Fitting Current from InP:Fe Under High Flux Xray Test Beam

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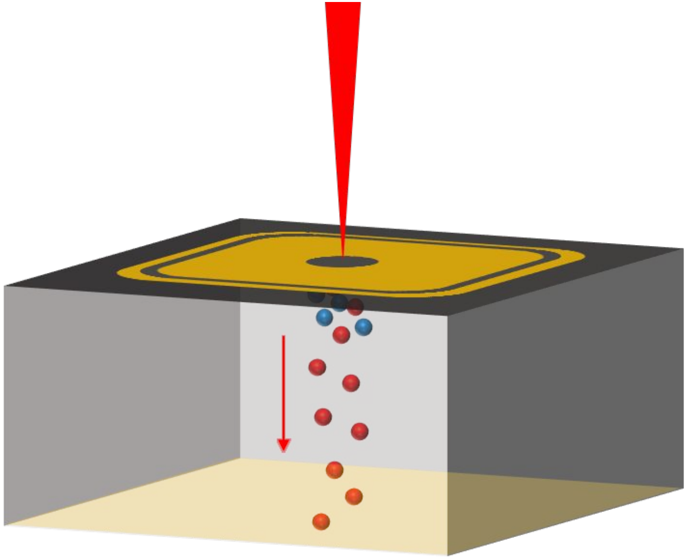
Overview

- Xray beam test measurements from DIAMOND Light Source to investigate persistent current phenomenon
- **~~Persistent Current~~ → Lag / Afterglow**
  - minutes-long decay of current after high flux of 15 keV xrays is removed
- In-Progress:
  - **Building a Theoretical Model**
    - What is persistent current? What causes it?
  - **Model Implications**
    - Framework → Predictive Model → Testable Hypotheses and Fits
  - **Data Processing**
    - Fitting model to measured data
    - Extracting parameters
    - Comparing fits to theoretical predictions

Experimental Setup - DLS

- **Focused xray beam of 15 keV photons**
    - Absorption length ~100 μm
    - Carriers generated most near frontside
    - Beam moved on and off device
- **Device biased on backside**
    - Carriers travel through bulk
- **Different Initial Conditions**
    - Temperature, photon flux, applied voltage, etc.
- Records: [Logbook]() and [Spreadsheet]()
    - [Plots]() and [Data]()
    - Data taken every 2 seconds



Schematic by Jennifer Ott

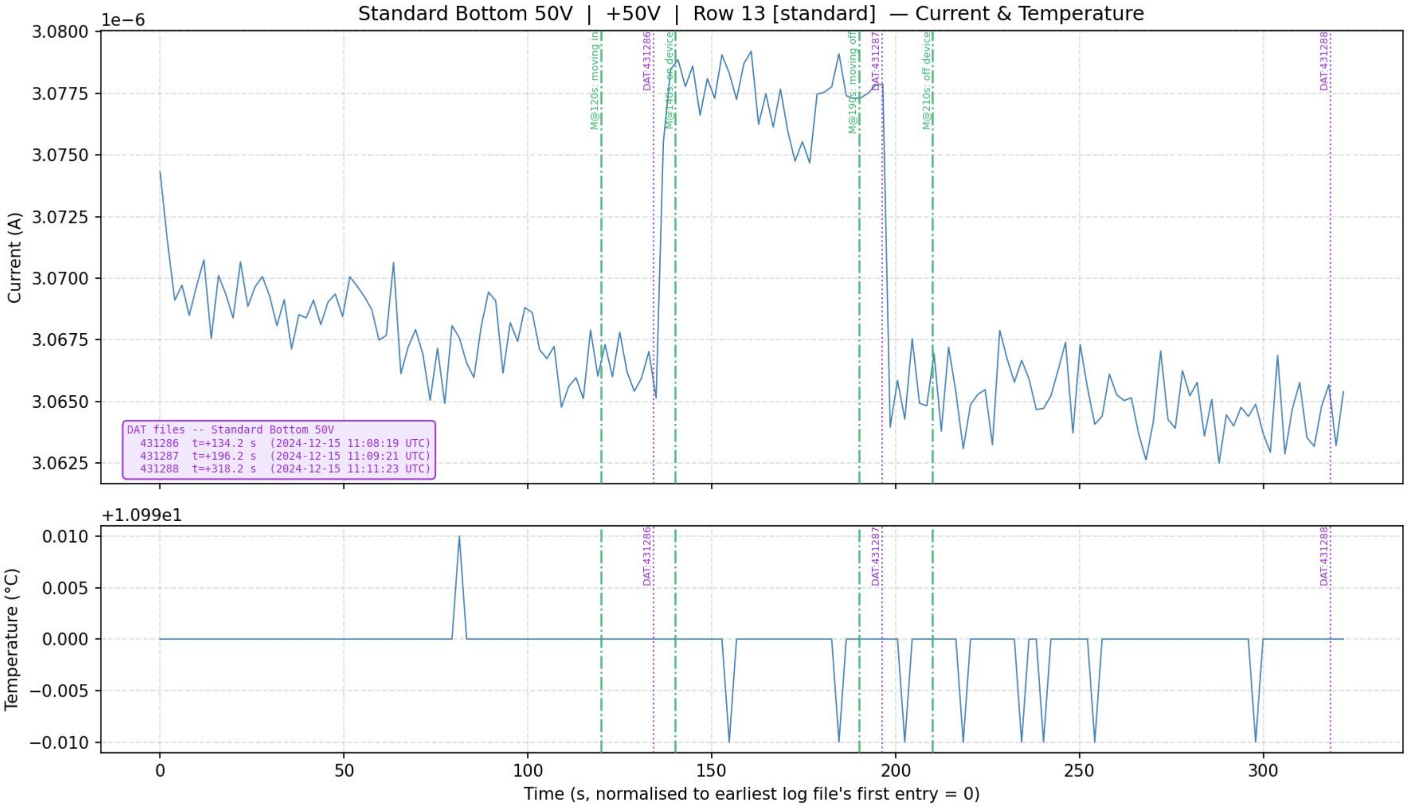
Initial Measurements

Timescale
O(5 min)

Baseline measurements of dark vs photocurrent

Stability of temperature

Locate active area/device edges

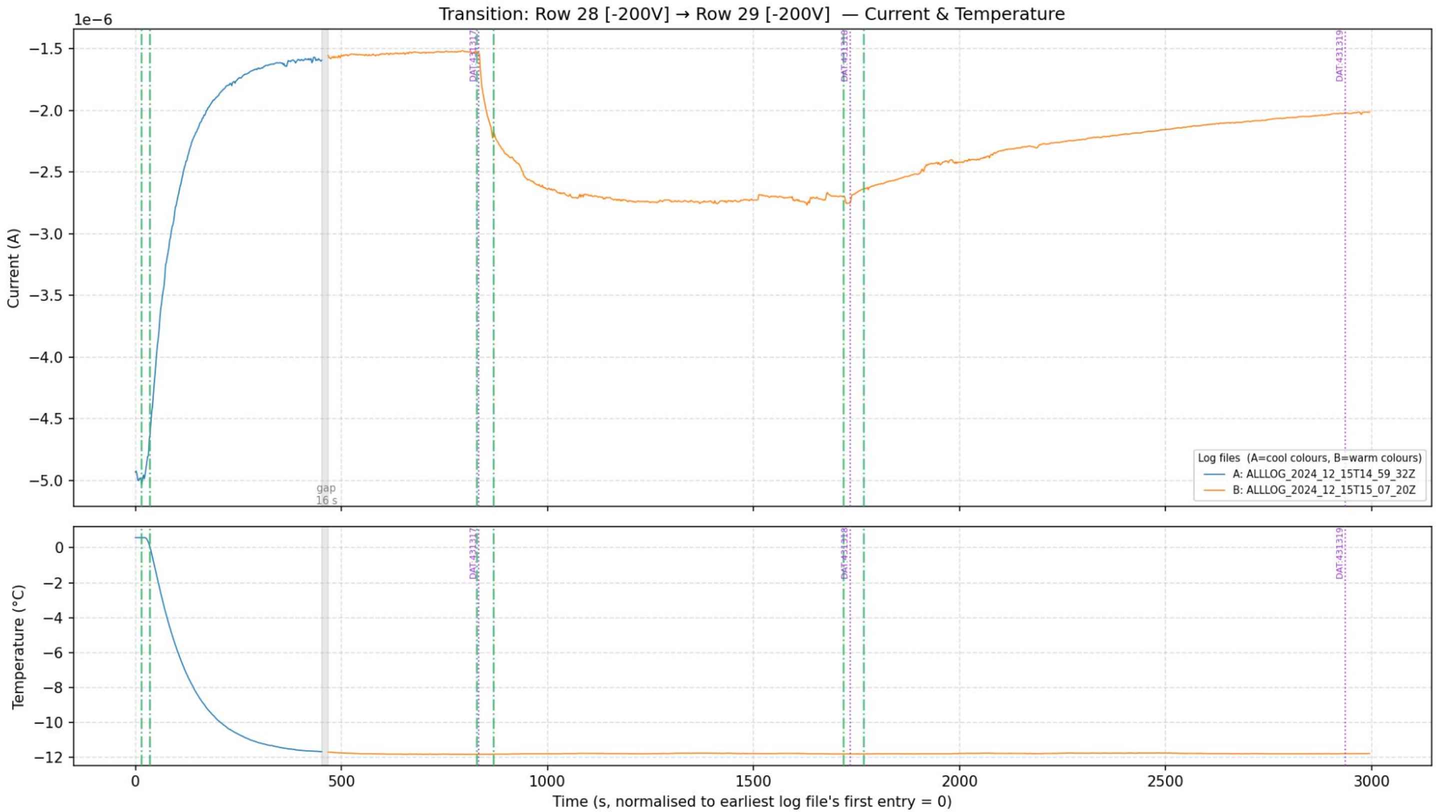


Updated Measurements - 1

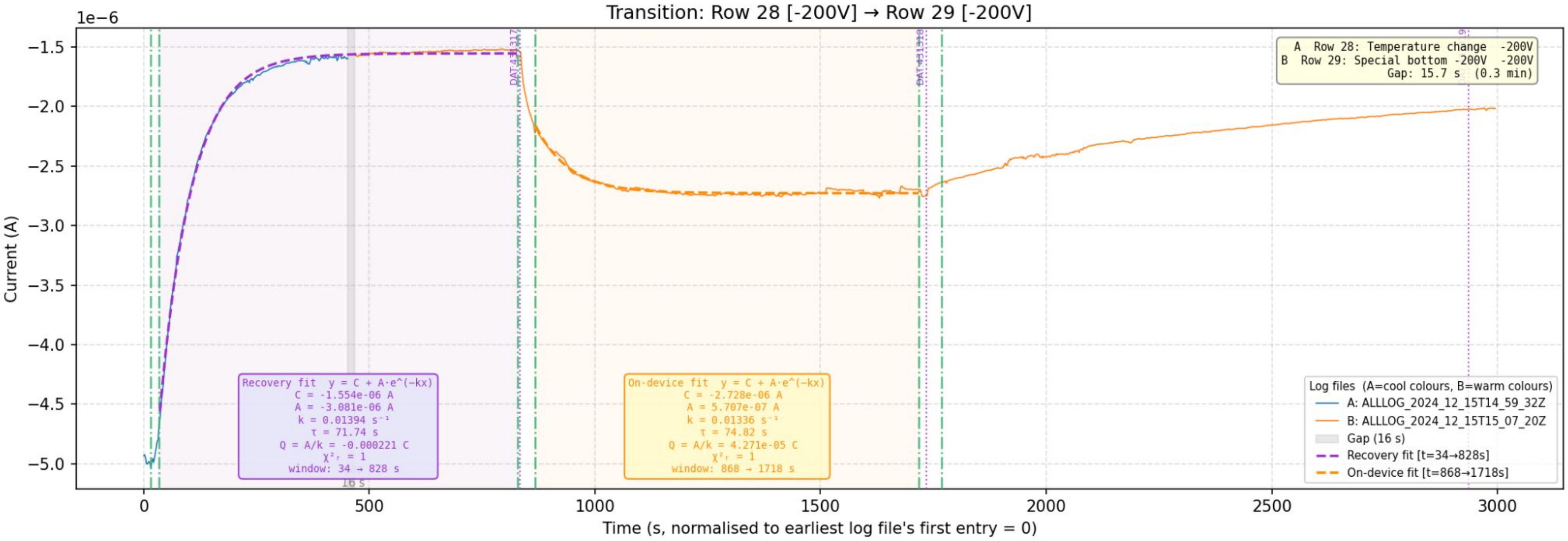
Timescale O(hours)

Effects of differences in Temperature

Observe full persistent current decay

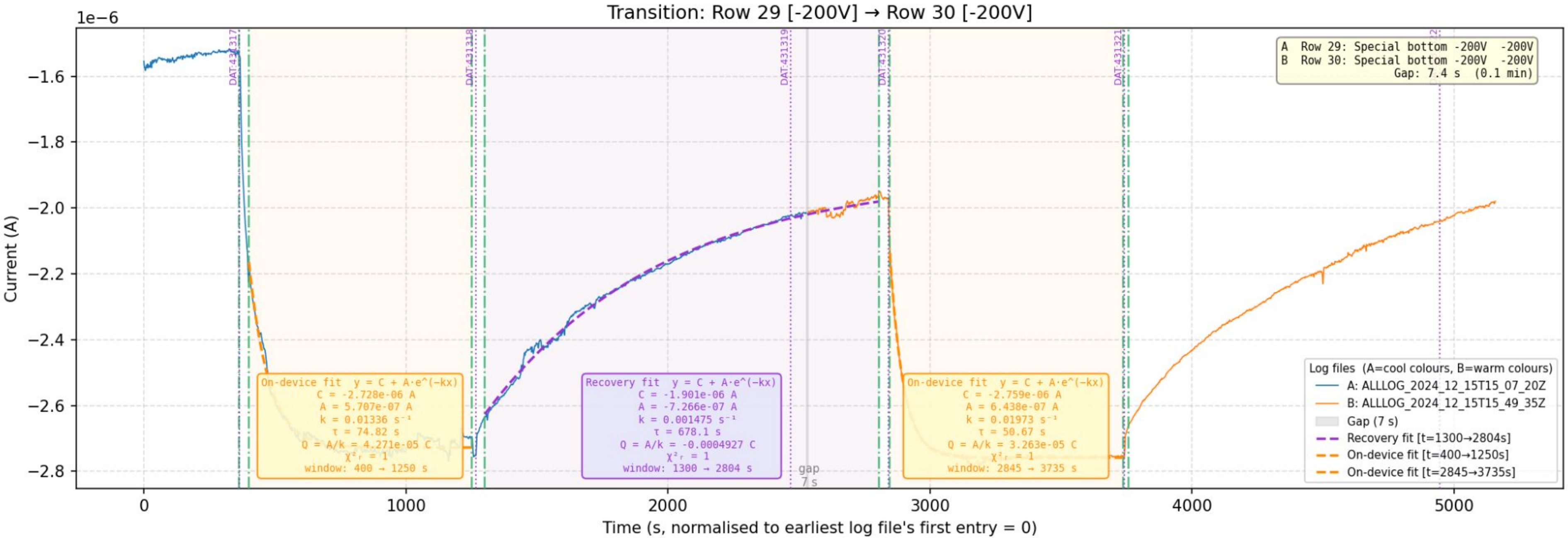


Updated Measurements - 2



Exponential fits give an interesting opportunity, as integrating current over time gives charge
Change in current → carrier concentrations –while–
time integral of current → change in trap occupancy

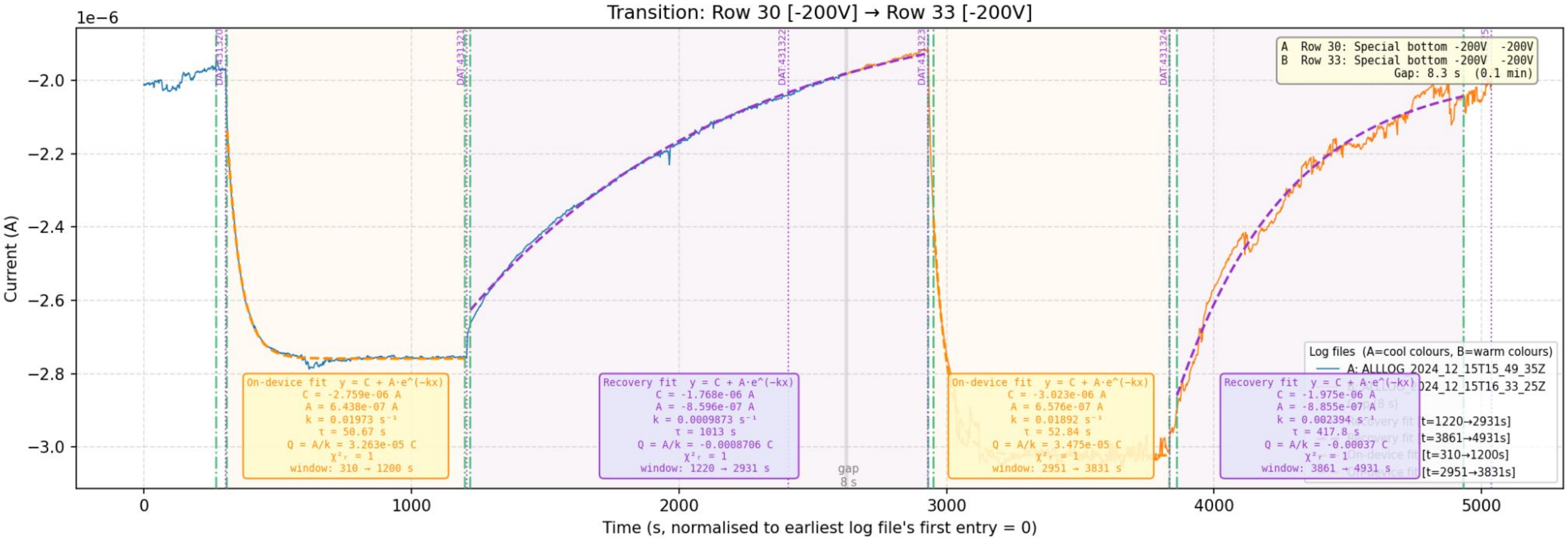
Updated Measurements - 3



Self-consistency check - given the same conditions, same fit parameters?

- For illuminated sort of? Same order of magnitude
- Check unilluminated region parameters against one another.

Updated Measurements - 4



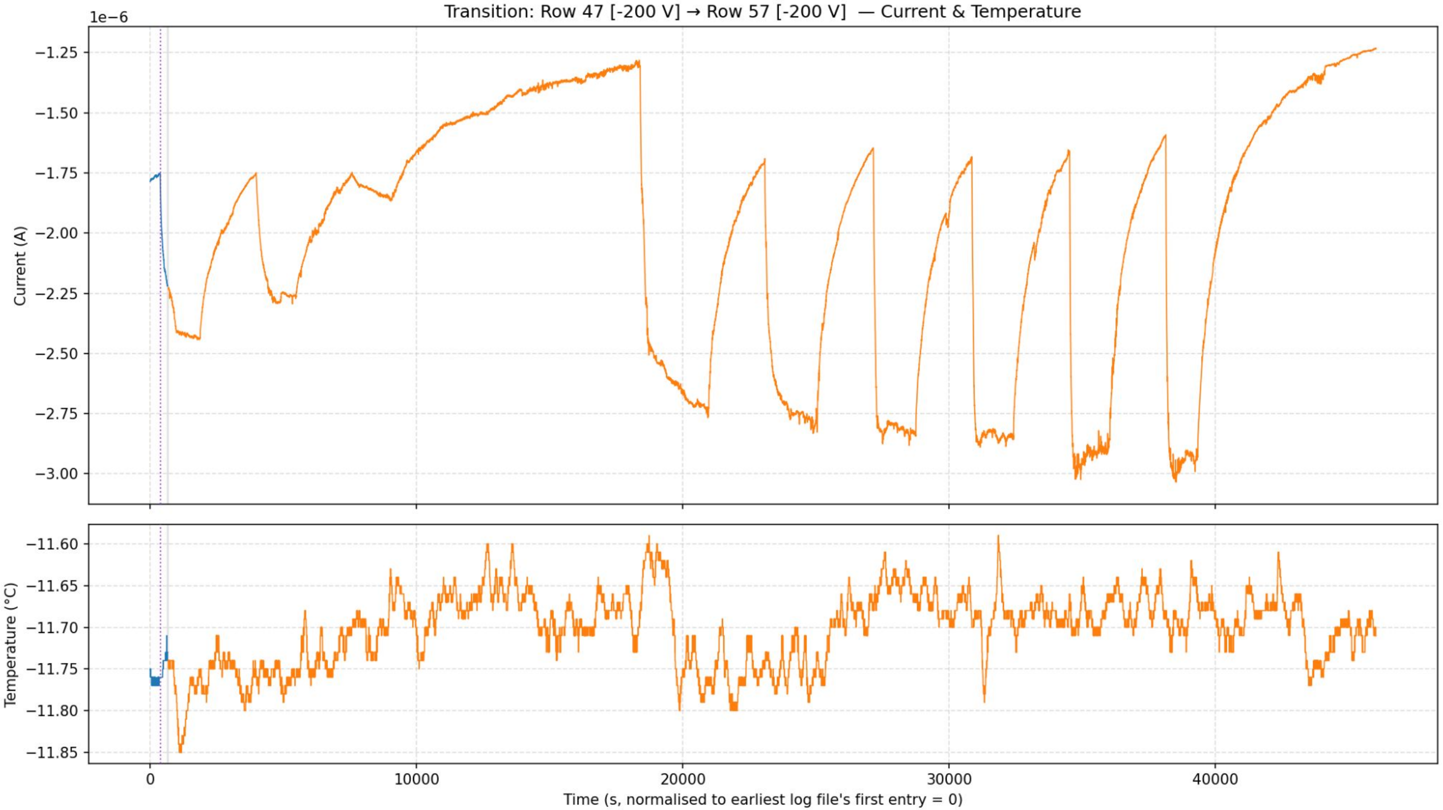
Different on-pad location between runs → beam subject to different E field → different region excited → maybe different trap filling?

Still Need to Parse…

Timescale O(day)

Multiple measurements overnight

Different flux using Aluminum sheets then
Effect of beam traversal speed on InP



Steps Going Forward

- Upload full set of plots to Drive
    - Need to parse plots to extract correlations between initial conditions and fit parameters
- Work on slides for theoretical model
    - Have general idea and written formulae
    - Dark equilibrium calculation in backup slides
    - Hope to cross-check this with Thin Film members offline before presenting better formal overview
- Connect extracted fit parameters to theoretical model

Backup

-

Dark Equilibrium Conditions

- Known Information:
  - Trap density: 1E16 cm^{-3} (manufacturer)
  - Undoped InP carrier density: 2-4E15 cm^{-3} (literature)
  - InP bandgap: 1.34 eV at 300K (literature)

    1.41 eV at 77K
  - Trap State: 0.6-0.7 eV below CB (Sungjoon)
  - Assumption: Most electrons in conduction band fall into the Fe traps (Sungjoon)
    - Conduction band almost unpopulated
    - InP:Fe is a semi-insulator - confirmed with measurements

Solid State Calculations

- Where is the Fermi level for this system?
- Using Fermi-Dirac Distribution and assumptions about InP:Fe...

$$f = \frac{1}{1+e^{\frac{E-E_F}{kT}}}$$

$$E = E_T$$

$$n_{total} = N_D^+$$

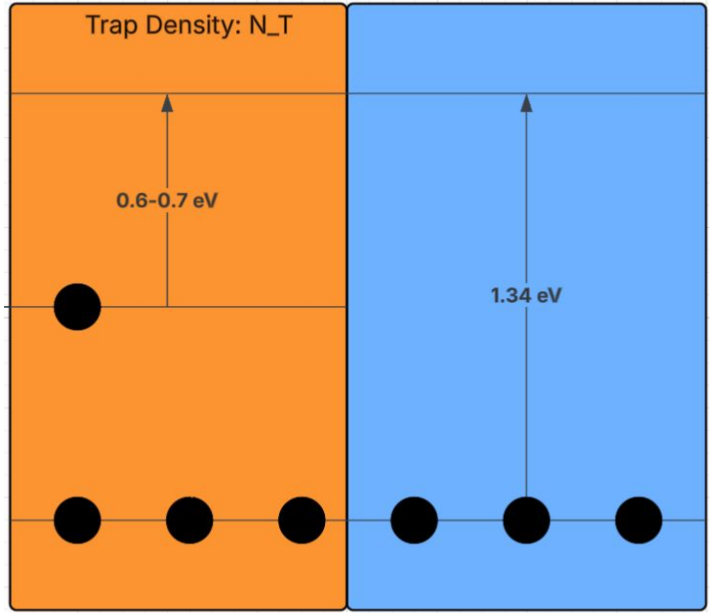
—

$$n_{total} = n_{trapped} \text{ at } 300\text{K}$$

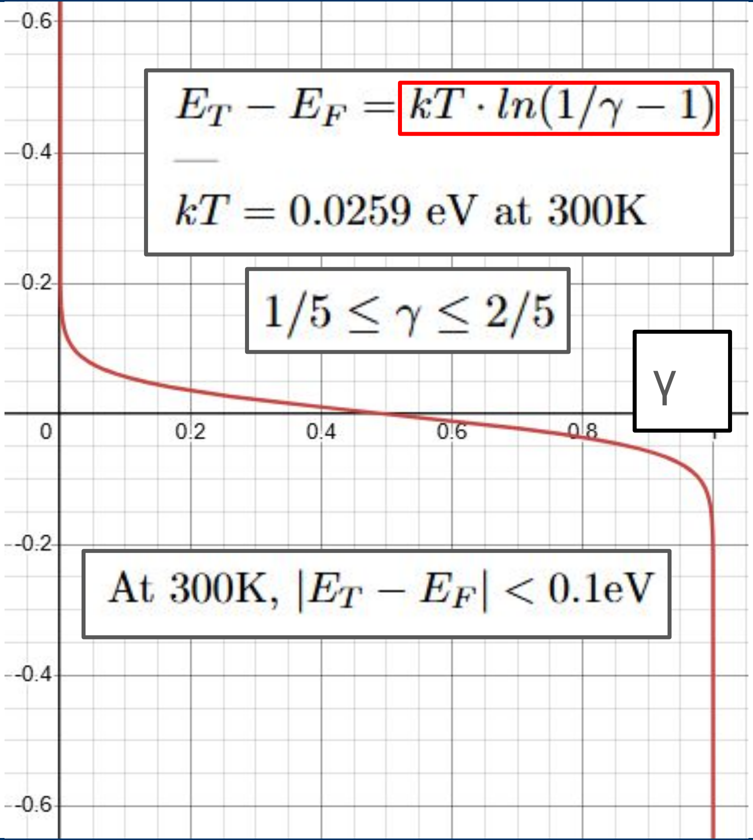
—

$$\gamma = N_D^+/N_T = n_{trapped}/N_T = f$$

$$\boxed{E_F = E_T - kT \cdot ln(1/\gamma - 1)}$$



Solid State Calculations

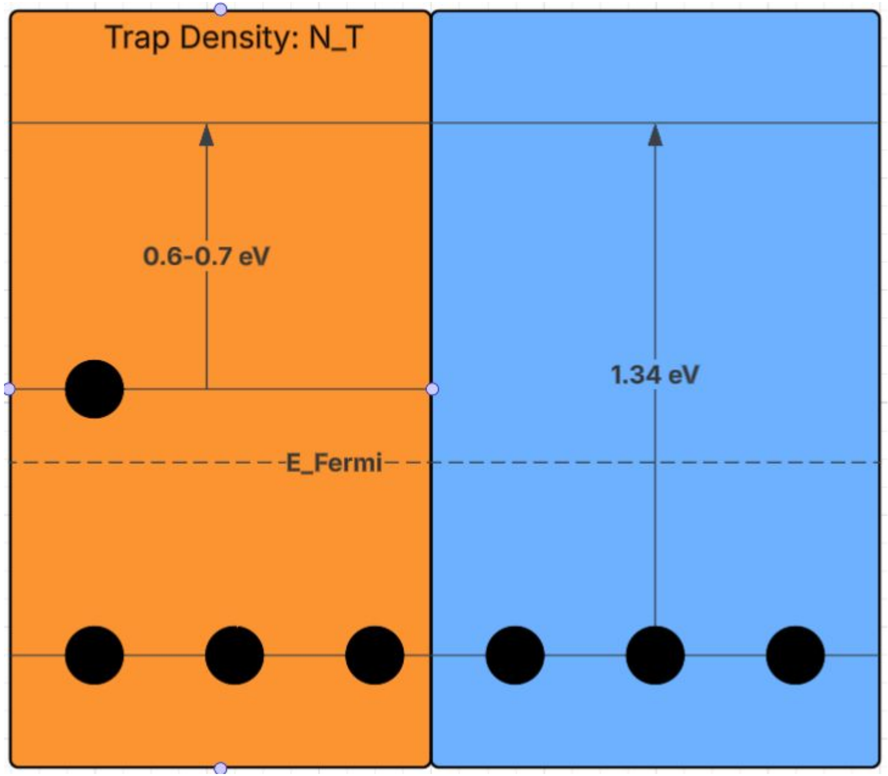


$$E_T - E_F = \boxed{kT \cdot ln(1/\gamma - 1)}$$

$$kT = 0.0259 \text{ eV at 300K}$$

$$1/5 \leq \gamma \leq 2/5$$

$$\text{At 300K, } |E_T - E_F| < 0.1\text{eV}$$



Solid State Calculations

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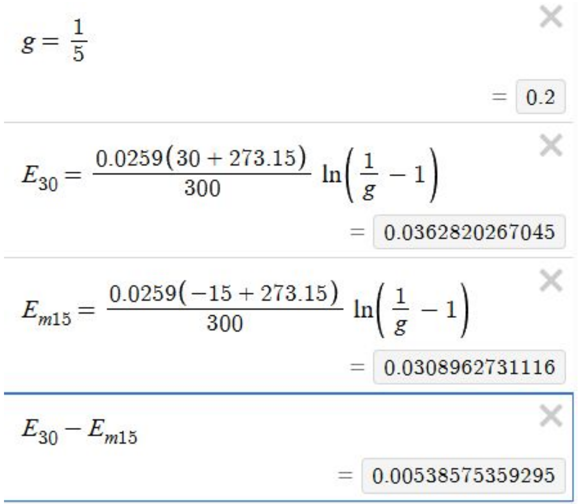


$$g = \frac{1}{5}$$

$= 0.2$

$$E_{30} = \frac{0.0259(30 + 273.15)}{300} \ln\left(\frac{1}{g} - 1\right)$$

$= 0.0362820267045$

$$E_{m15} = \frac{0.0259(-15 + 273.15)}{300} \ln\left(\frac{1}{g} - 1\right)$$

$= 0.0308962731116$

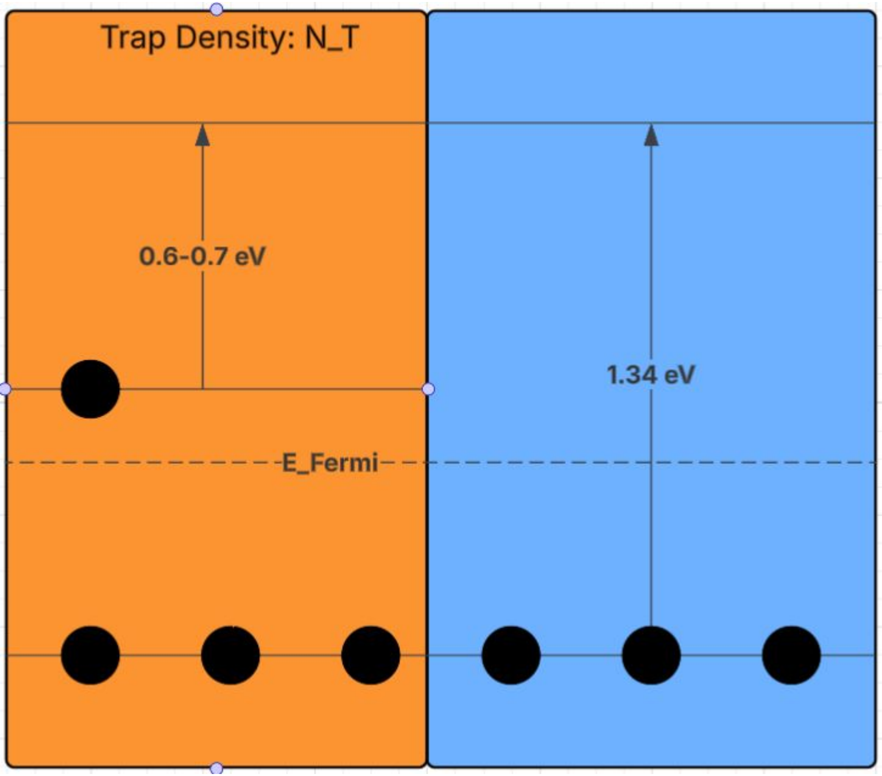
$$E_{30} - E_{m15}$$

$= 0.00538575359295$

30C

-15C

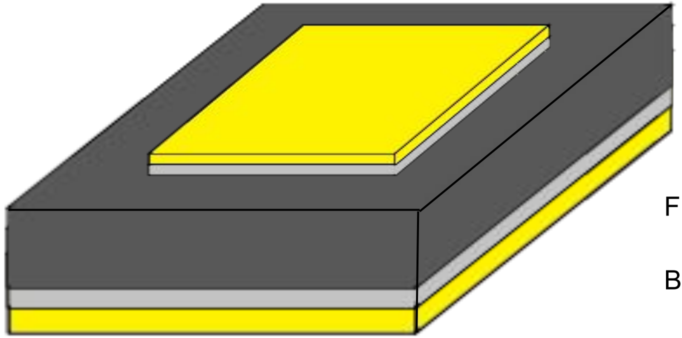
ΔE_F from temp change = ~0.005 eV



Theoretical Model

- From TCT measurements, holes do not traverse the bulk fully compared to electrons
  - Assumption 1: Could be explained by fast hole trapping by Fe traps. Assume hole trapping rate > hole emission
    - Implication: holes release could be responsible for persistent current
- Strategy:
  - Identify approximate steady states with and without illumination
  - Identify mechanisms for transitioning from with to without illumination and their approximate timescales
    - Calculate roughly the timescale for this transition
    - Dependence on this model on measurable/known quantities
      - Bandgap, trap energy, total integrated charge, characteristic time for persistent current, etc.

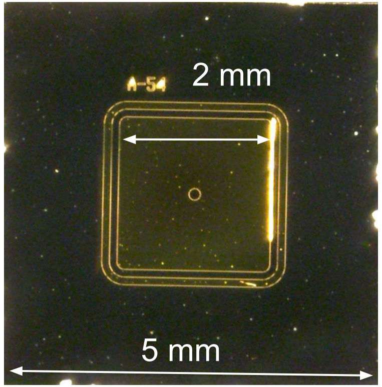
Fabricated Device Structure

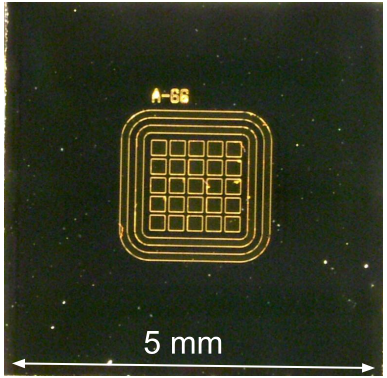


Gold	**(100 nm)**
Chromium	**(10 nm)**
InP:Fe	**(350 µm)**
Chromium	**(10nm)**
Gold	**(100 nm)**

Frontside: e-beam metal deposition

Backside: sputter





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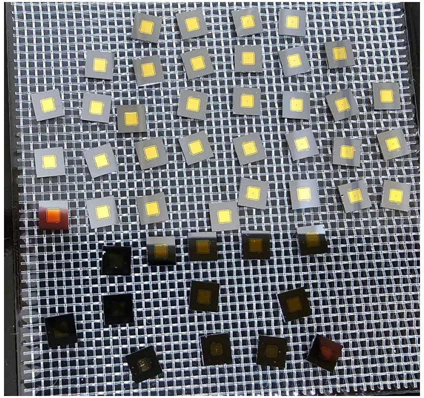
- 2nd iteration of devices
- Check properties with Crystalline InP
  - Commercially Available
  - Test properties with crystalline wafers as a benchmark for thin film devices, whether they be amorphous or crystalline

Device Size = 5 x 5 mm^2
Pads = 2 x 2 mm^2
Guard Rings = 100 µm
GR Spacing = 100 µm
Hole Diameter = 150 µm
Multipad Pads = 200 x 200 µm^2



X-ray Parameters

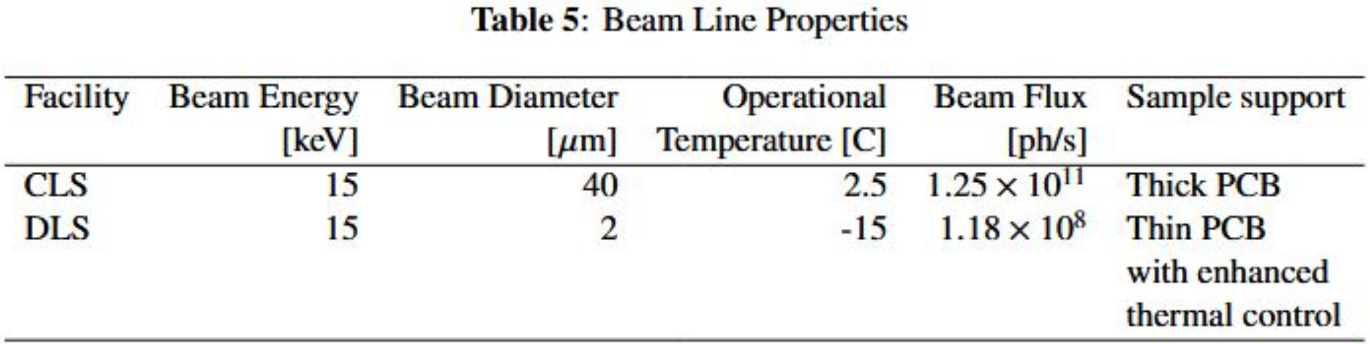


Table 5: Beam Line Properties

Facility	Beam Energy [keV]	Beam Diameter [μm]	Operational Temperature [C]	Beam Flux [ph/s]	Sample support
CLS	15	40	2.5	1.25×10^{11}	Thick PCB
DLS	15	2	-15	1.18×10^{8}	Thin PCB with enhanced thermal control