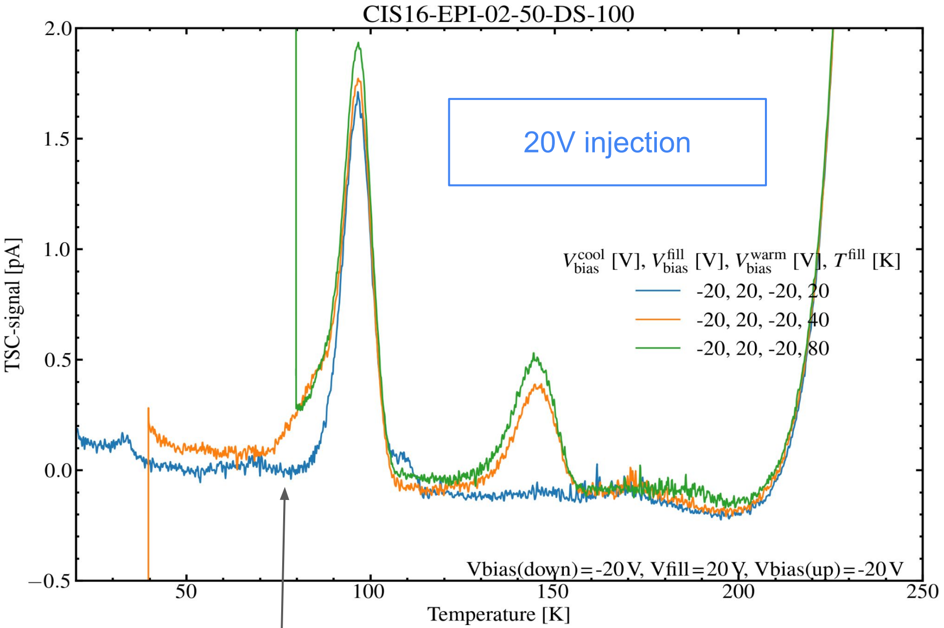


TSC: 0V cooling does not make a difference in filled defects (comparing cooldown at 0, -100 and -20V) for Tfill 40K

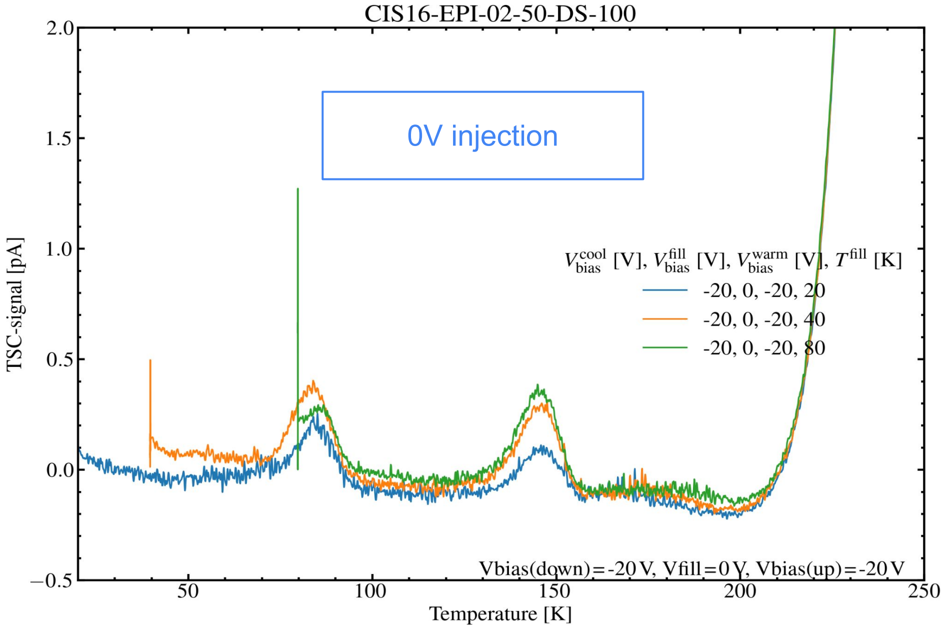

20V injection


0V injection

TSC: Dependence on Filling Temperature (20, 40 80K) w/ cool down under reverse bias



x-defect not filled at 20K



TSC: Dependence on Bias, cool down 0V