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UNIVERSITY of HAWAI'I at MĀNOA

Contributions to HEP Thin Films

Richville Fagaragan

Outline

1. Gaussian Trap Distribution Model for InP:Fe
2. IV curves with temperature dependency
3. Geant4 with CLS and DLS Beam Information
4. Geant4 CLS and DLS Profiles into TCAD using Optical Generation Module
5. Arrhenius Plots for the IV Temperature Dependency Curves using Geant4 Energy Deposition Profiles for CLS and DLS Profiles



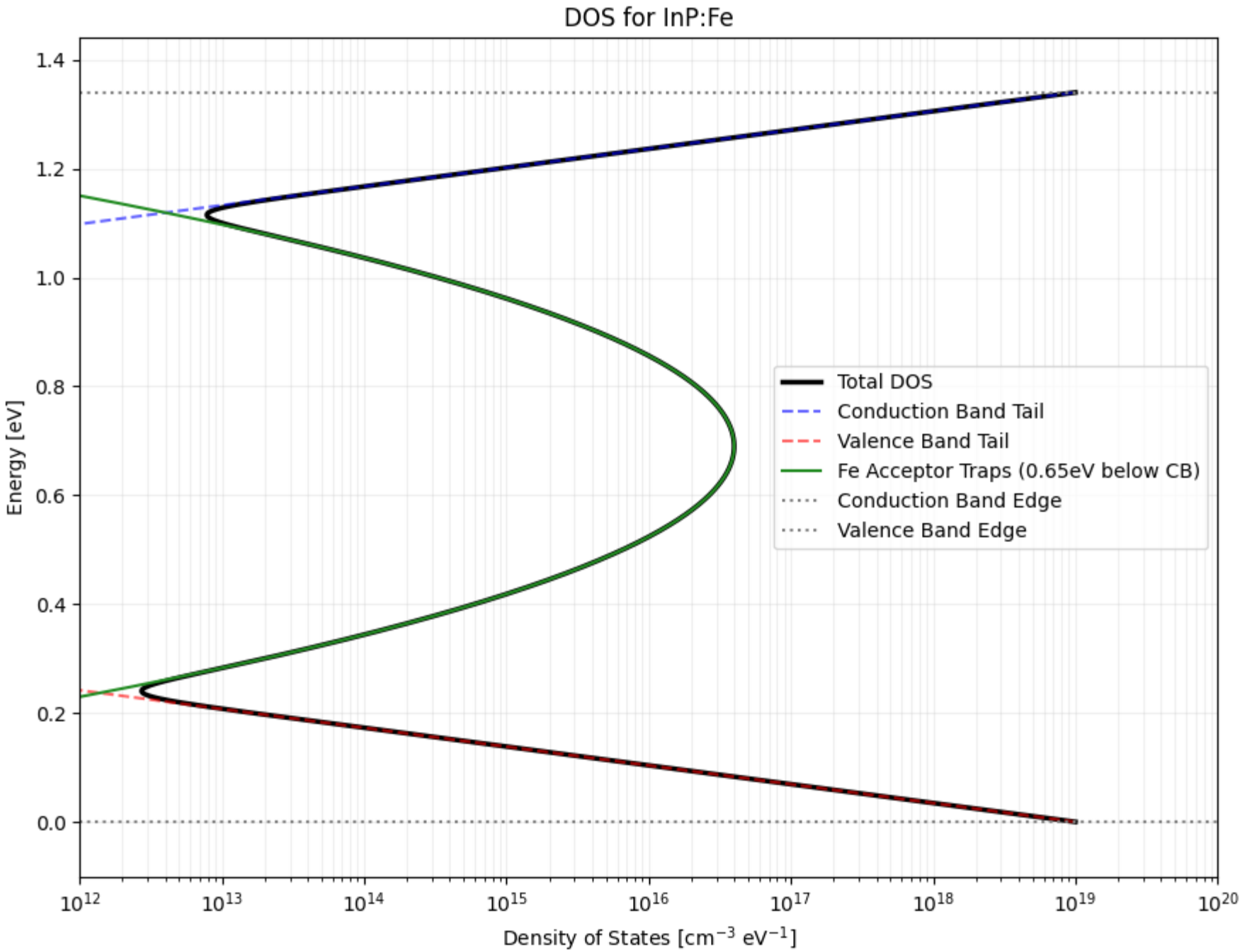


Gaussian Trap Distribution Model for InP:Fe

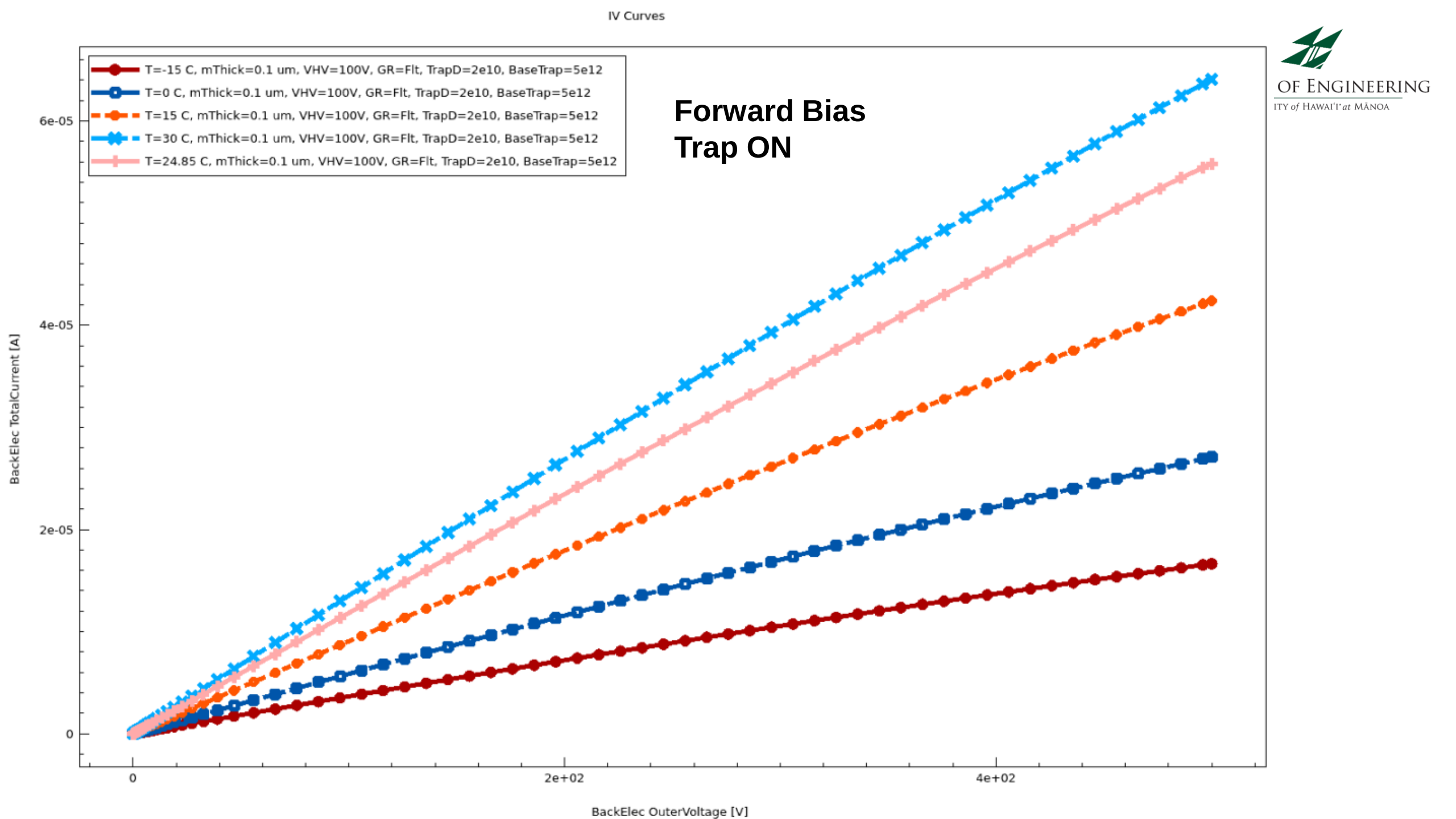
Trap Distribution Model

- 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

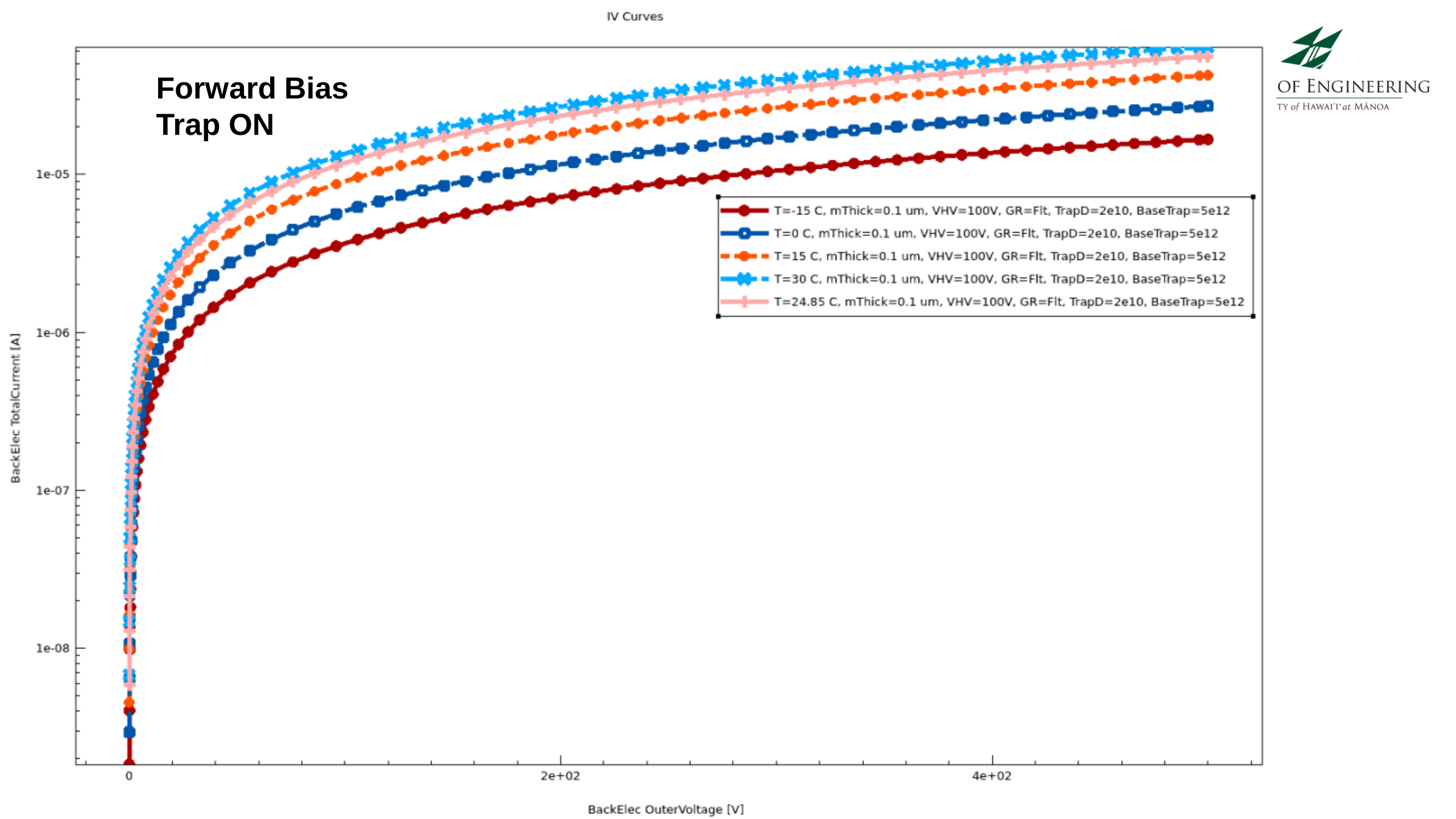
```
Traps (
(Acceptor Gaussian
  Conc            = 1e16
  FromConductionBand
  EnergyMid       = 0.65   # 0.6-0.7 eV below CB
  EnergySigma     = 0.1
  eXsection       = 1e-15
  hXsection       = 1e-14)
)
```


DOS for InP:Fe
Energy [eV]
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
10^{12}
10^{13}
10^{14}
10^{15}
10^{16}
10^{17}
10^{18}
10^{19}
10^{20}
Density of States [cm^{-3} eV^{-1}]
Total DOS
Conduction Band Tail
Valence Band Tail
Fe Acceptor Traps (0.65eV below CB)
Conduction Band Edge
Valence Band Edge

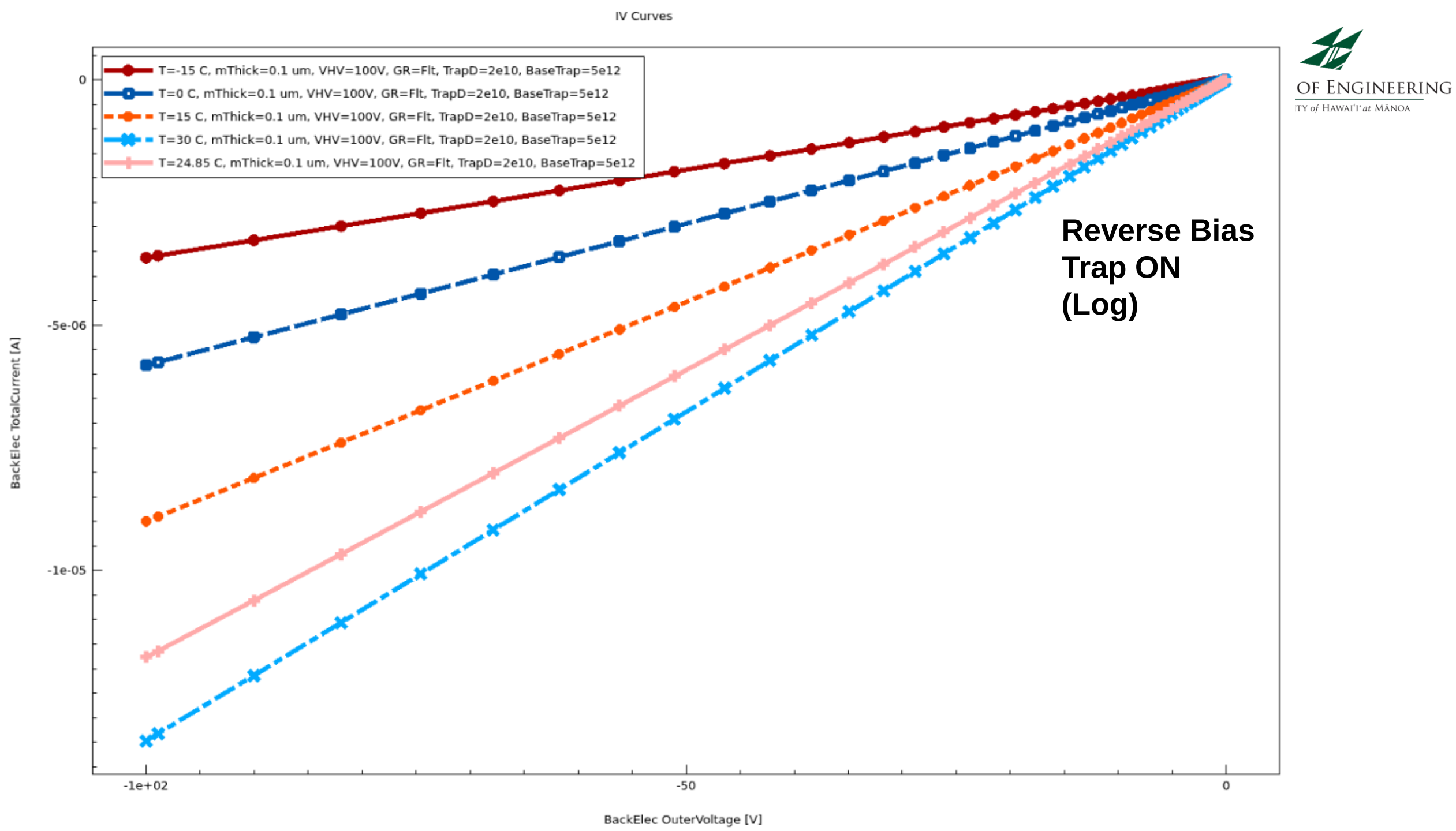
IV Curves with Temperature Dependency



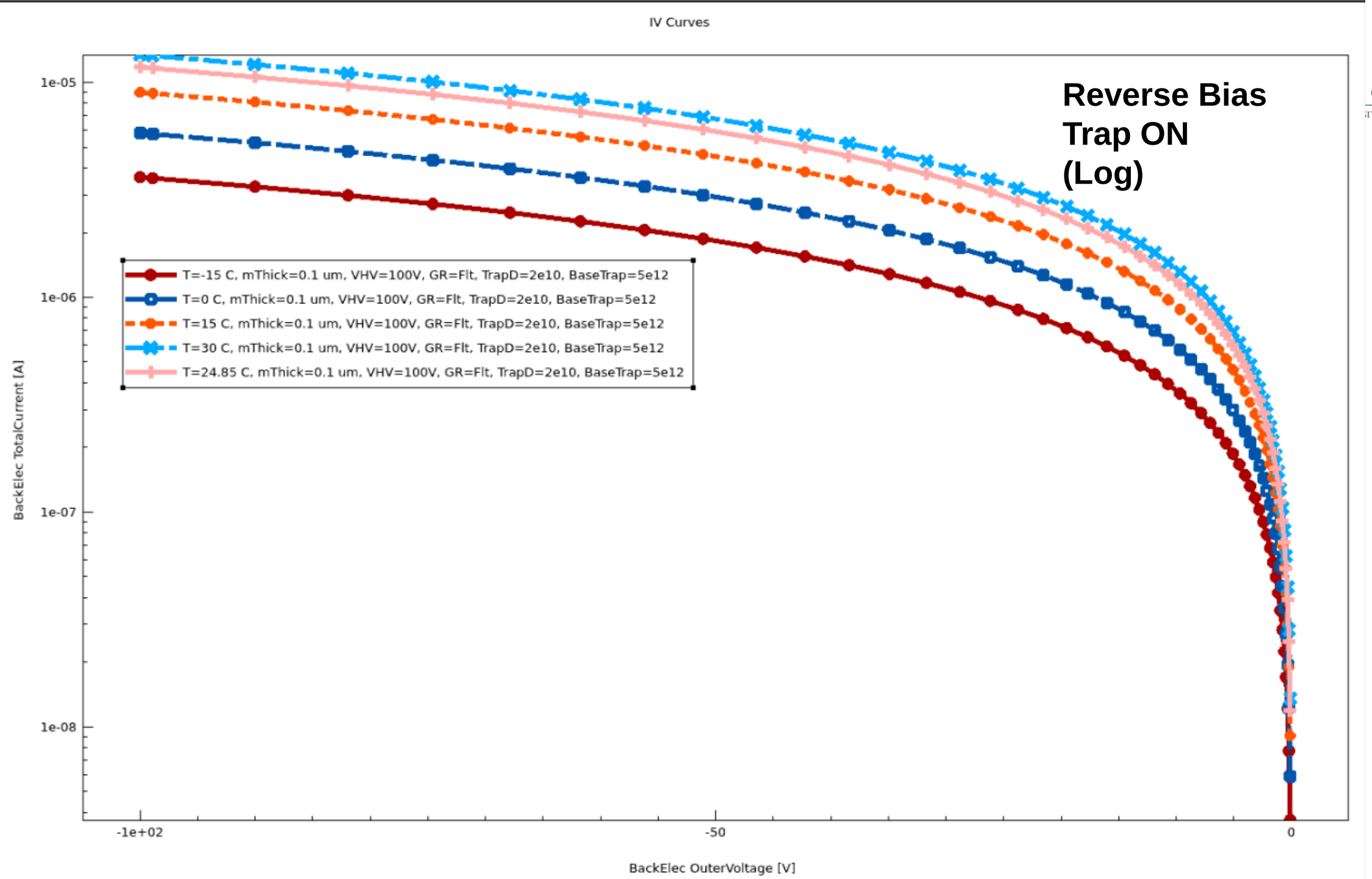
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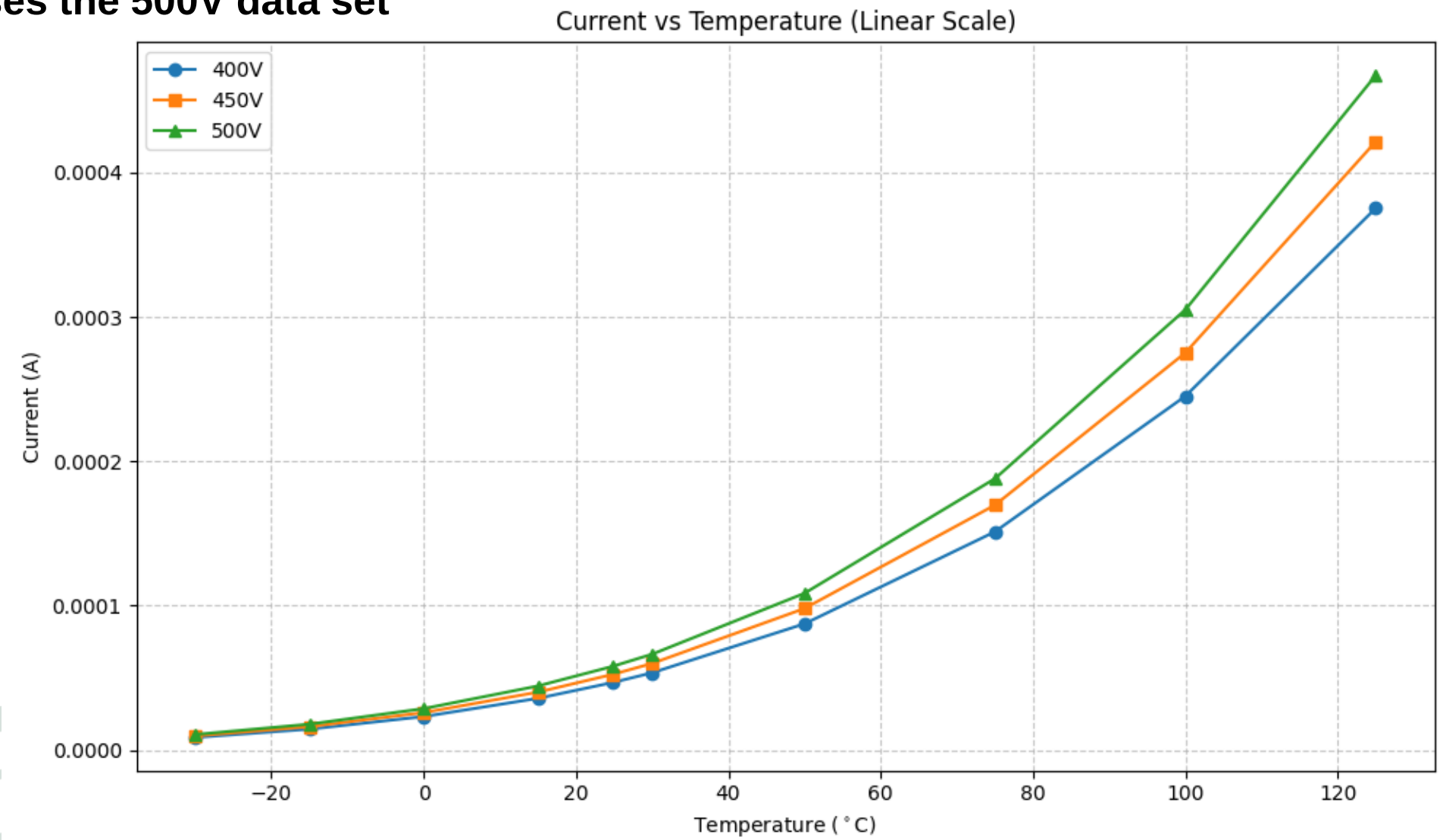
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Current vs Temperature (Forward Bias)

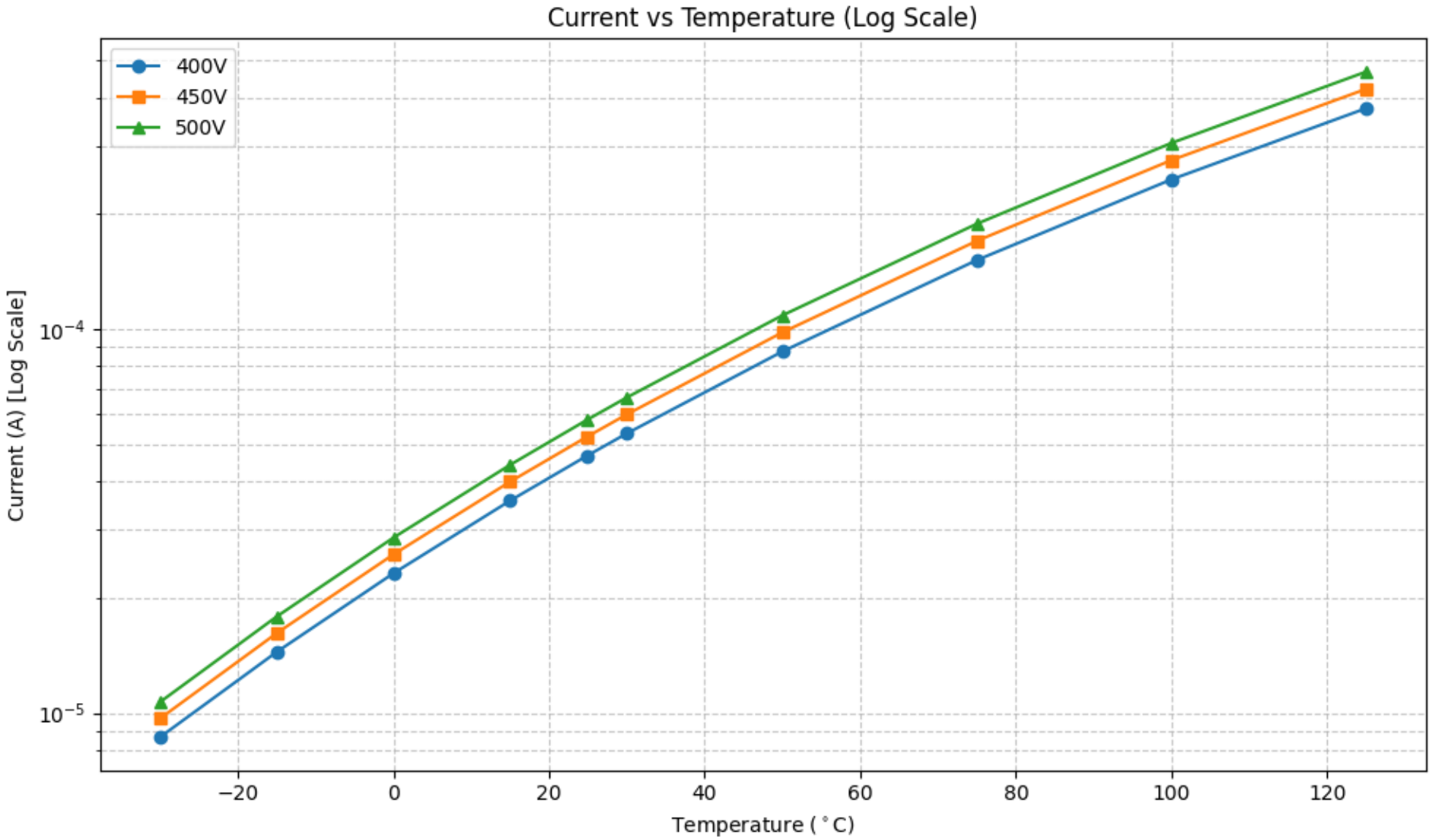
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Uses the 500V data set



Current vs Temperature (Forward Bias) [Log Scale]

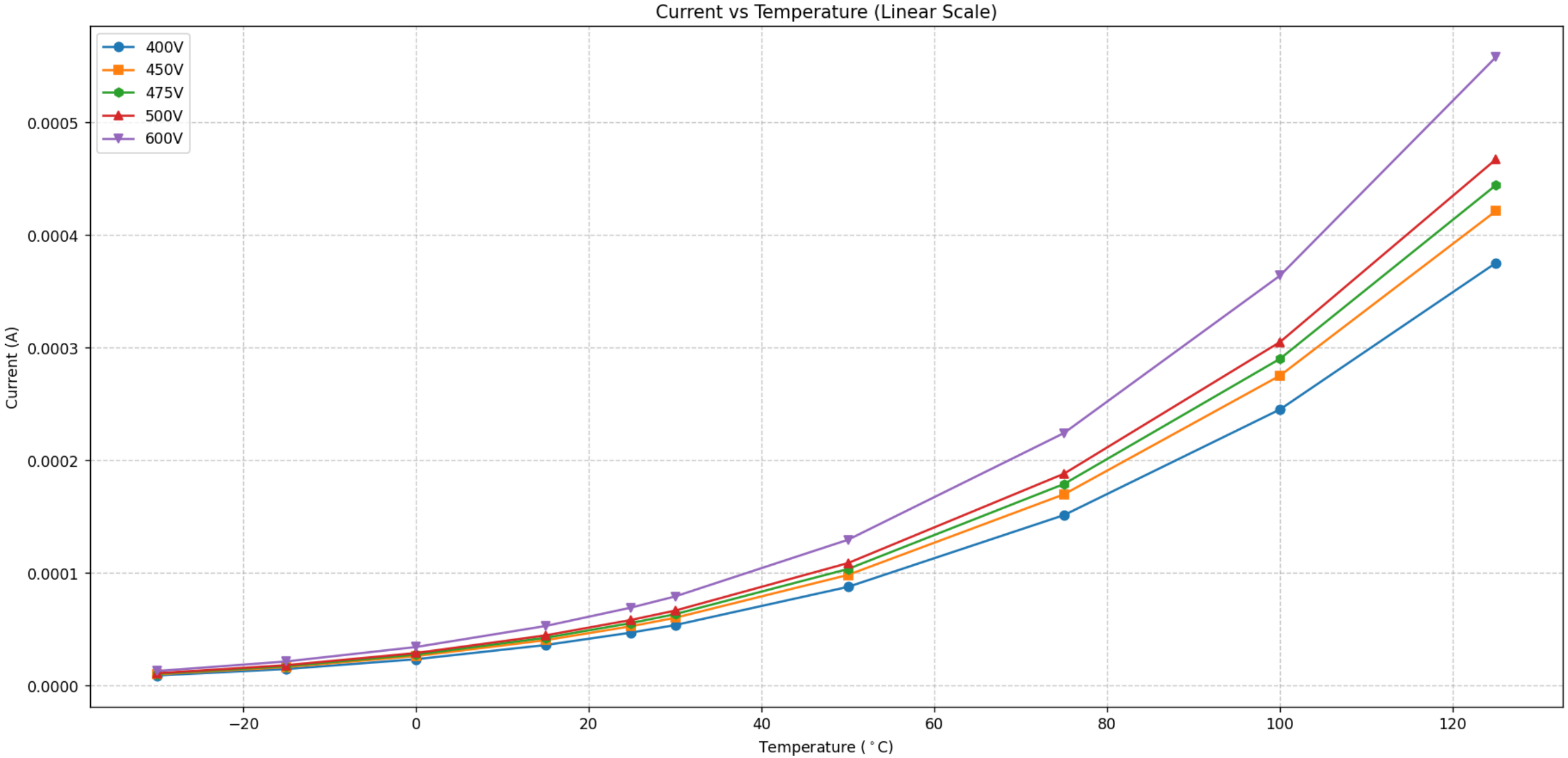
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Current vs Temperature (Forward Bias)

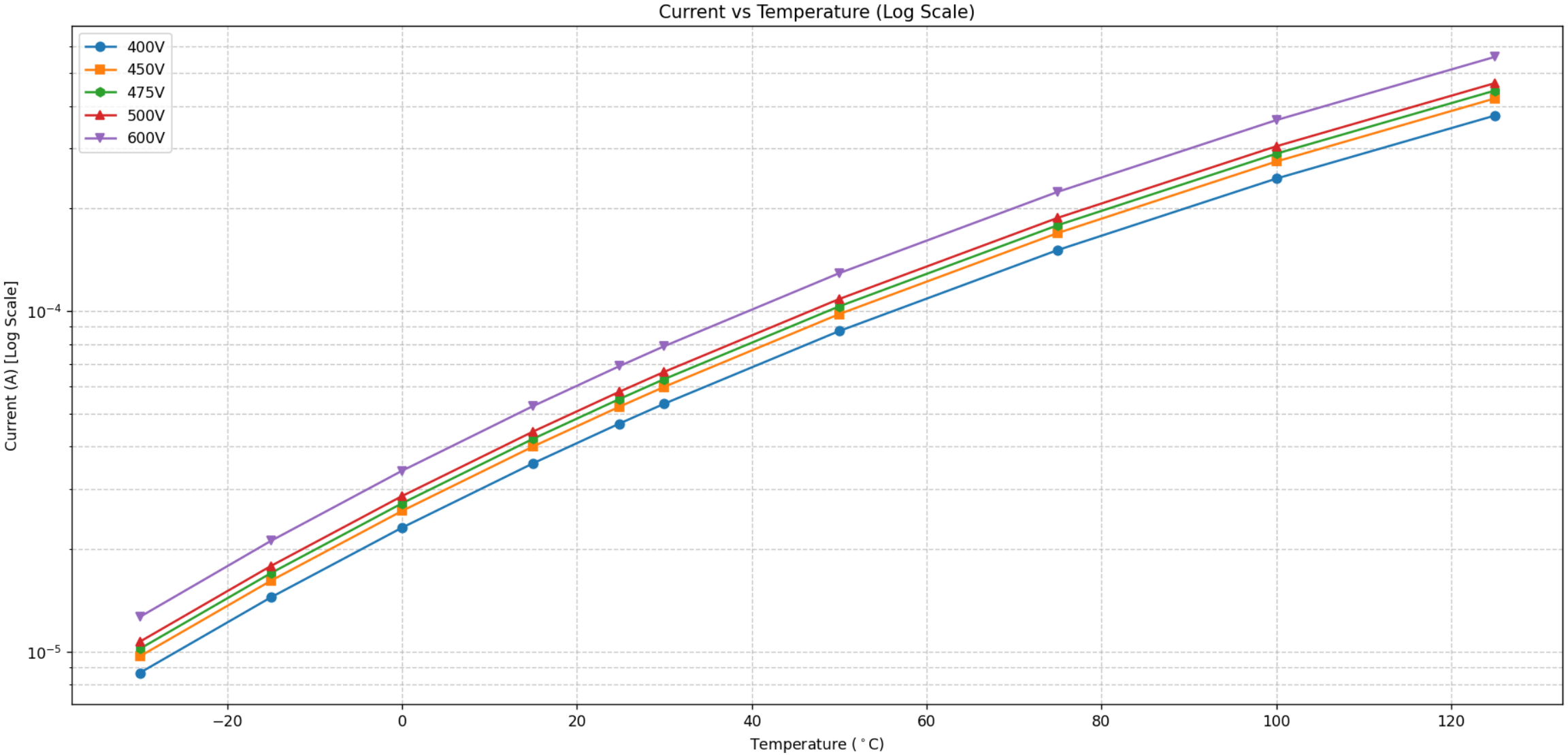
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Uses the 600V data set

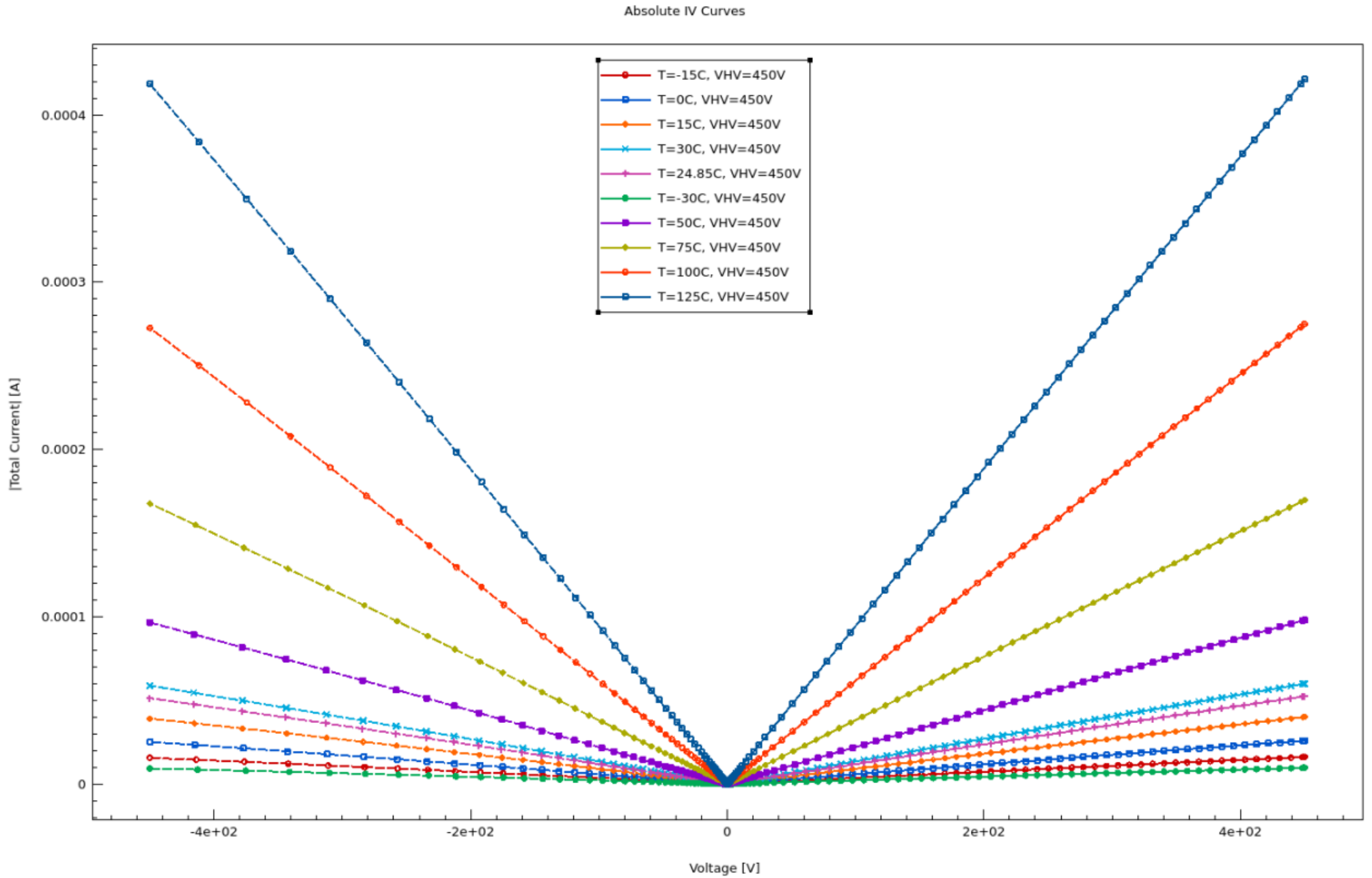


Current vs Temperature (Forward Bias) [Log Scale]

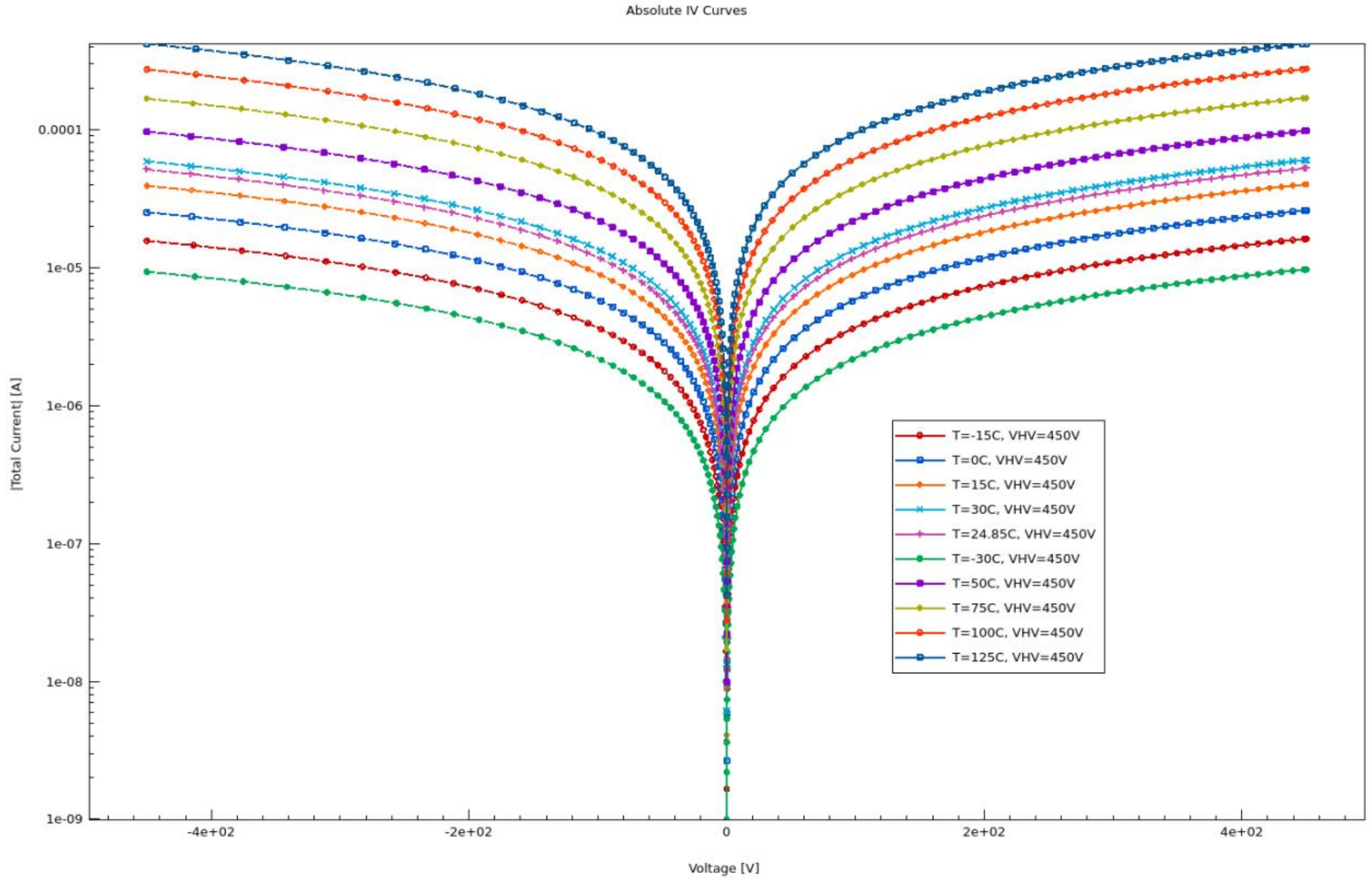
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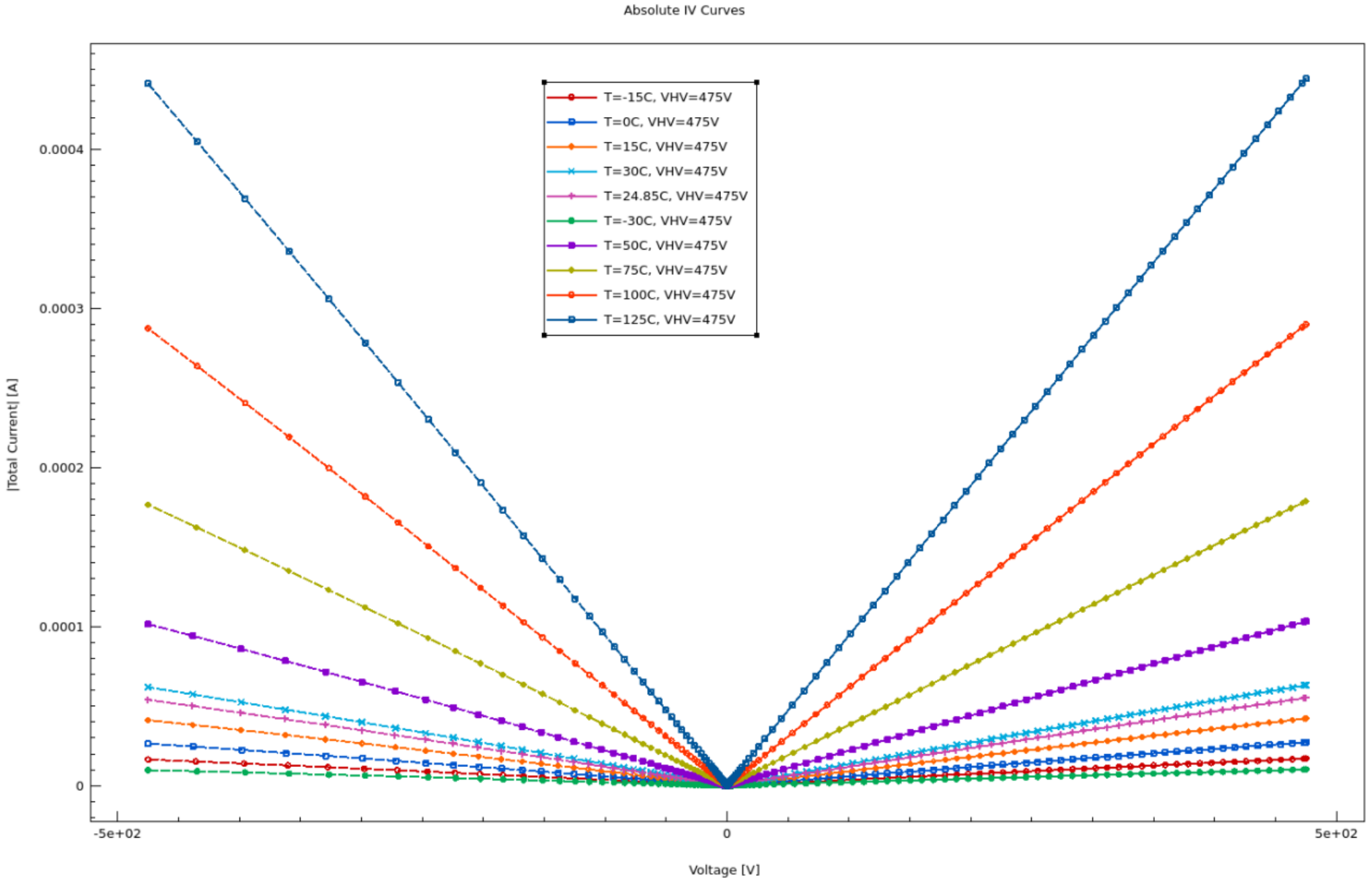
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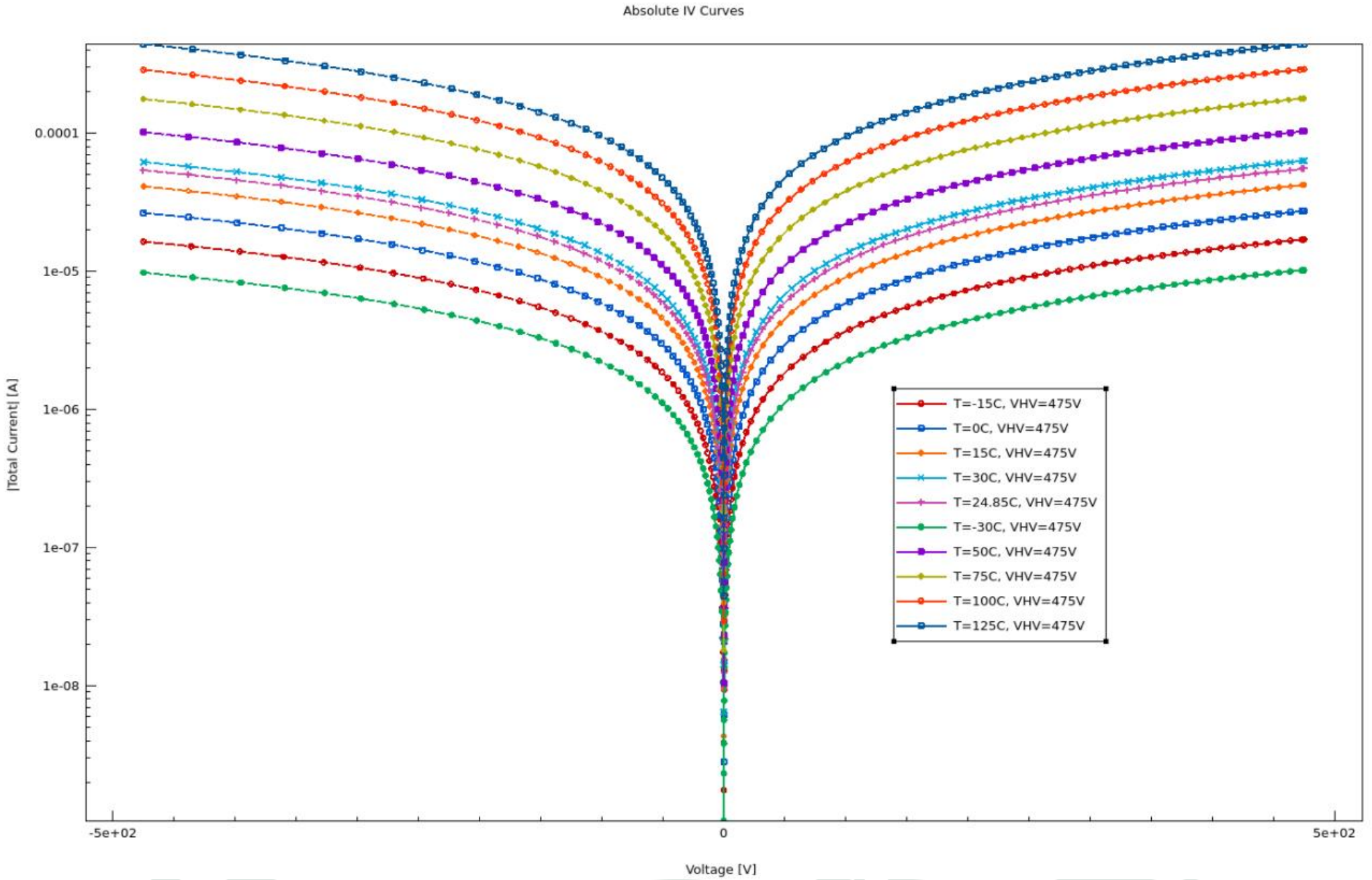
Linear


Absolute IV Curves
[Total Current] [A]
0.0001
1e-05
1e-06
1e-07
1e-08
1e-09
-4e+02
-2e+02
0
2e+02
4e+02
Voltage [V]
T=-15C, VHV=450V
T=0C, VHV=450V
T=15C, VHV=450V
T=30C, VHV=450V
T=24.85C, VHV=450V
T=-30C, VHV=450V
T=50C, VHV=450V
T=75C, VHV=450V
T=100C, VHV=450V
T=125C, VHV=450V

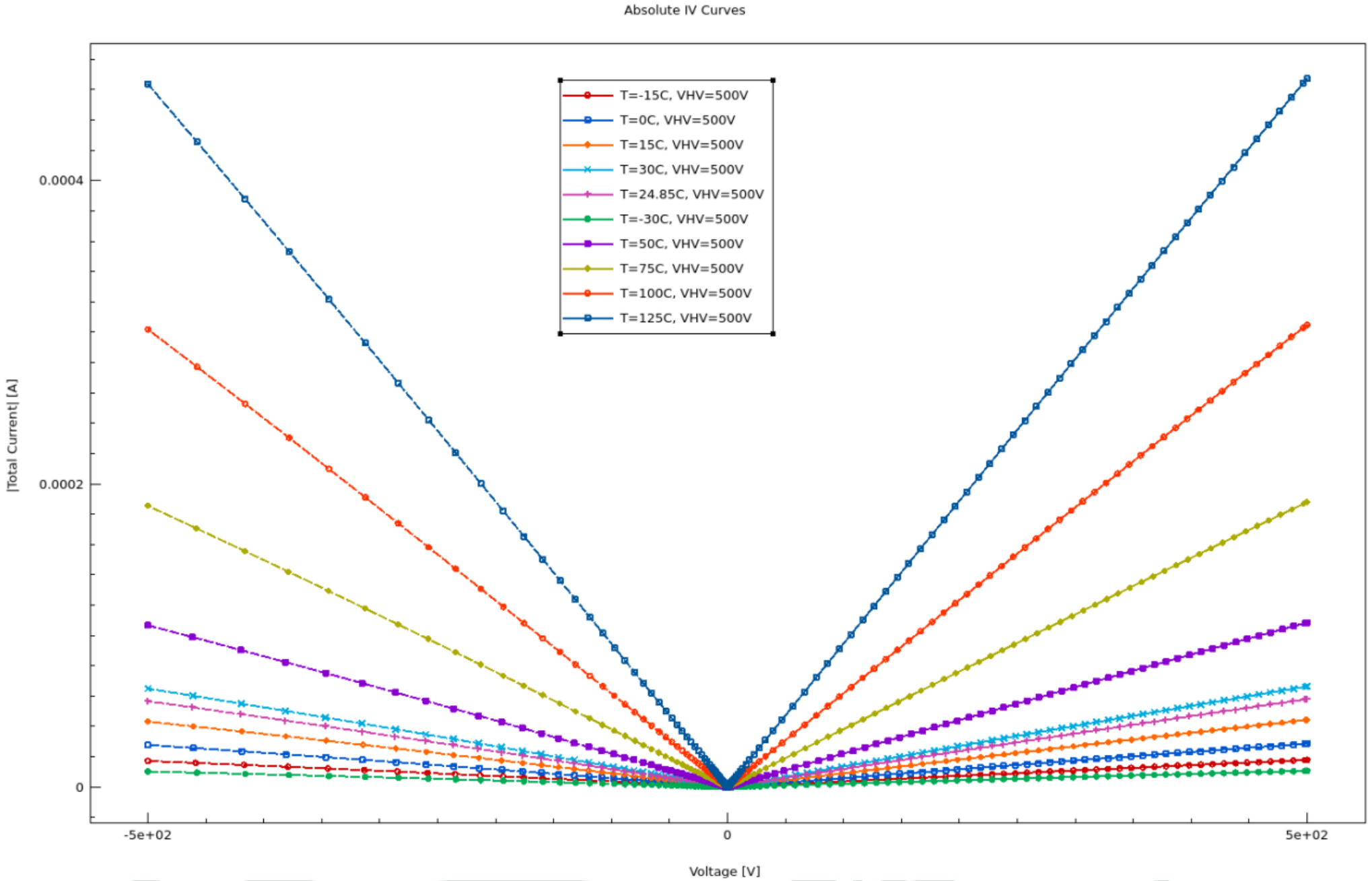
Log


Absolute IV Curves
T=-15C, VHV=475V
T=0C, VHV=475V
T=15C, VHV=475V
T=30C, VHV=475V
T=24.85C, VHV=475V
T=-30C, VHV=475V
T=50C, VHV=475V
T=75C, VHV=475V
T=100C, VHV=475V
T=125C, VHV=475V
|Total Current| [A]
0.0004
0.0003
0.0002
0.0001
0
-5e+02
0
5e+02
Voltage [V]

Linear

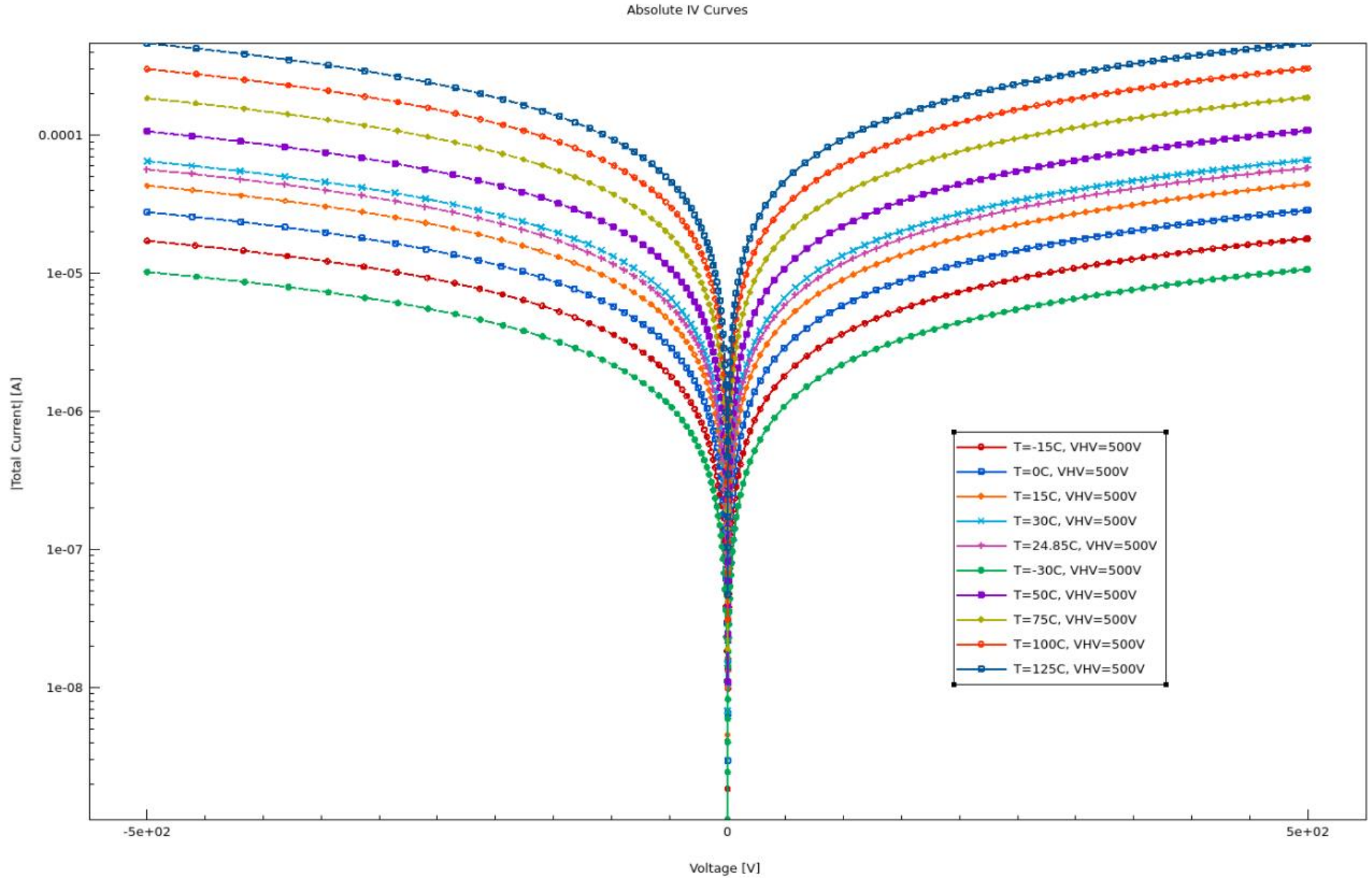

Absolute IV Curves
0.0001
1e-05
1e-06
1e-07
1e-08
|Total Current| [A]
-5e+02
0
5e+02
Voltage [V]
T=-15C, VHV=475V
T=0C, VHV=475V
T=15C, VHV=475V
T=30C, VHV=475V
T=24.85C, VHV=475V
T=-30C, VHV=475V
T=50C, VHV=475V
T=75C, VHV=475V
T=100C, VHV=475V
T=125C, VHV=475V

Log

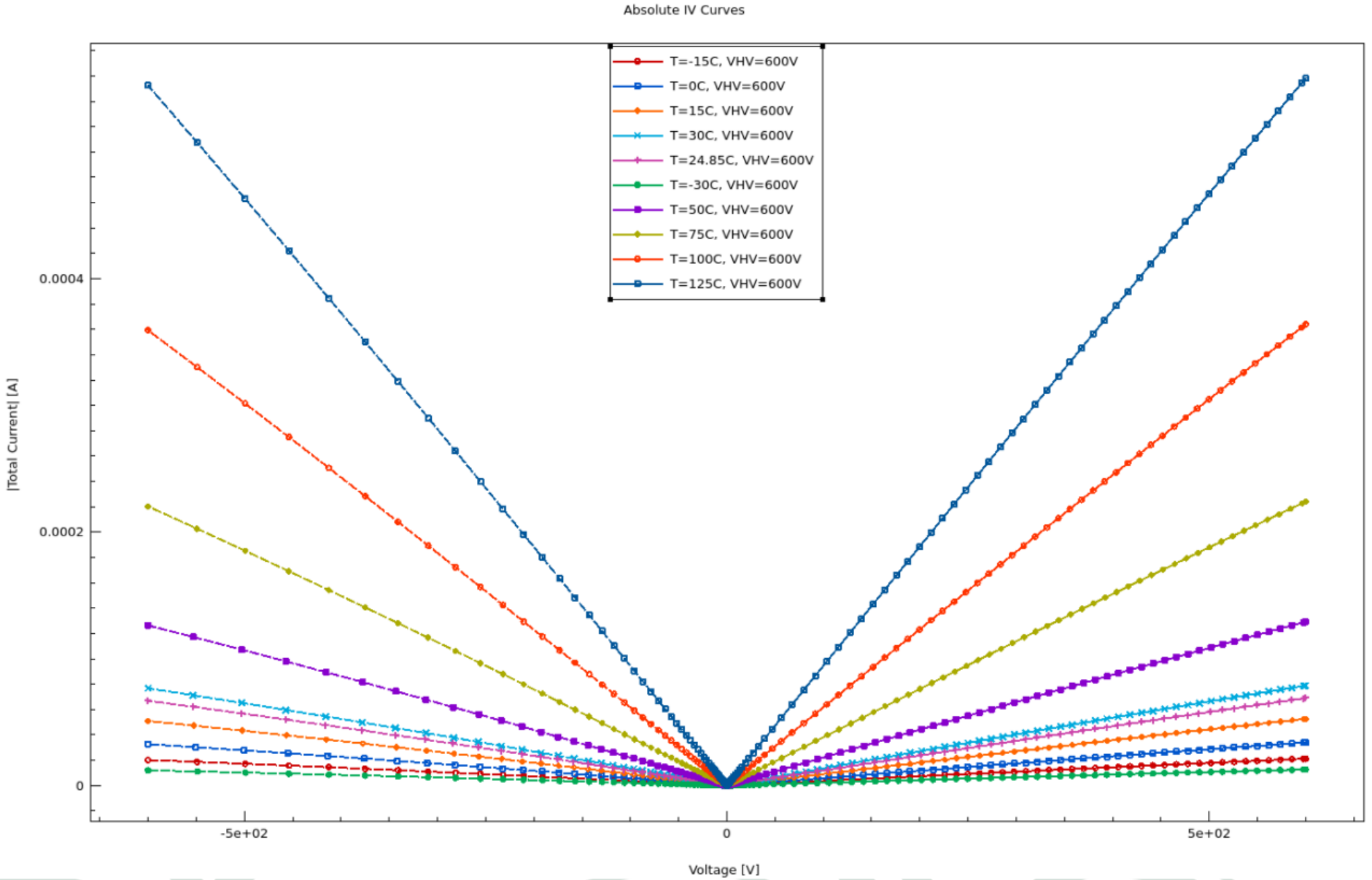


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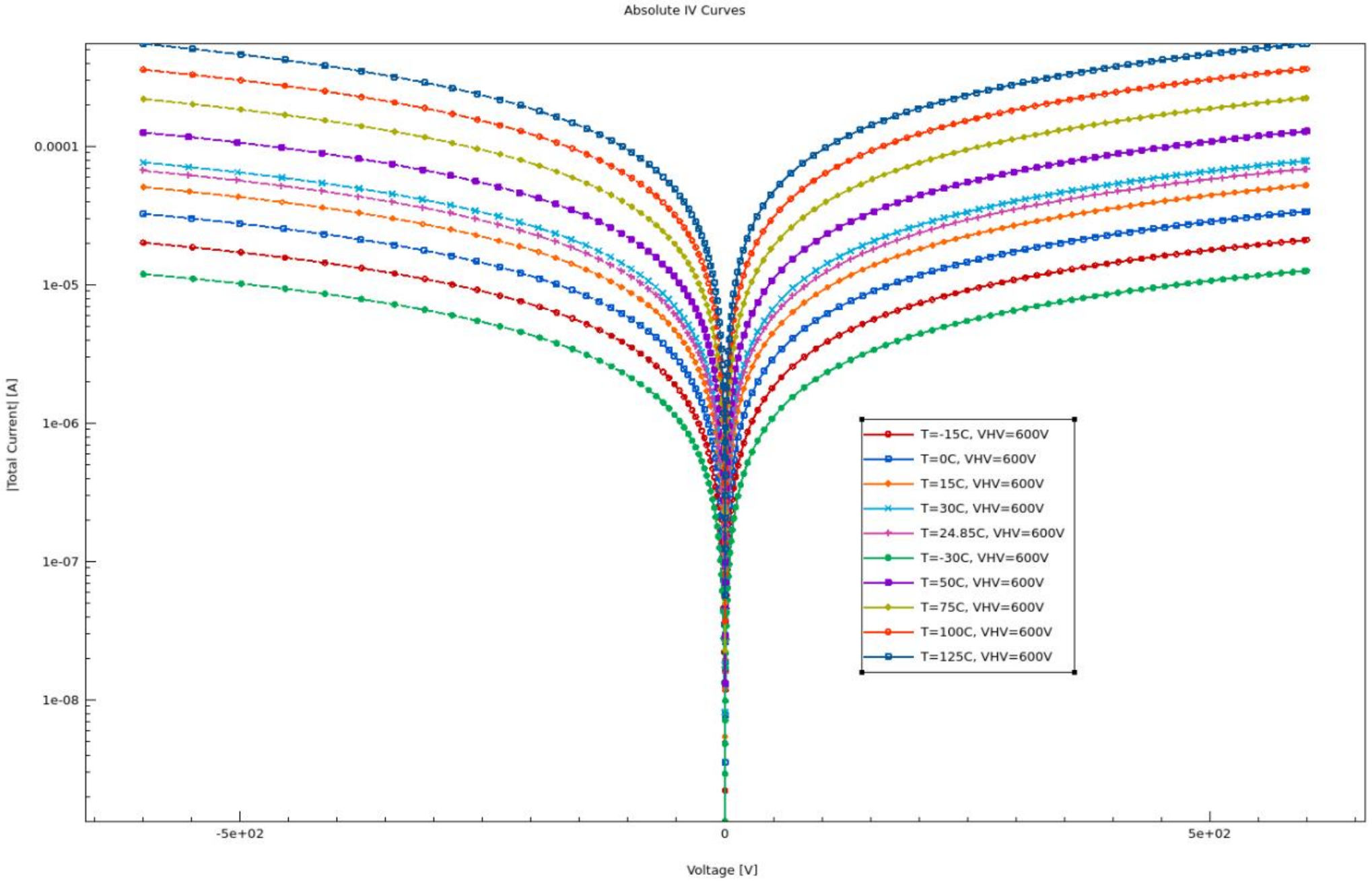
Linear


Absolute IV Curves
|Total Current| [A]
0.0001
1e-05
1e-06
1e-07
1e-08
-5e+02
0
5e+02
Voltage [V]
T=-15C, VHV=500V
T=0C, VHV=500V
T=15C, VHV=500V
T=30C, VHV=500V
T=24.85C, VHV=500V
T=-30C, VHV=500V
T=50C, VHV=500V
T=75C, VHV=500V
T=100C, VHV=500V
T=125C, VHV=500V

Log


Absolute IV Curves
T=-15C, VHV=600V
T=0C, VHV=600V
T=15C, VHV=600V
T=30C, VHV=600V
T=24.85C, VHV=600V
T=-30C, VHV=600V
T=50C, VHV=600V
T=75C, VHV=600V
T=100C, VHV=600V
T=125C, VHV=600V
0.0004
0.0002
0
|Total Current| [A]
-5e+02
0
5e+02
Voltage [V]

Linear


Absolute IV Curves
|Total Current| [A]
0.0001
1e-05
1e-06
1e-07
1e-08
-5e+02
0
5e+02
Voltage [V]
T=-15C, VHV=600V
T=0C, VHV=600V
T=15C, VHV=600V
T=30C, VHV=600V
T=24.85C, VHV=600V
T=-30C, VHV=600V
T=50C, VHV=600V
T=75C, VHV=600V
T=100C, VHV=600V
T=125C, VHV=600V

Log

Geant4 with CLS and DLS Beam Information

Beam Parameters

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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

CLS Beam

```
/gps/particle gamma
/gps/energy 15 keV

/gps/pos/type Beam
/gps/pos/centre 0 0 -176.11 um

# CLS: 40 um diameter, Gaussian sigma = diameter/2 =
20 um
/gps/pos/sigma_x 20 um
/gps/pos/sigma_y 20 um

# Perfectly collimated
/gps/ang/type beam1d
/gps/ang/sigma_r 0 rad

/gps/direction 0 0 1

/run/initialize
/run/beamOn 10000
```

DLS Beam

```
/gps/particle gamma
/gps/energy 15 keV

/gps/pos/type Beam
/gps/pos/centre 0 0 -176.11 um

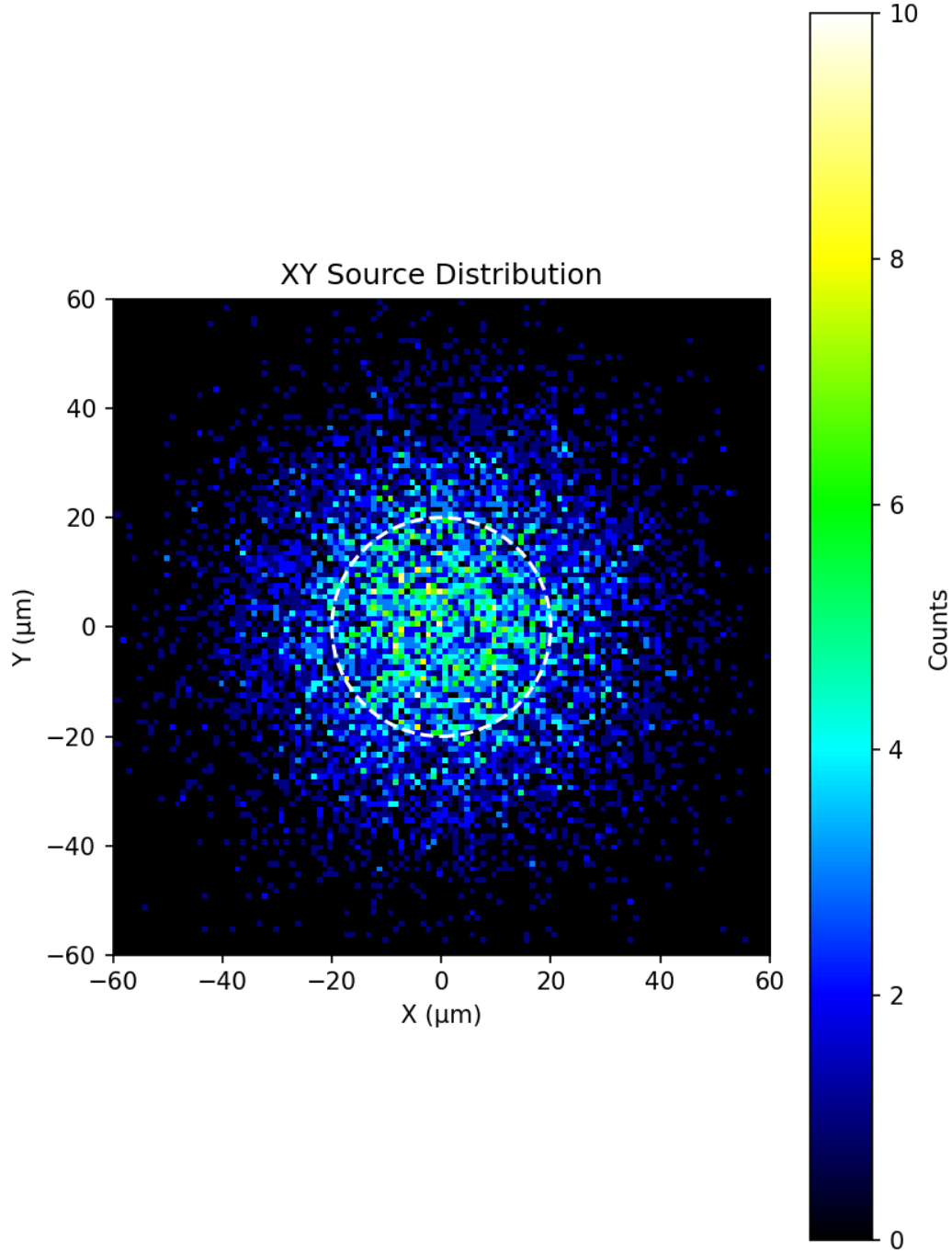
# DLS: 2 um diameter, Gaussian sigma = diameter/2 = 1
um
/gps/pos/sigma_x 1 um
/gps/pos/sigma_y 1 um

# Perfectly collimated
/gps/ang/type beam1d
/gps/ang/sigma_r 0 rad

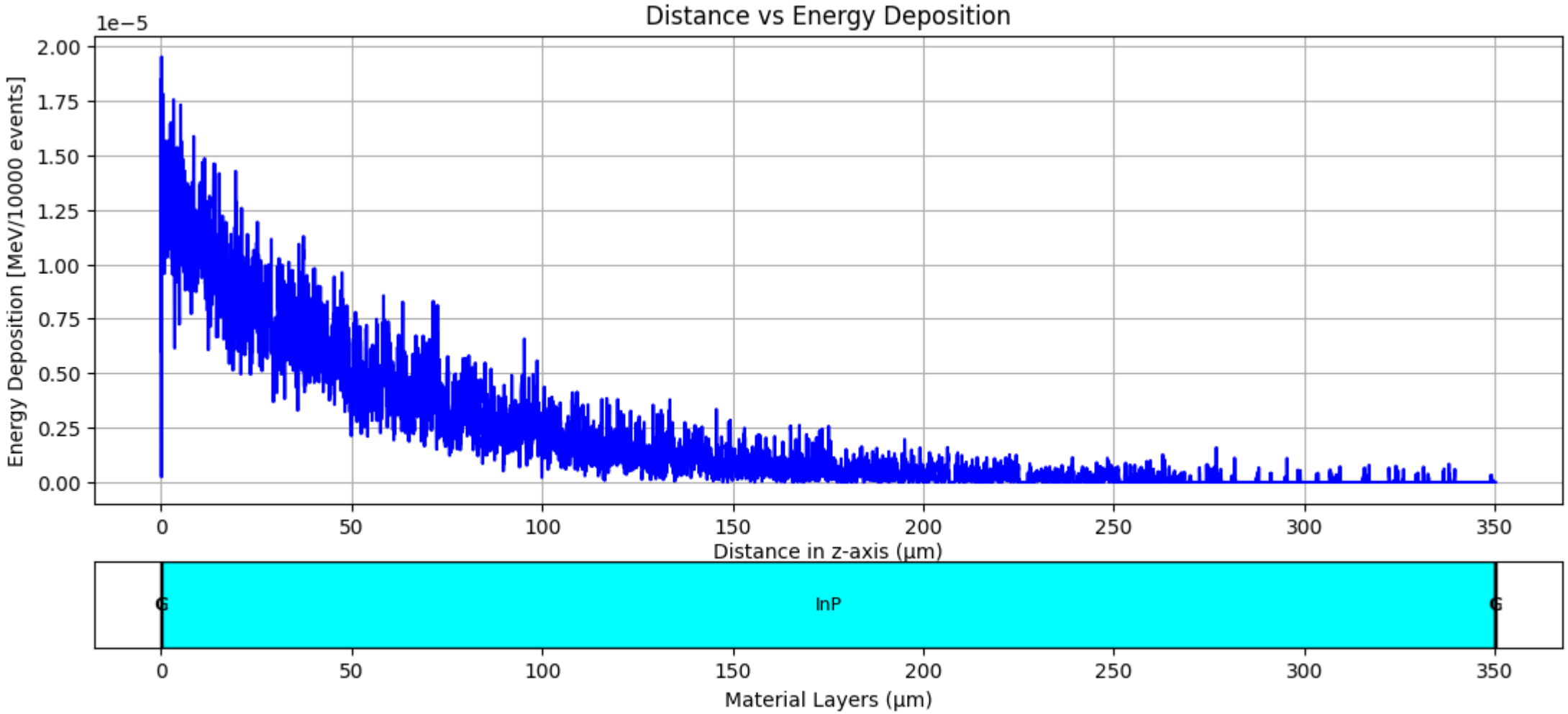
/gps/direction 0 0 1

/run/initialize
/run/beamOn 10000
```

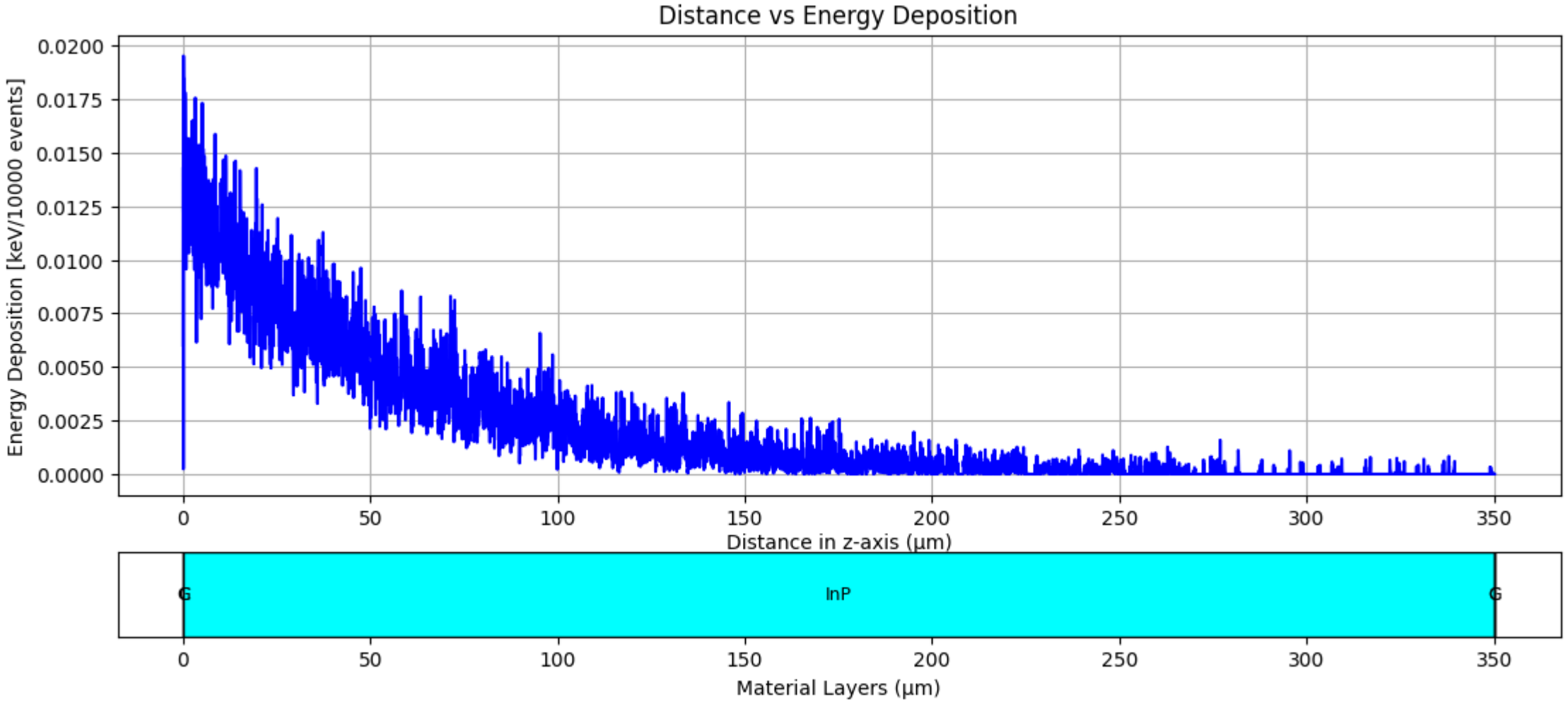
CLS 40µm Diameter Beam


XY Source Distribution
Y (µm)
X (µm)
60
40
20
0
−20
−40
−60
Counts
10
8
6
4
2
0

Energy Deposition (in MeV/10000 events)

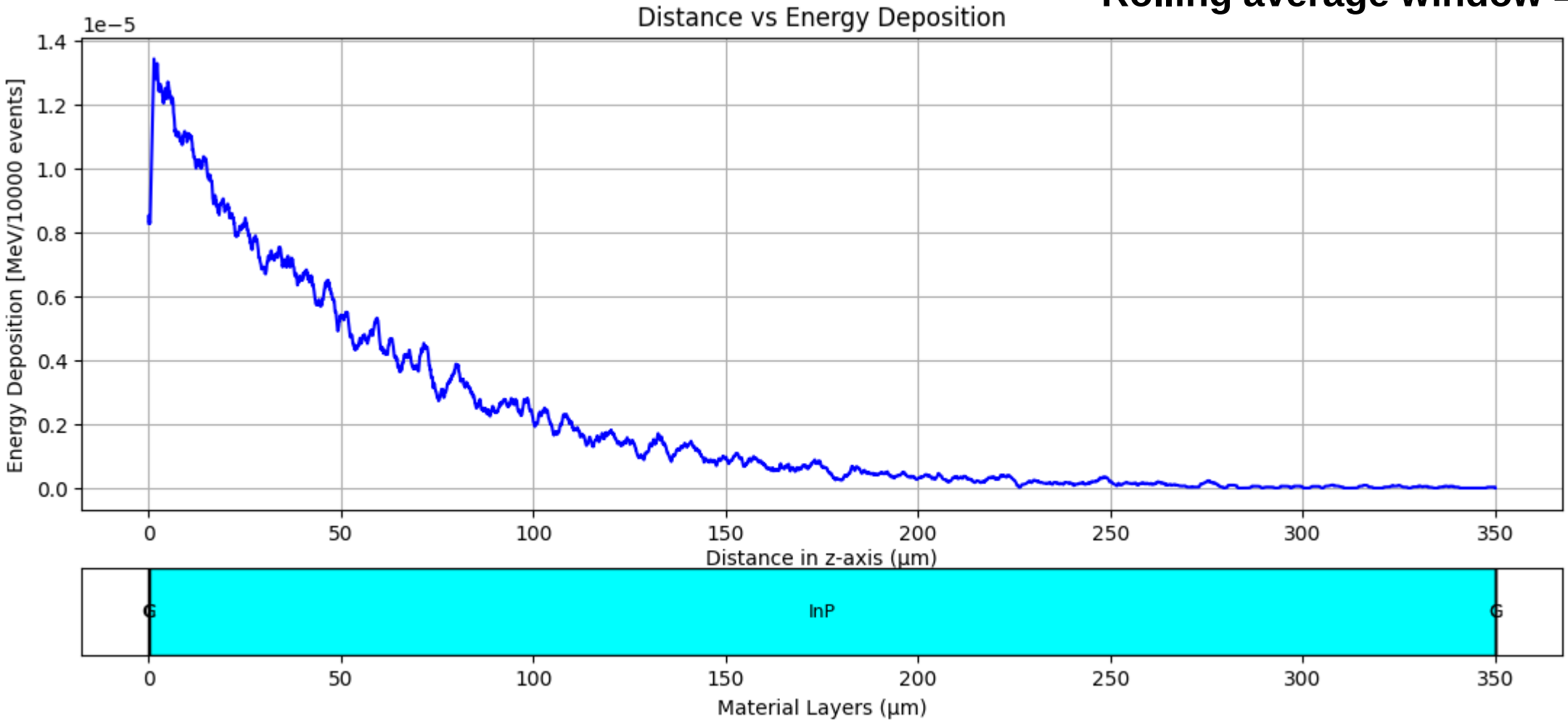


Energy Deposition (in keV/10000 events)



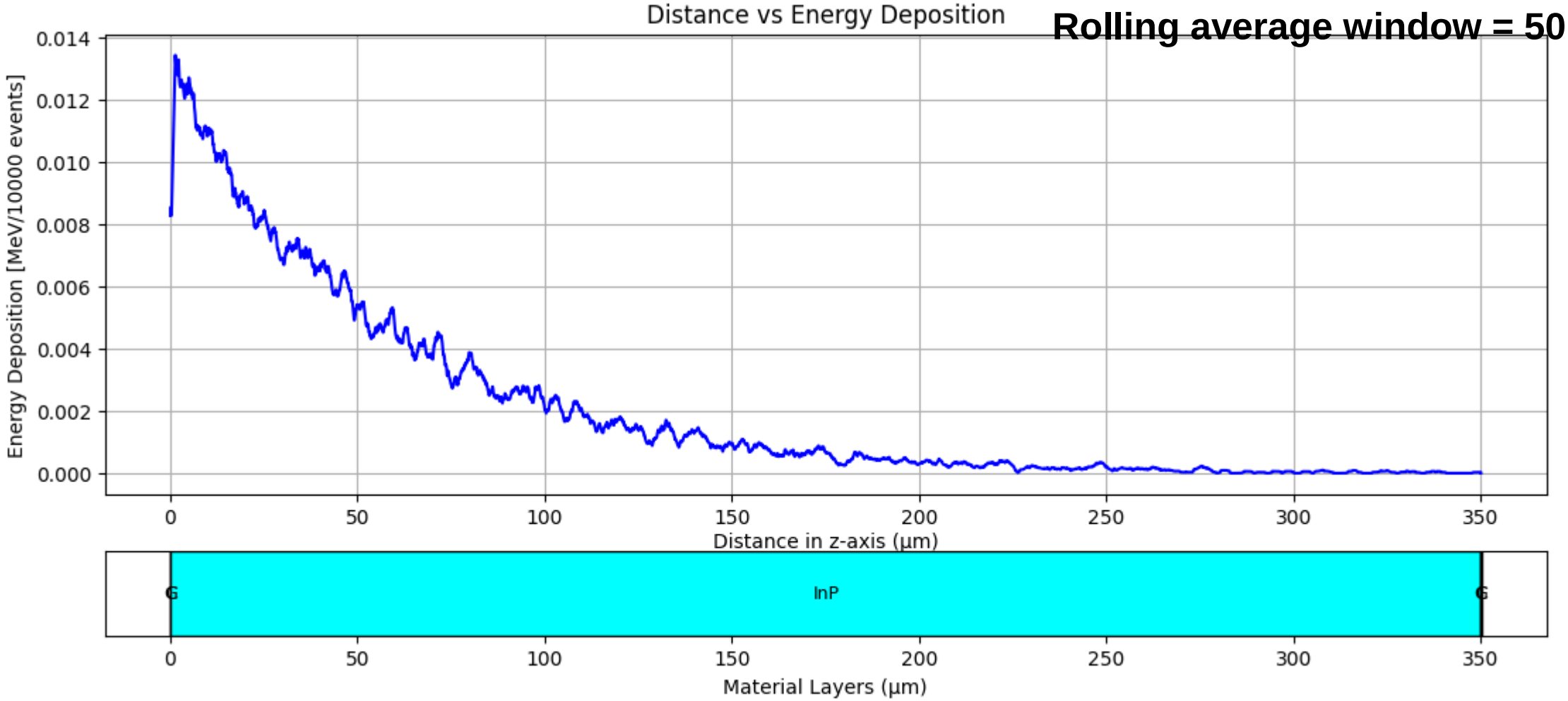
Energy Deposition (in MeV/10000 events)

Rolling average window = 50




```
df2['edep_smooth'] = y2.rolling(window=50,center=True).mean()
y2_smooth = df2['edep_smooth']
```

Energy Deposition (in keV/10000 events)

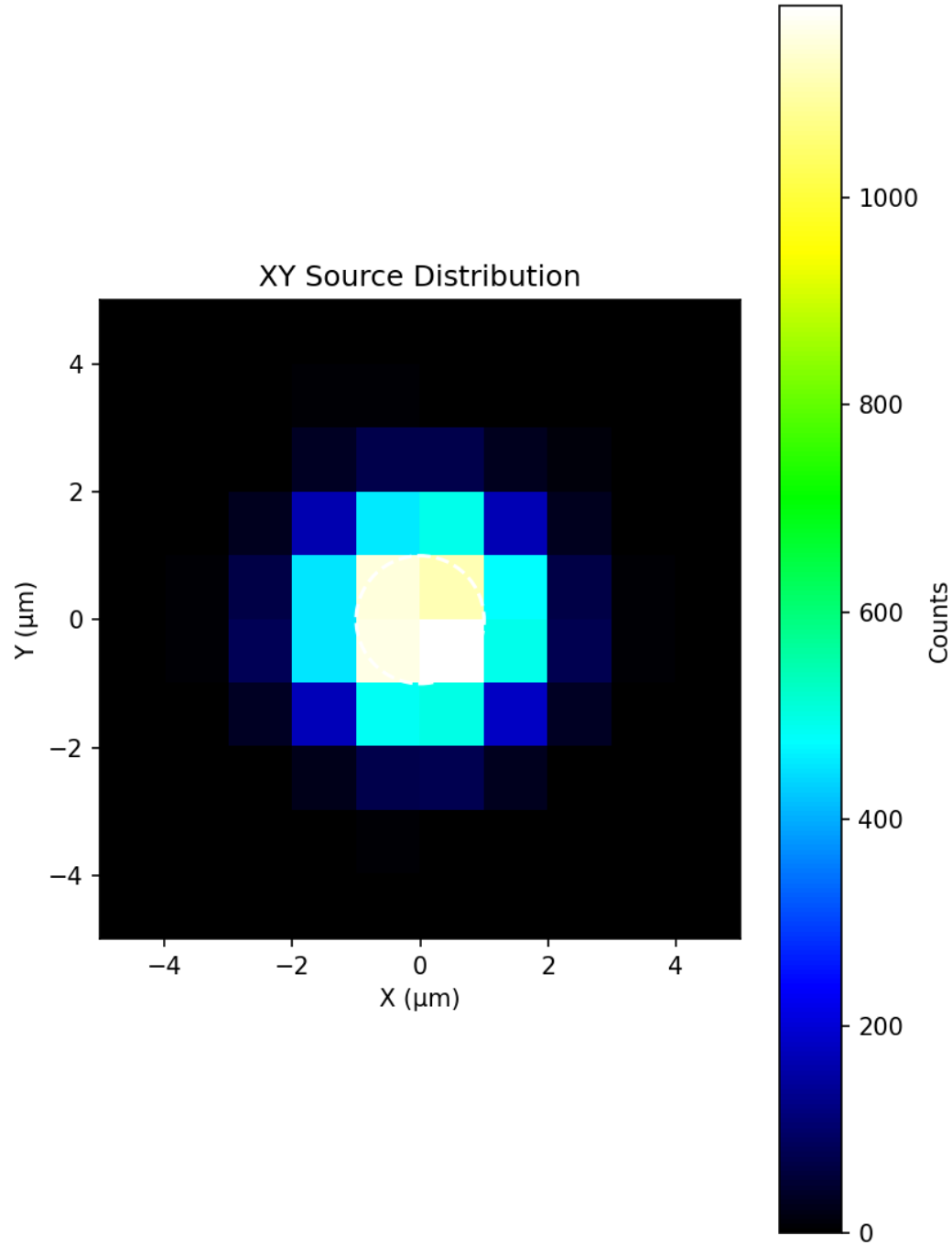


Rolling average window = 50

```
df2['edep_smooth'] = y2.rolling(window=50,center=True).mean()
y2_smooth = df2['edep_smooth']
```

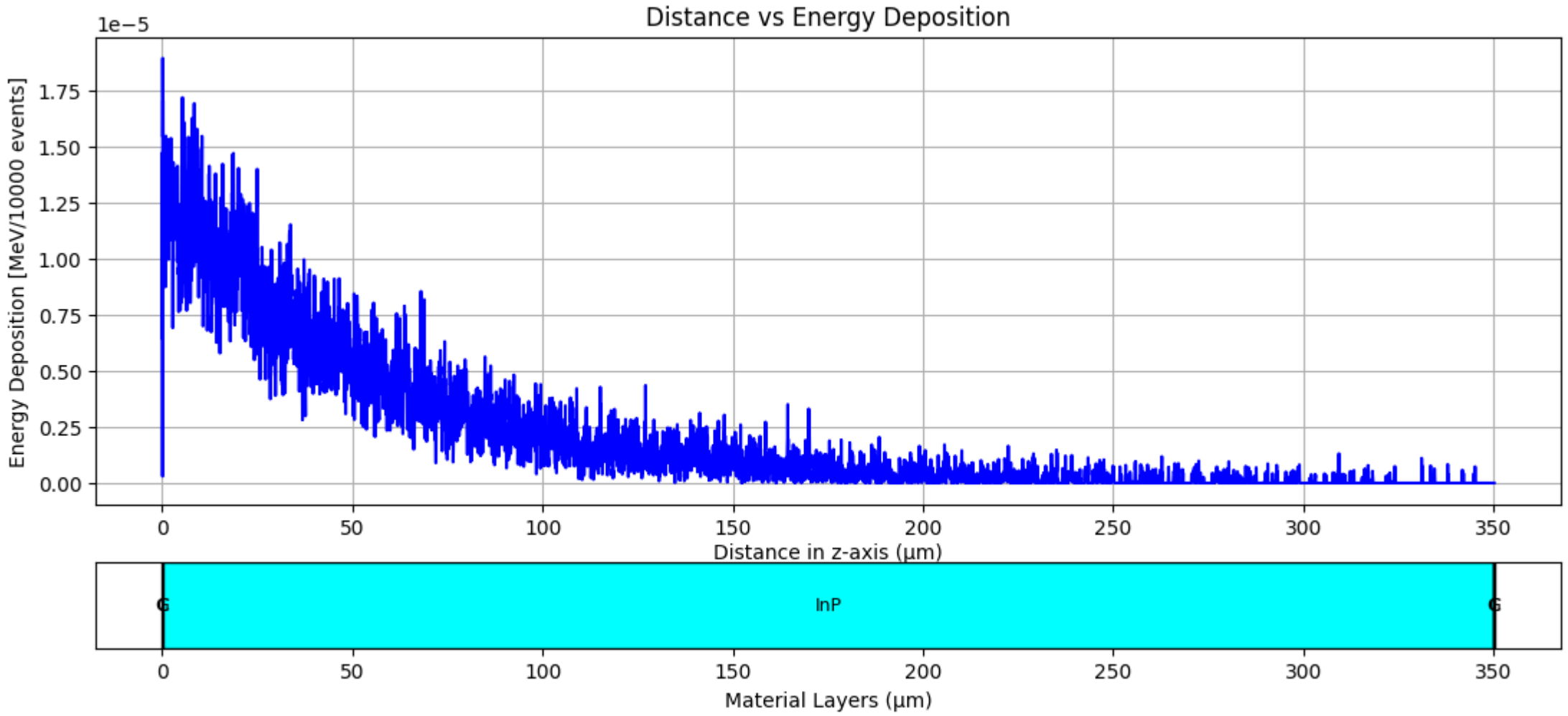
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DLS 2µm Beam

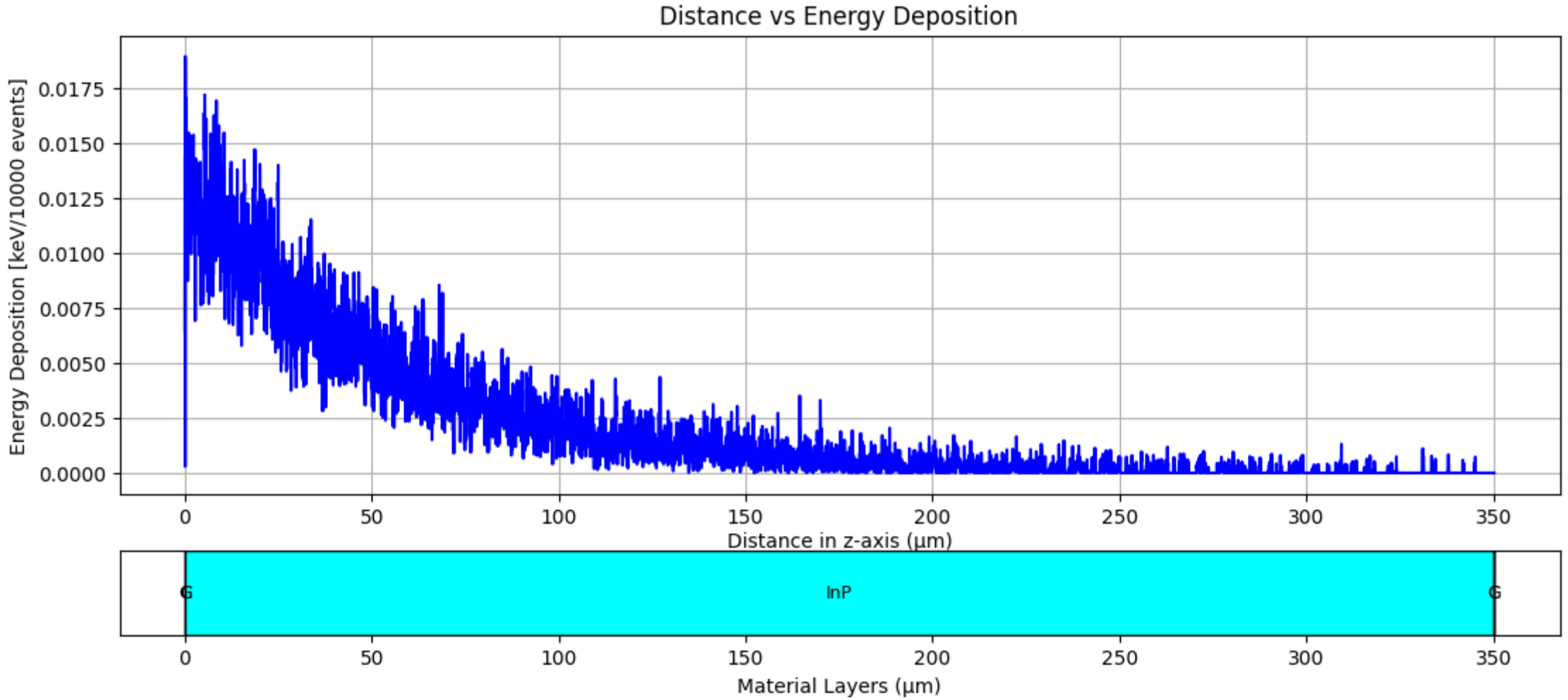

XY Source Distribution
Y (µm)
X (µm)
4
2
0
−2
−4
−4
−2
0
2
4
Counts
1000
800
600
400
200
0

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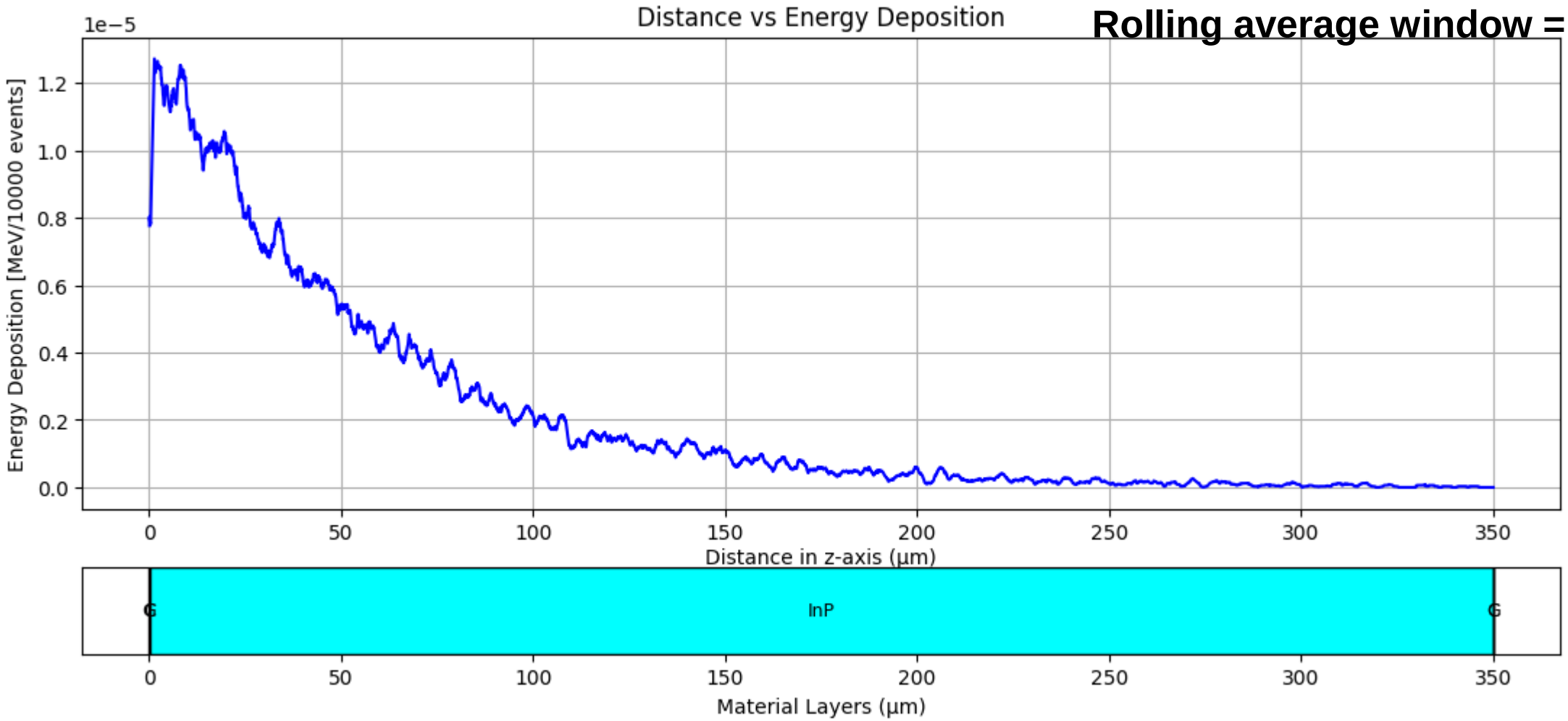
Energy Deposition (in MeV/10000 events)



Energy Deposition (in keV/10000 events)



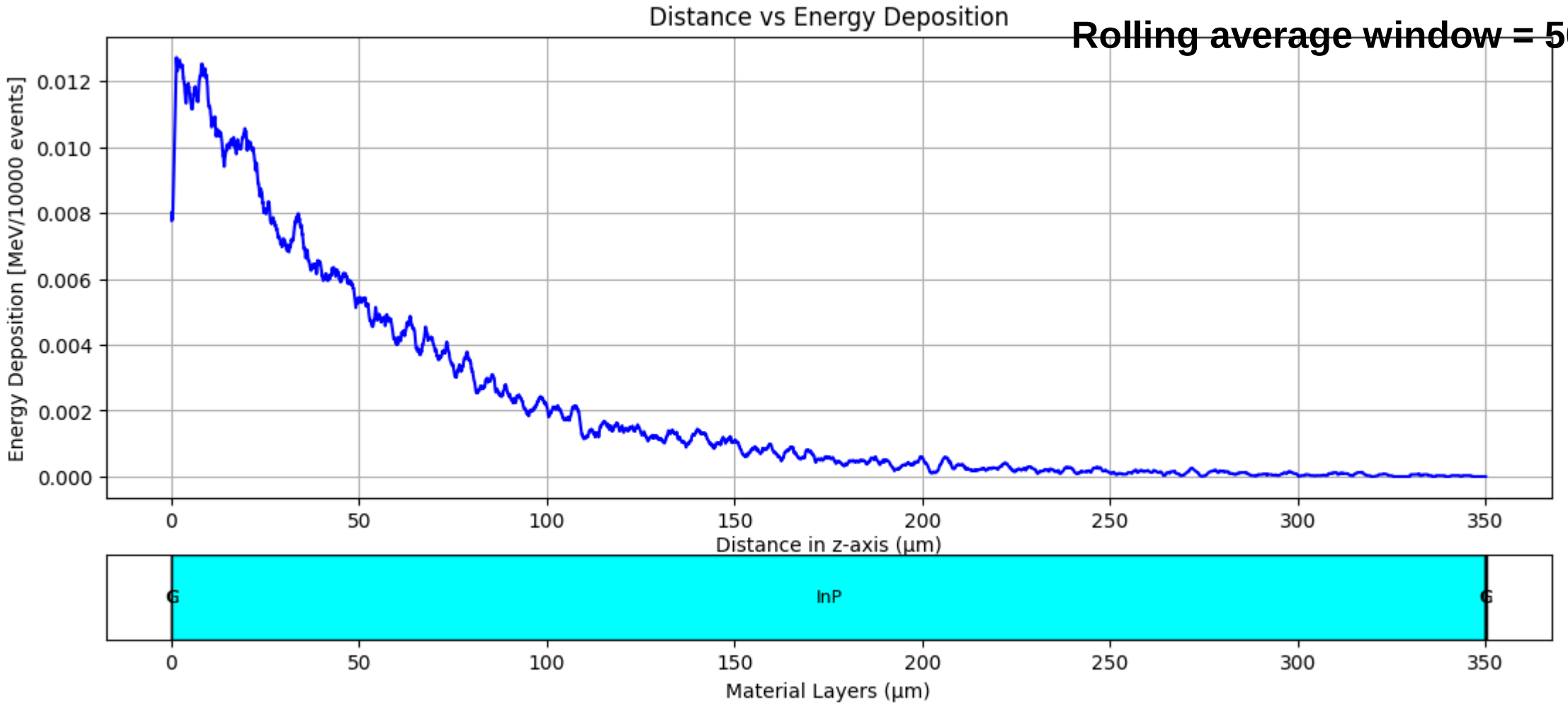
Energy Deposition (in MeV/10000 events)



Rolling average window = 50

```
df2['edep_smooth'] = y2.rolling(window=50,center=True).mean()
y2_smooth = df2['edep_smooth']
```

Energy Deposition (in keV/10000 events)



Rolling average window = 50

```
df2['edep_smooth'] = y2.rolling(window=50,center=True).mean()
y2_smooth = df2['edep_smooth']
```





Geant4 CLS and DLS Profiles into TCAD using Optical Generation Module

Importing Optical Generation Profile into SDE


```
;;; 4.  Load optical generation profile
;;  -- Get the node number of the opticalprofile tool for this experiment --
(define ref_node "@node|opticalprofile@")
;;  -- Construct path to the scaled optical generation file --
(define OptFile (string-append "scaled_Gopt_node" ref_node ".plx"))

;;  -- Define the 1D external profile --
(sdedr:define-1d-external-profile "1d_opt_def" OptFile
    "Scale" 1.0 "Range" 0 T)

(sdedr:define-refeval-window "globalopt_window" "Line"
    (position 0  0  0)
    (position L  0  0))

;; "Positive" = profile runs from Y=0 upward (cathode to anode)
(sdedr:define-analytical-profile-placement "1d_opt_place"
    "1d_opt_def" "globalopt_window"
    "Positive" "NoReplace" "Eval")
```

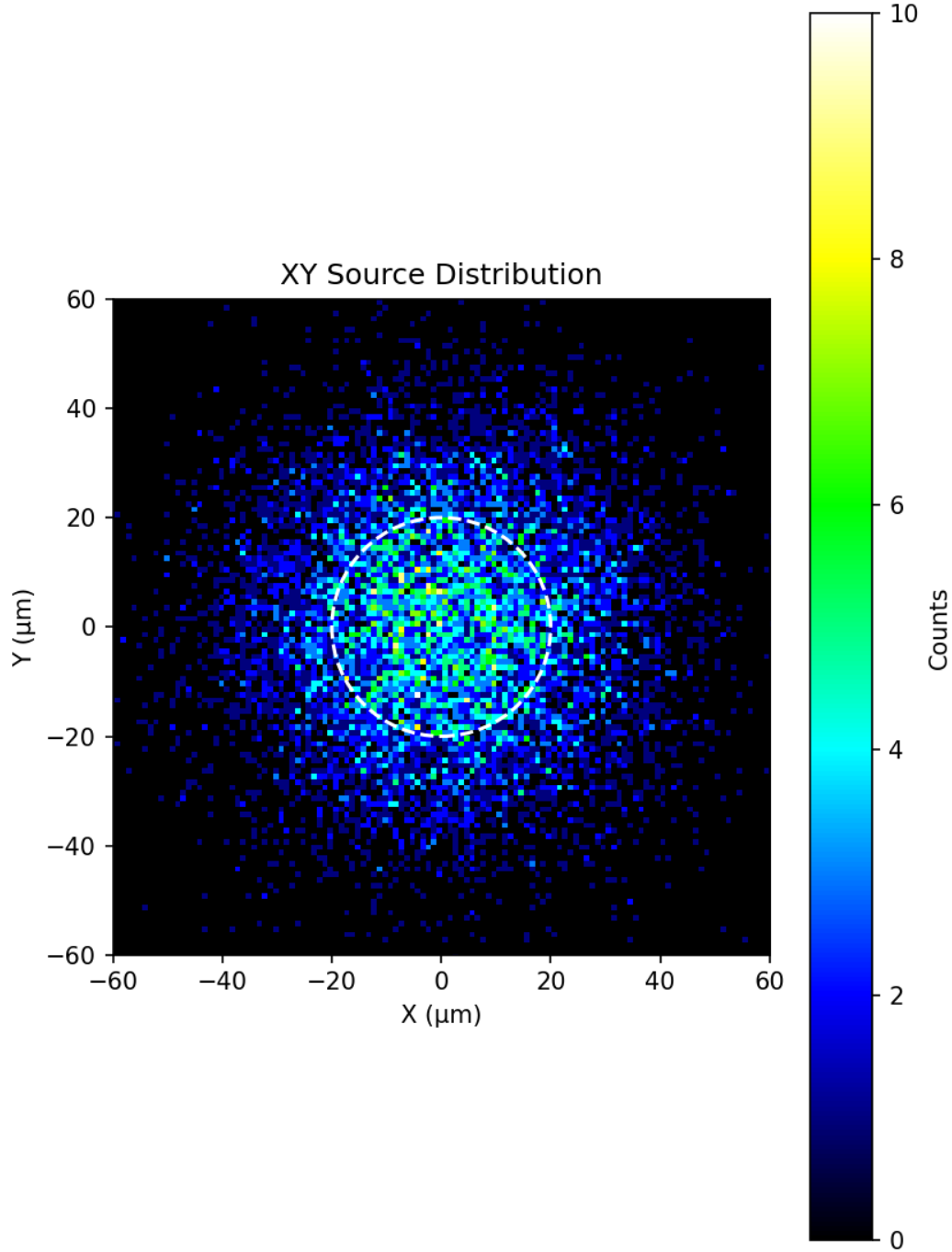
T = Thickness (350µm)
L = Lateral length of the device (5mm)

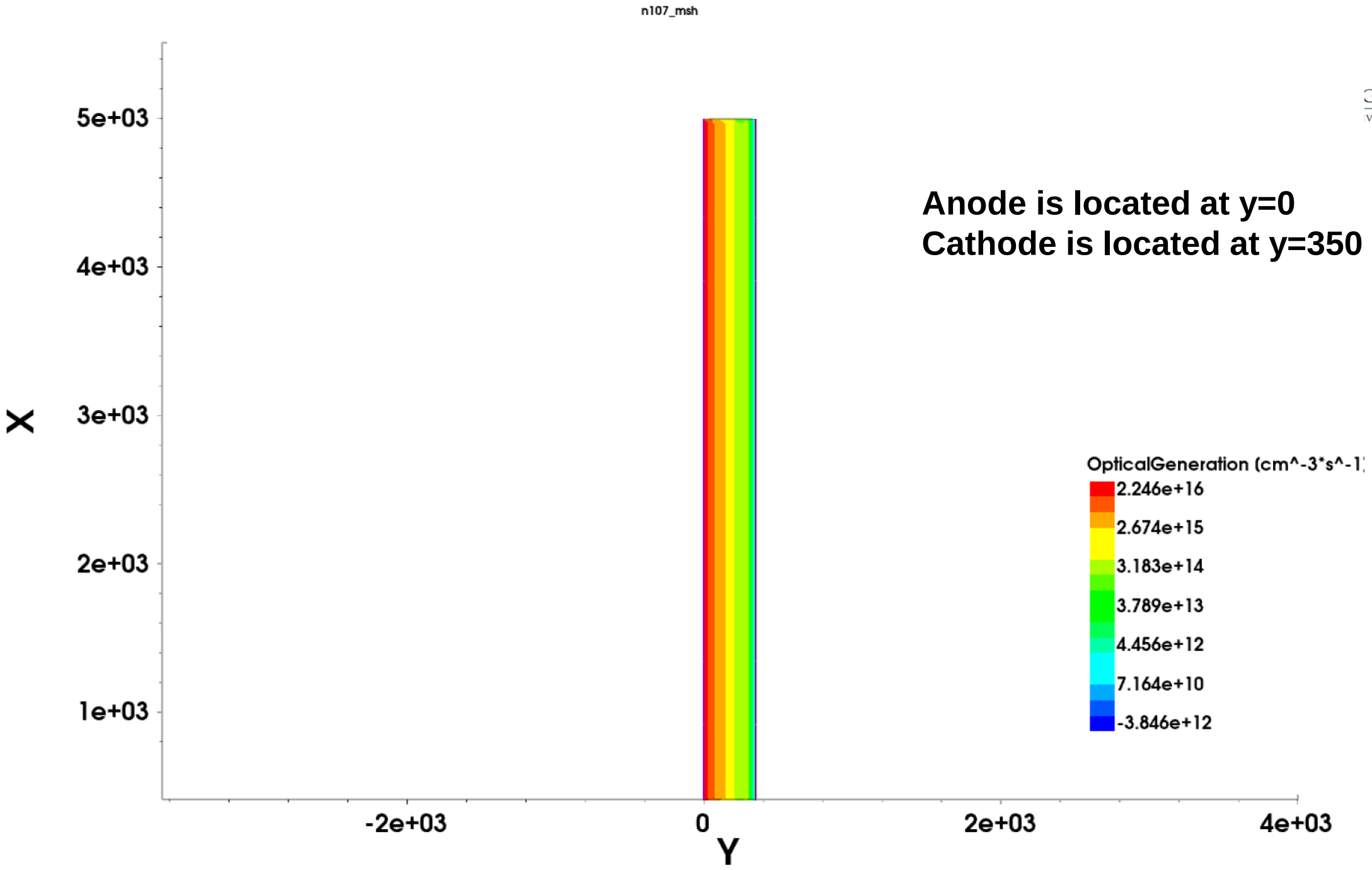
Importing Optical Generation into SDevice

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```
File {
        Grid = "@tdr@"
        Parameters = "@parameter@"
        Plot = "@tdrdat@"
        Current = "@plot@"
        Output = "@log@"
        OpticalGenerationInput= "@tdr@"
}

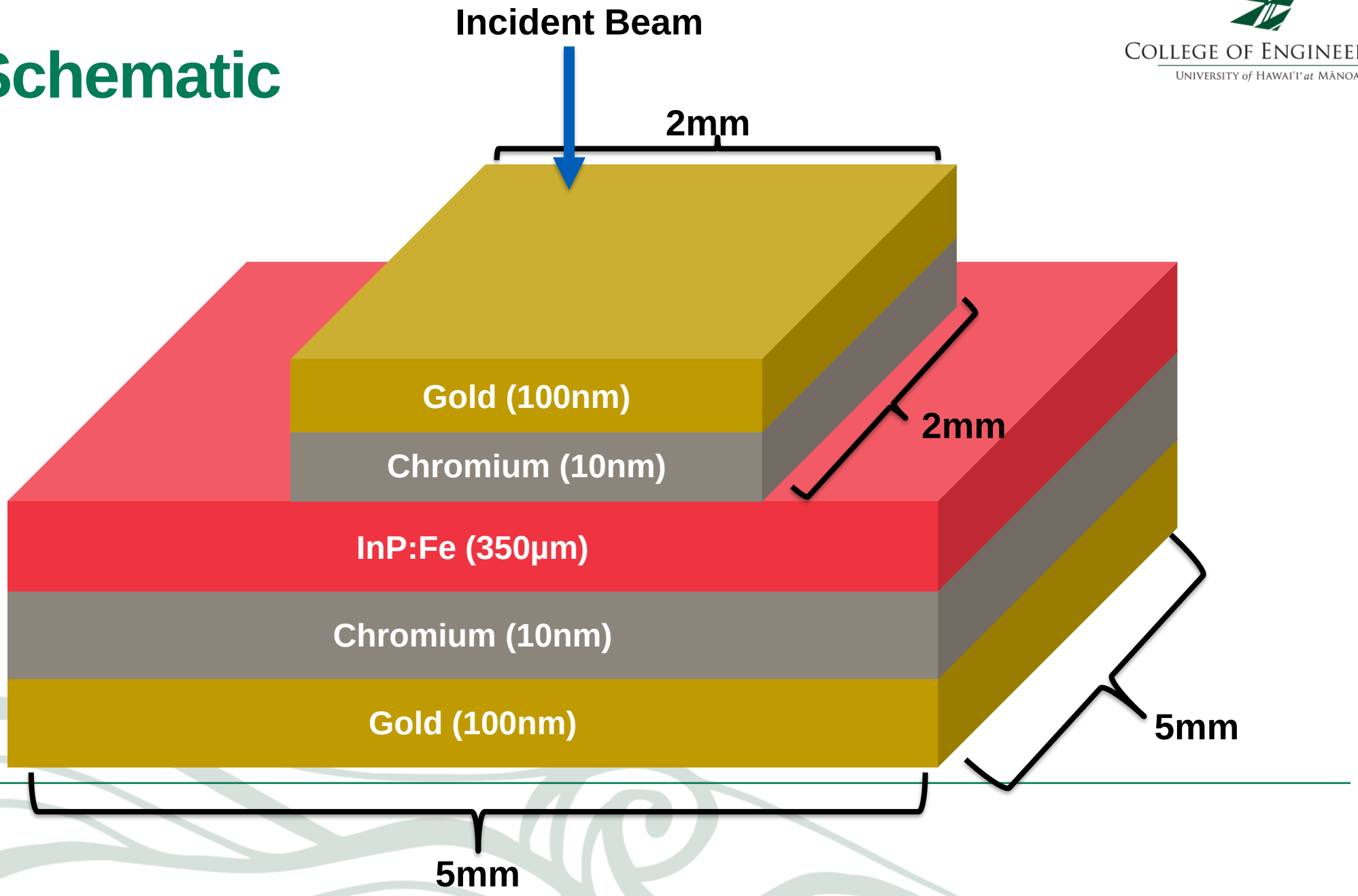
#if "@light@" == "on"
        Optics( OpticalGeneration( ReadFromFile() ) )
#endif
```


XY Source Distribution
Y (µm)
X (µm)
60
40
20
0
−20
−40
−60
Counts
10
8
6
4
2
0

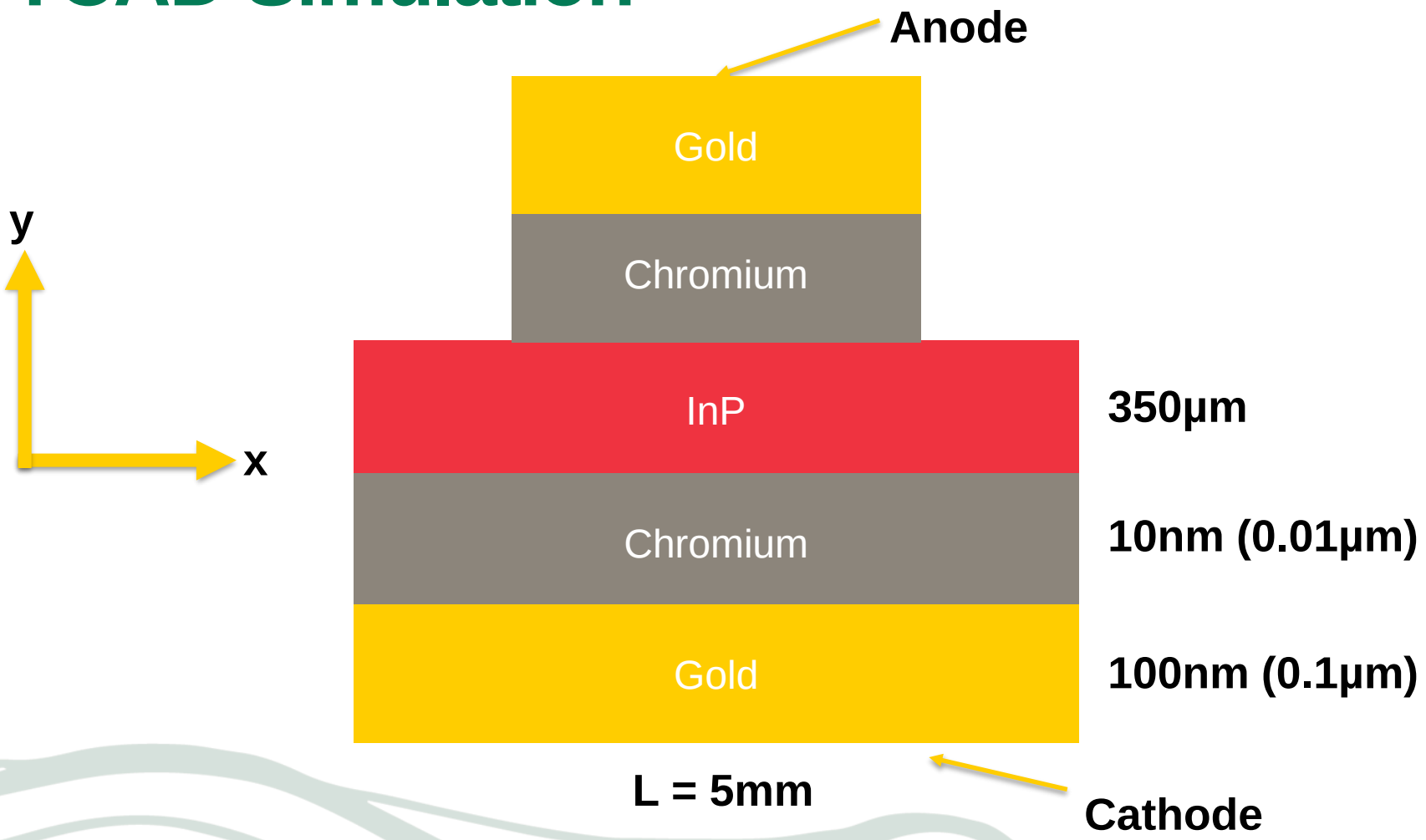


Anode is located at y=0
Cathode is located at y=350

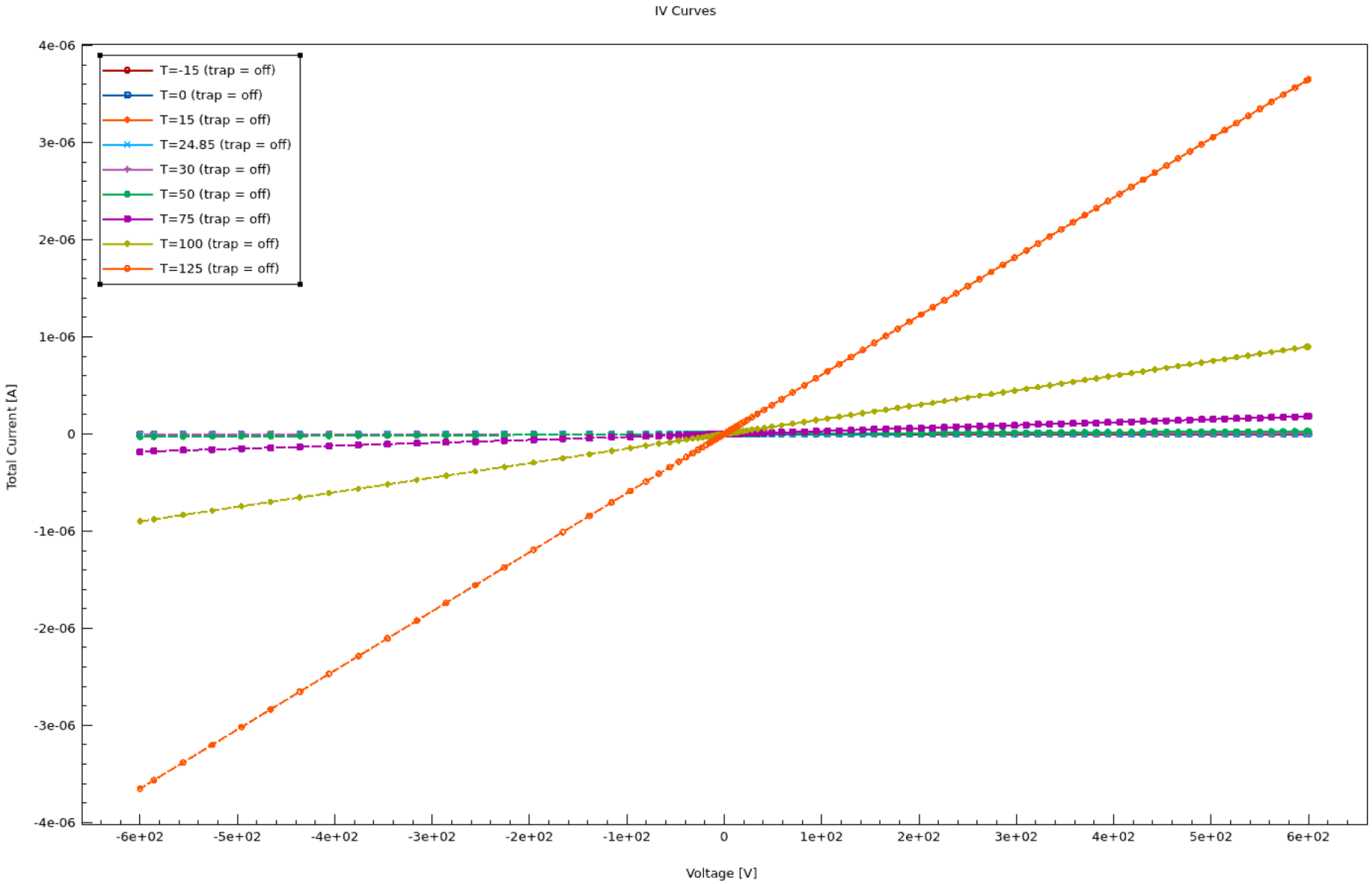
Basic Schematic



2D TCAD Simulation

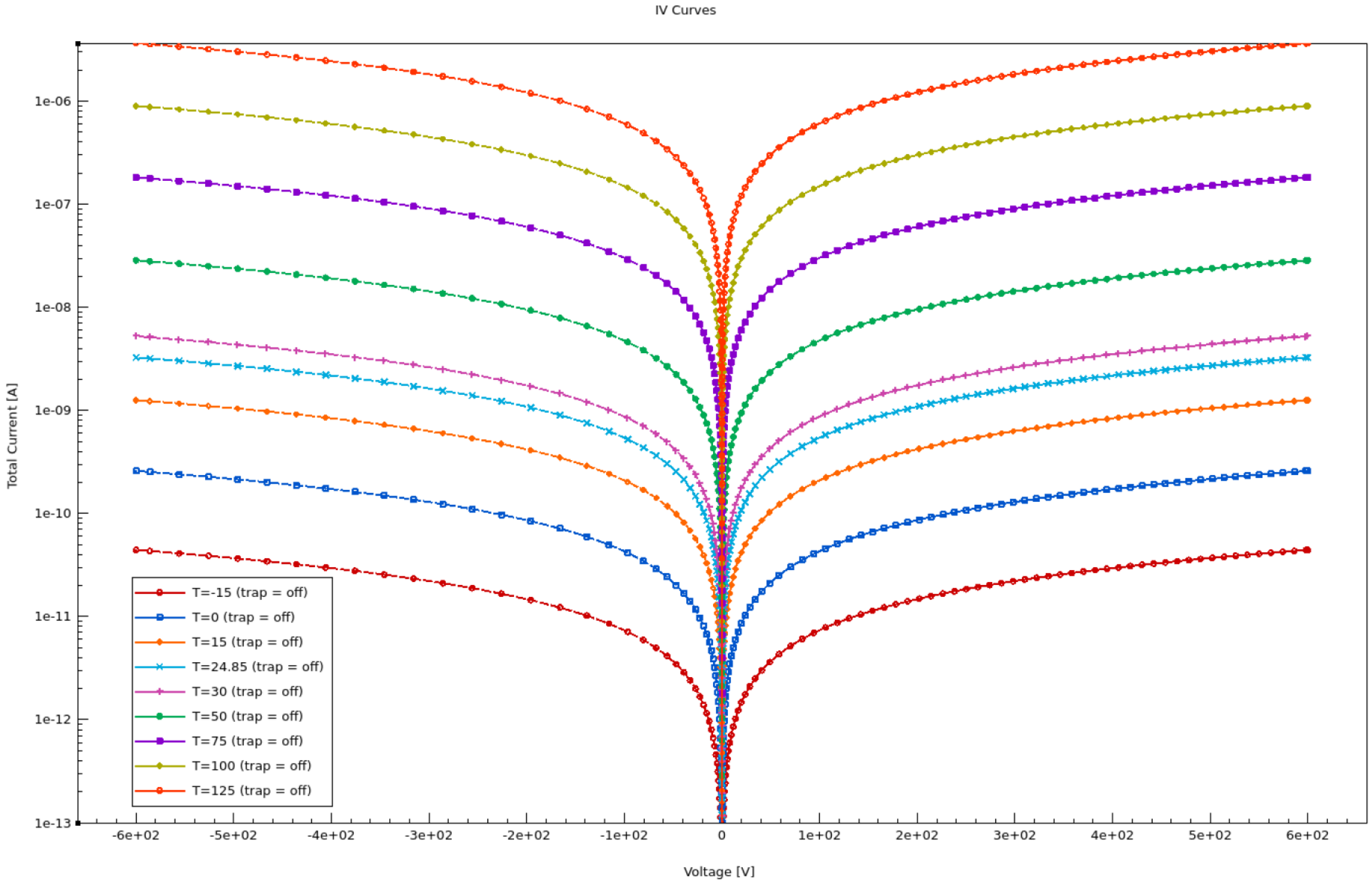


Without CLS + DLS IV Curve



Linear

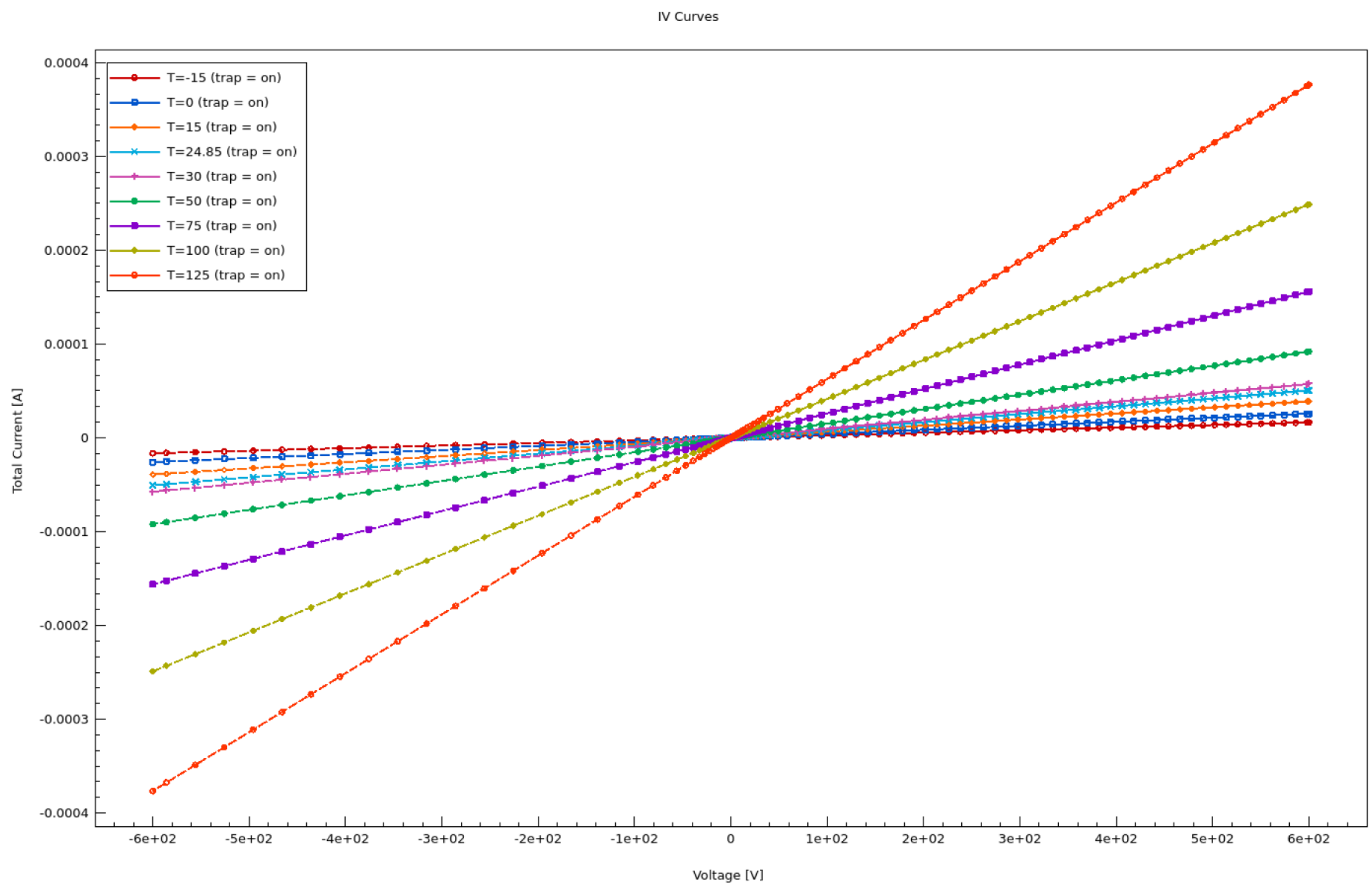
Trap Distribution Model Off



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Log

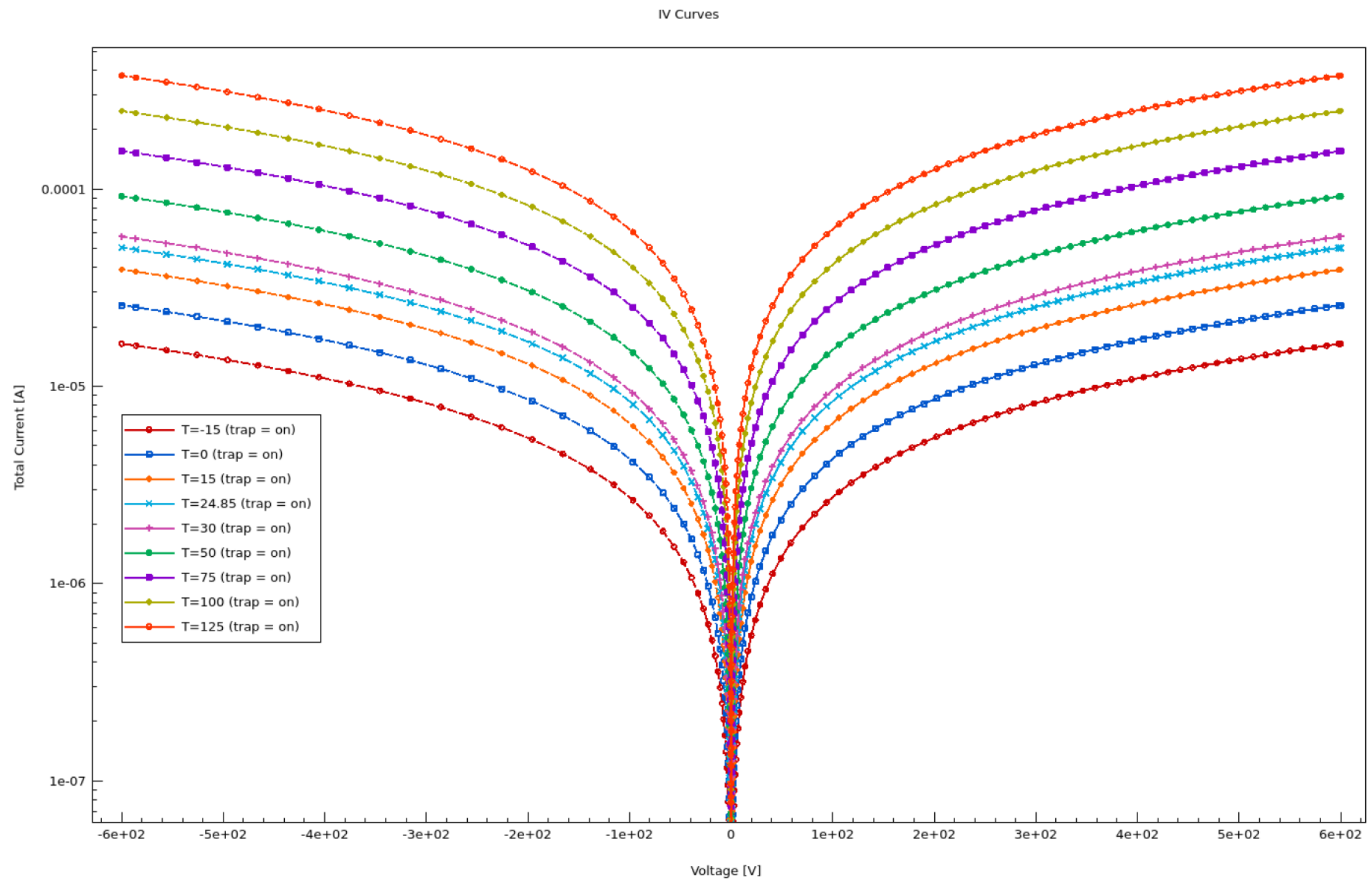
Trap Distribution Model Off



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TY of HAWAI'I at MĀNOA

Linear

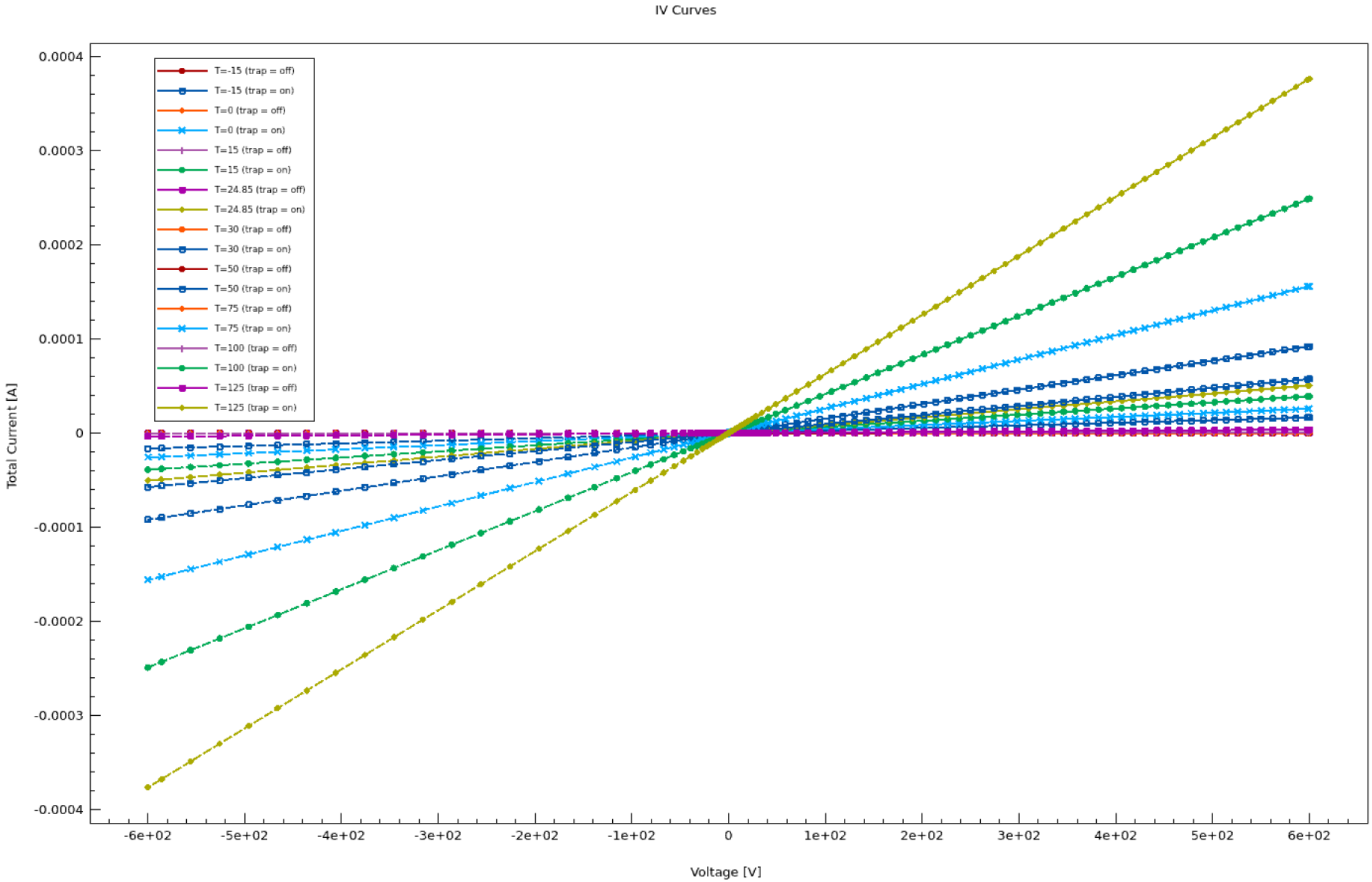
Trap Distribution Model On



OF ENGINEERING
TY of HAWAI'I at MĀNOA

Log

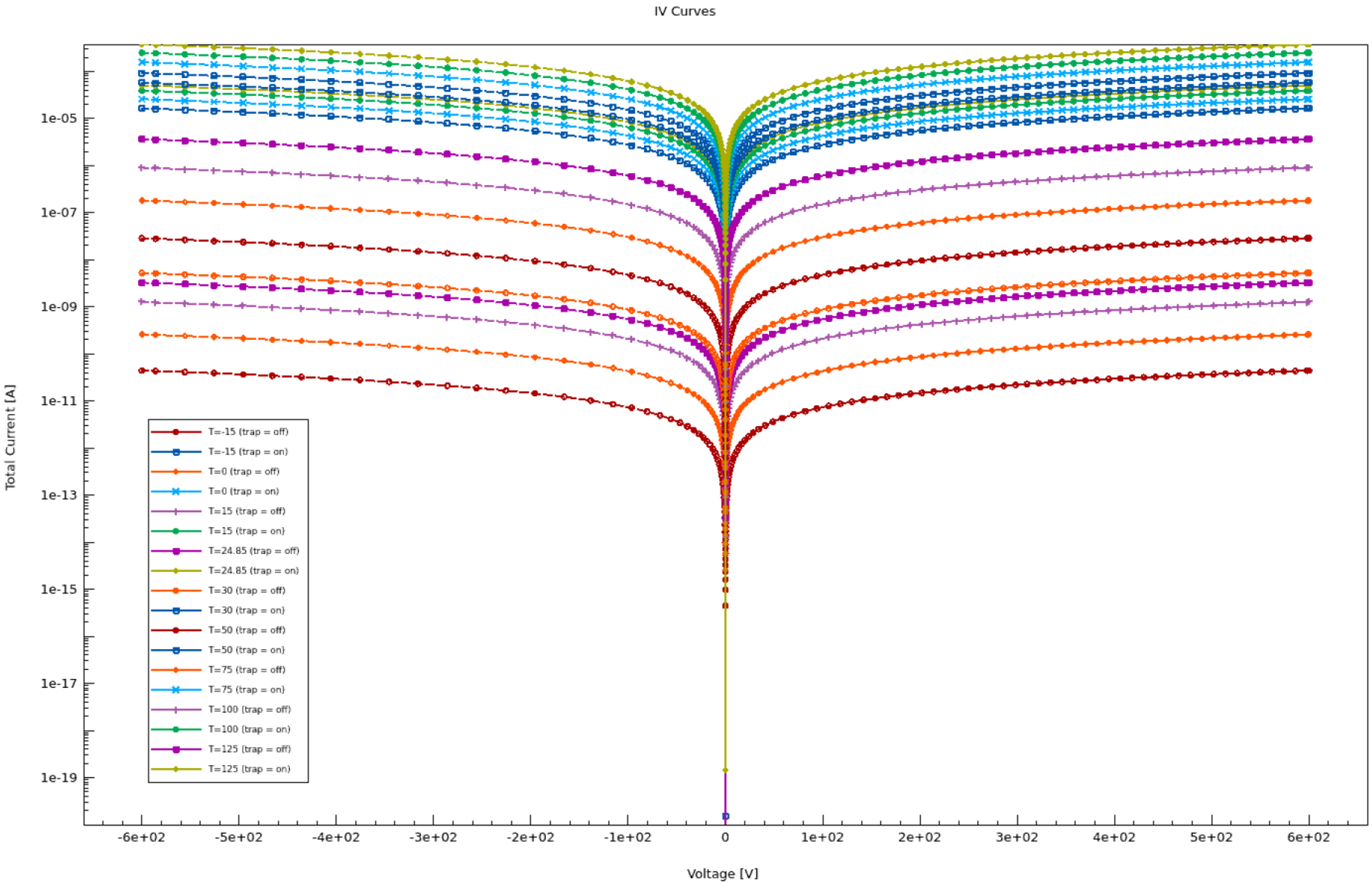
Trap Distribution Model On



OF ENGINEERING
'Y of HAWAI'I at MĀNOA

Linear

Trap Distribution On/Off

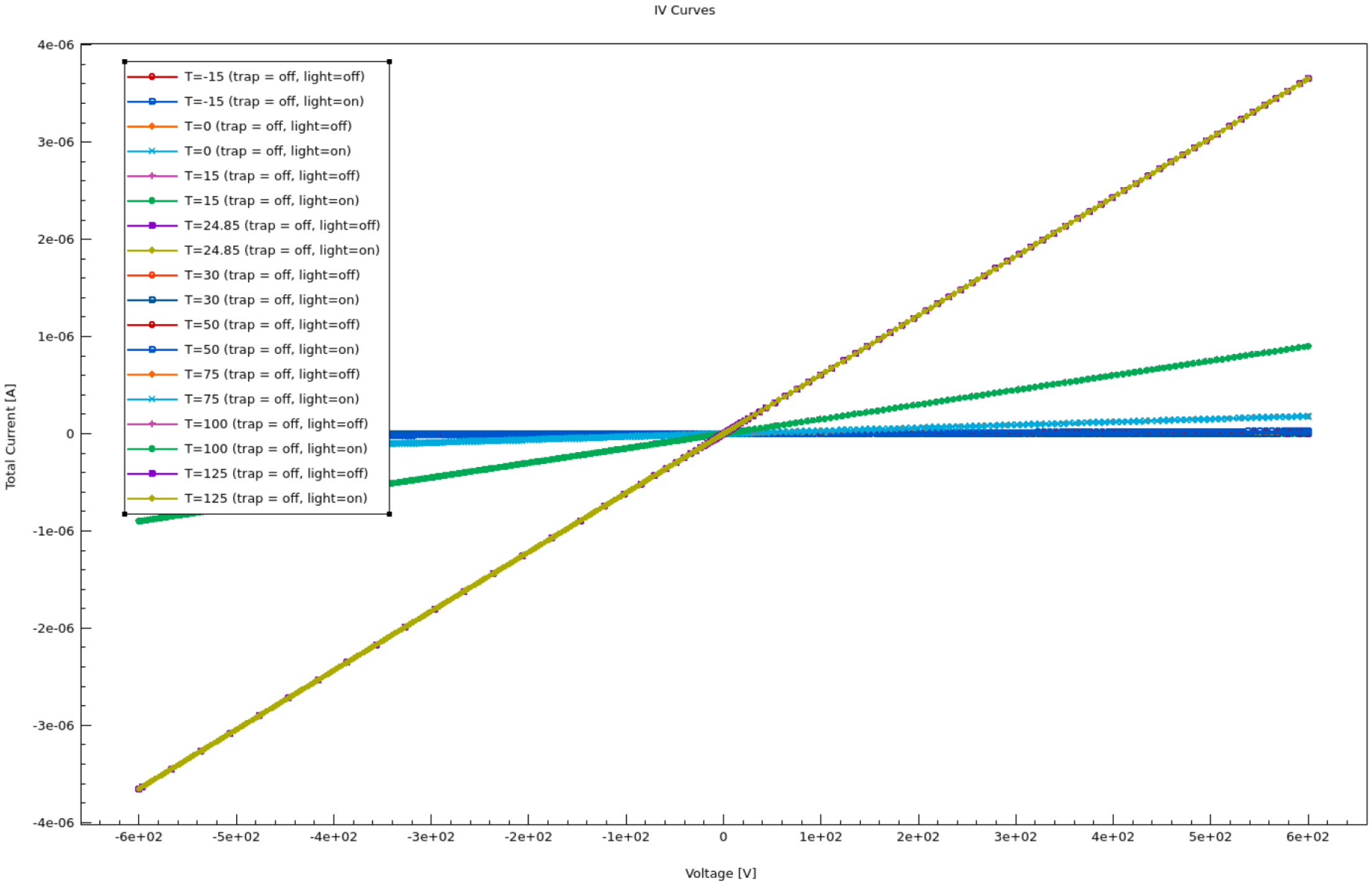


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IIVERSITY of HAWAI'I at MĀNOA

Log

Trap Distribution On/Off

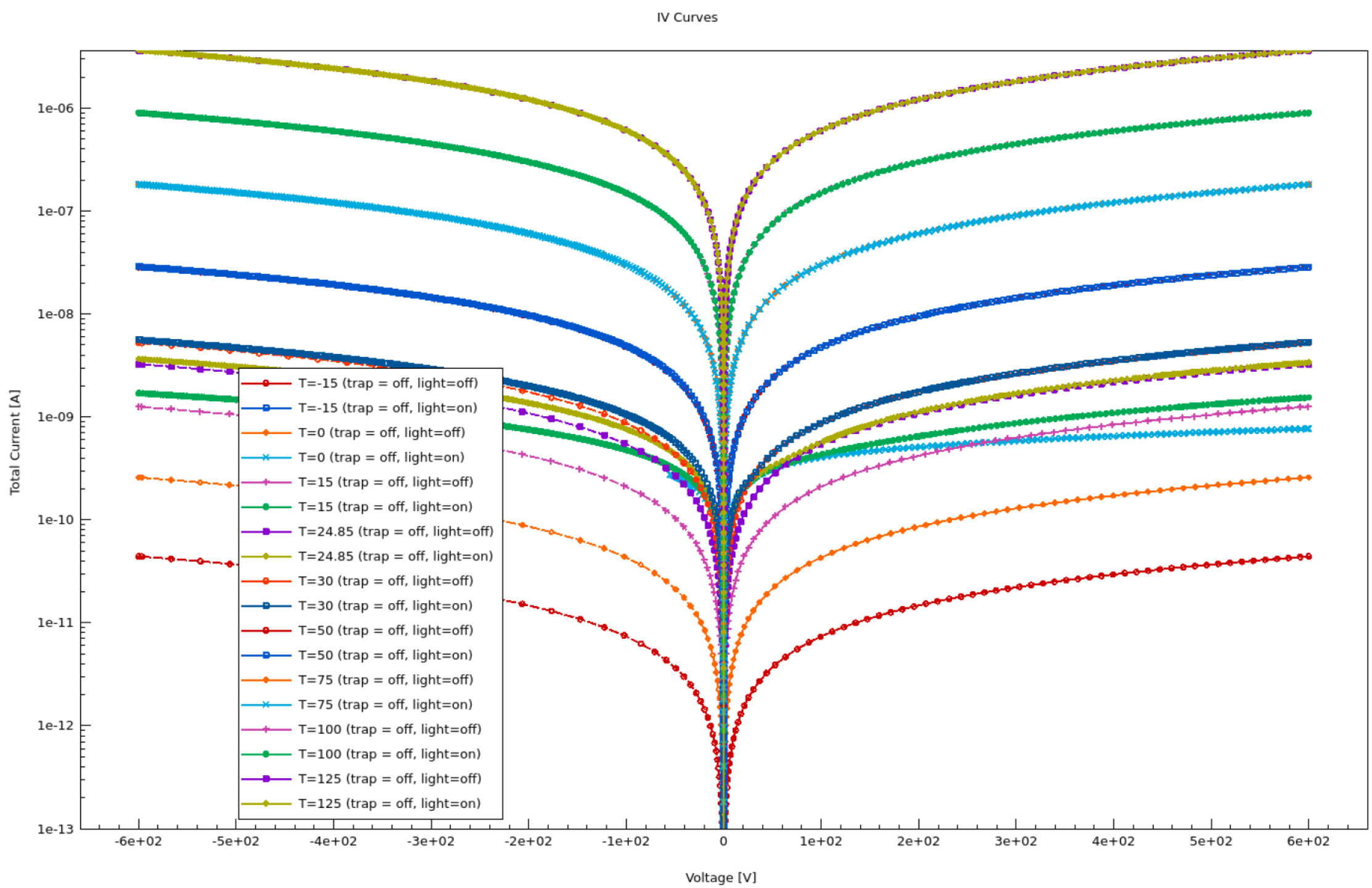
With CLS



OF ENGINEERING
'Y of HAWAI'I at MĀNOA

Linear

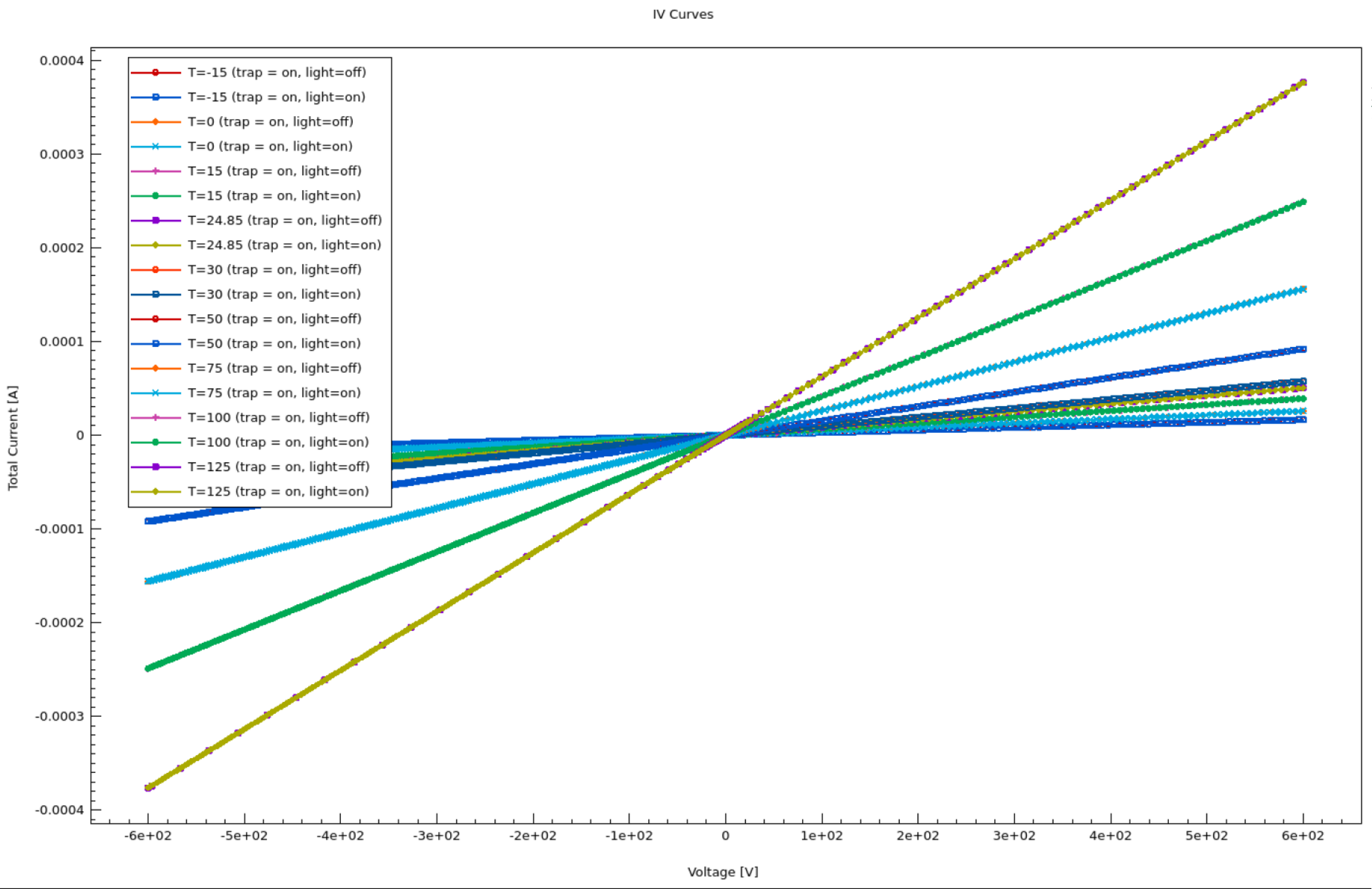
Trap Distribution Model Off



OF ENGINEERING
TY of HAWAI'I at MĀNOA

Log

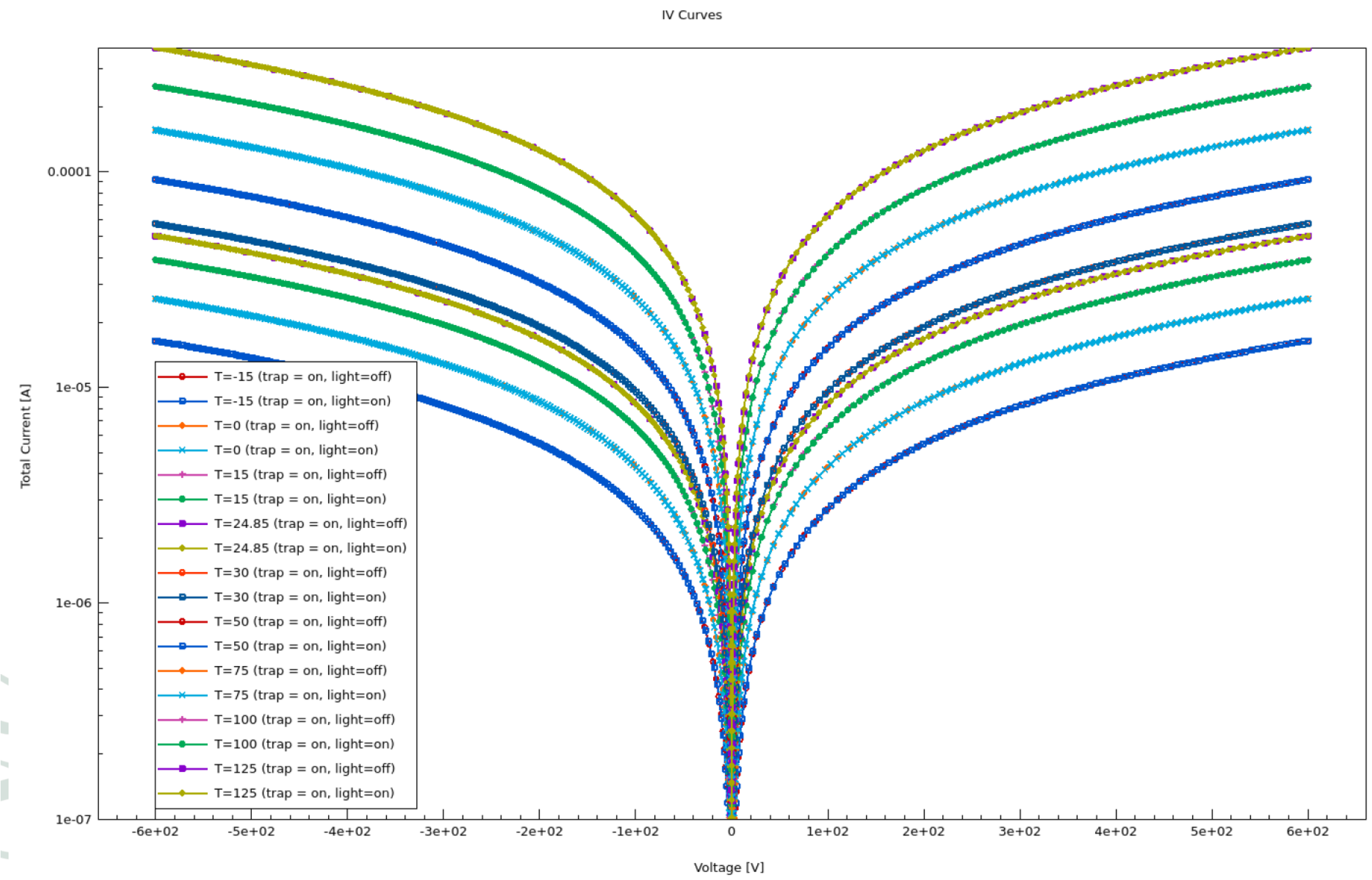
Trap Distribution Model Off



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RSITY of HAWAI'I at MĀNOA

Linear

Trap Distribution Model On

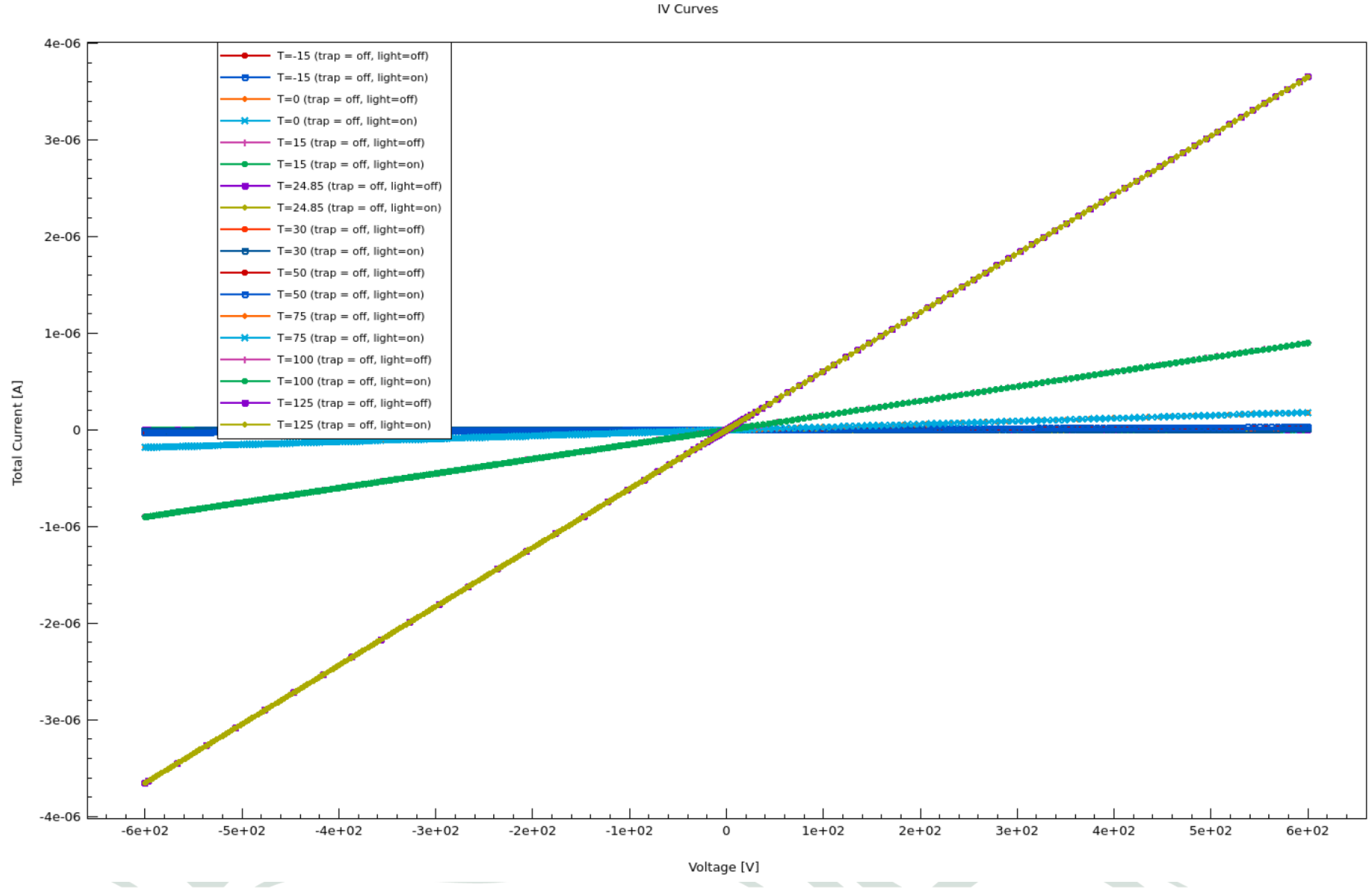


OF ENGINEERING
Y of HAWAI'I at MĀNOA

Log

Trap Distribution Model On

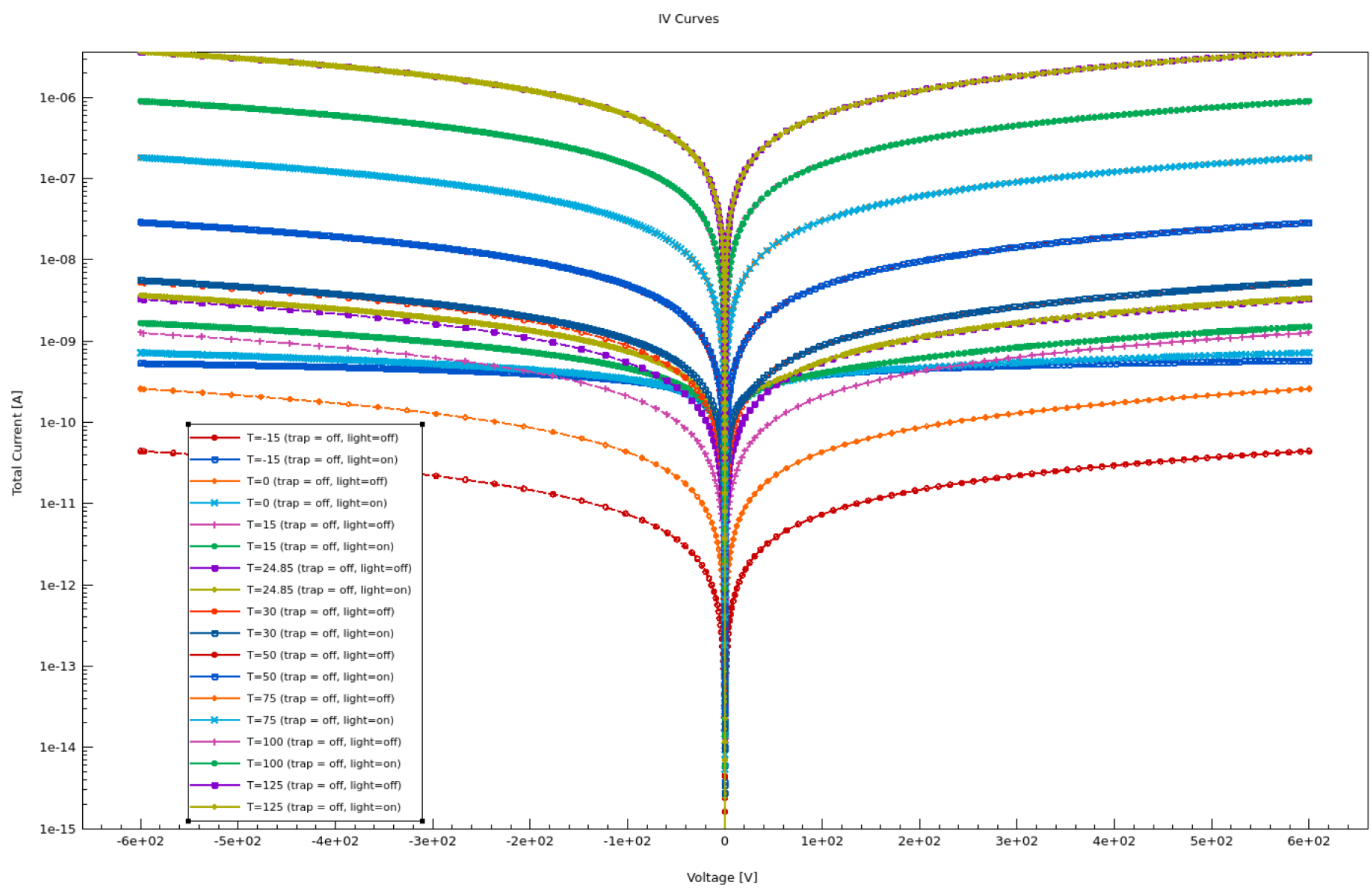
With DLS



OF ENGINEERING
SITY of HAWAI'I at MĀNOA

Linear

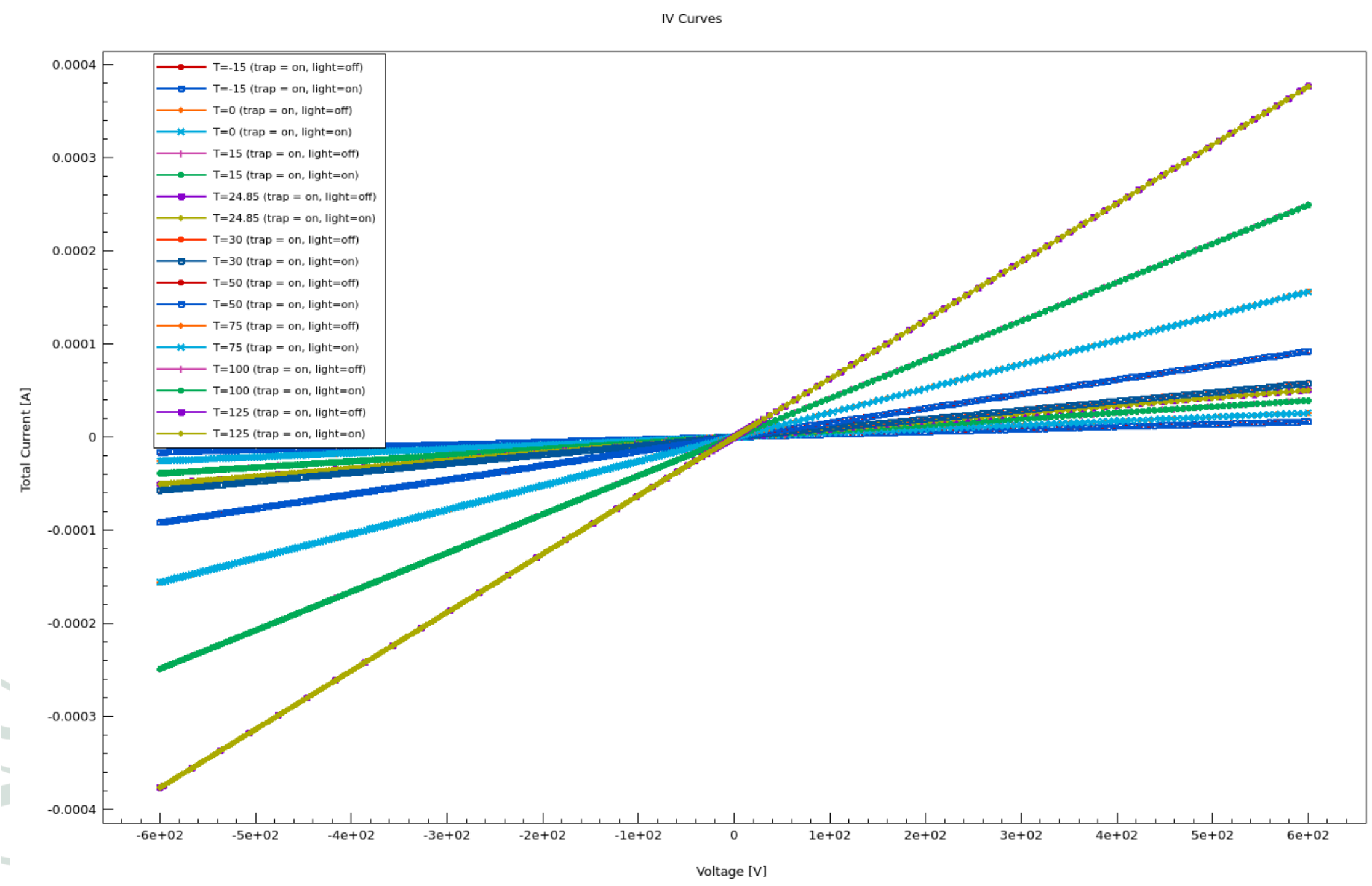
Trap Distribution Model Off



OF ENGINEERING
SITY of HAWAI'I at MĀNOA

Log

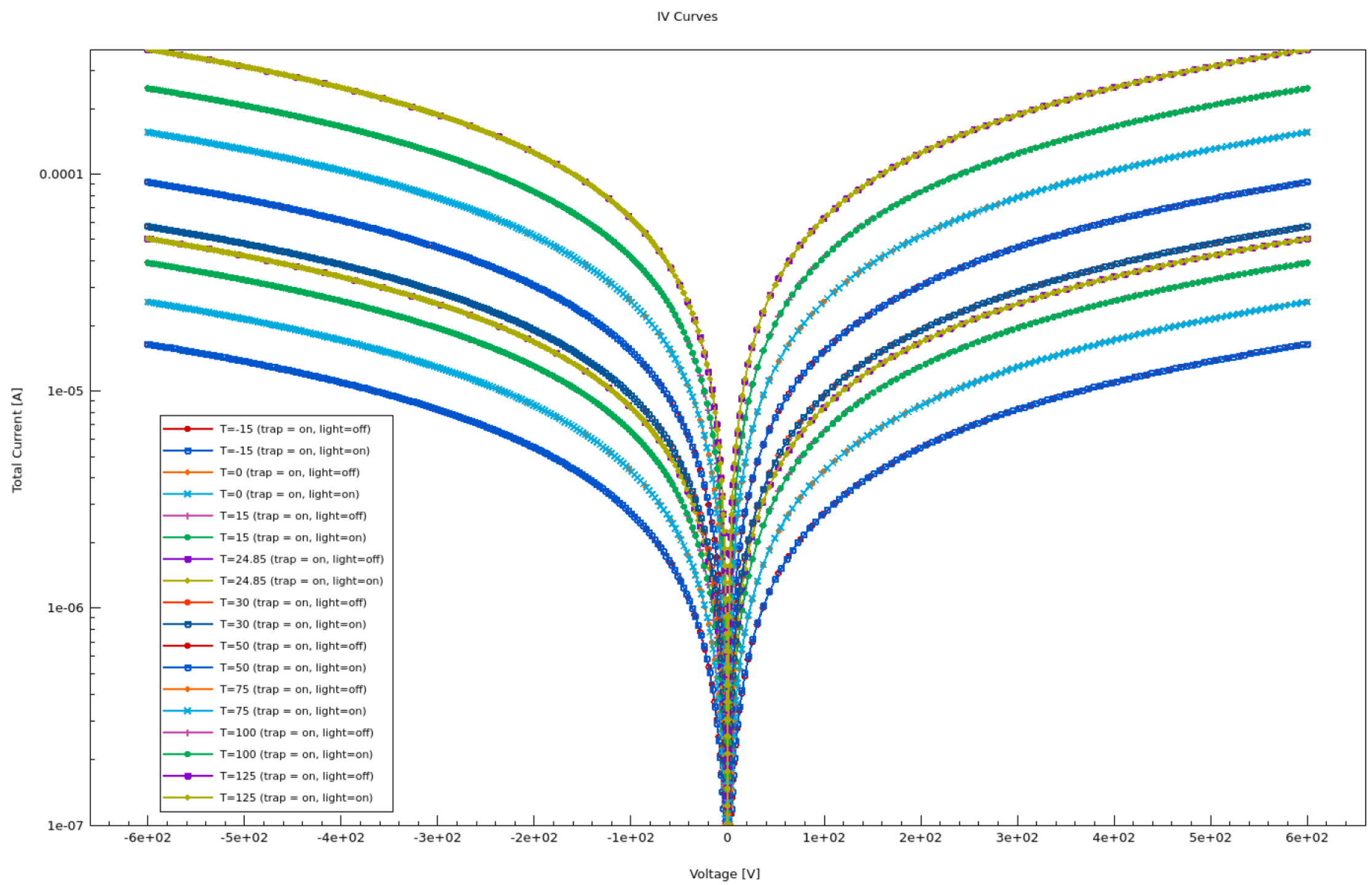
Trap Distribution Model Off



OF ENGINEERING
ITY of HAWAI'I at MĀNOA

Linear

Trap Distribution Model On



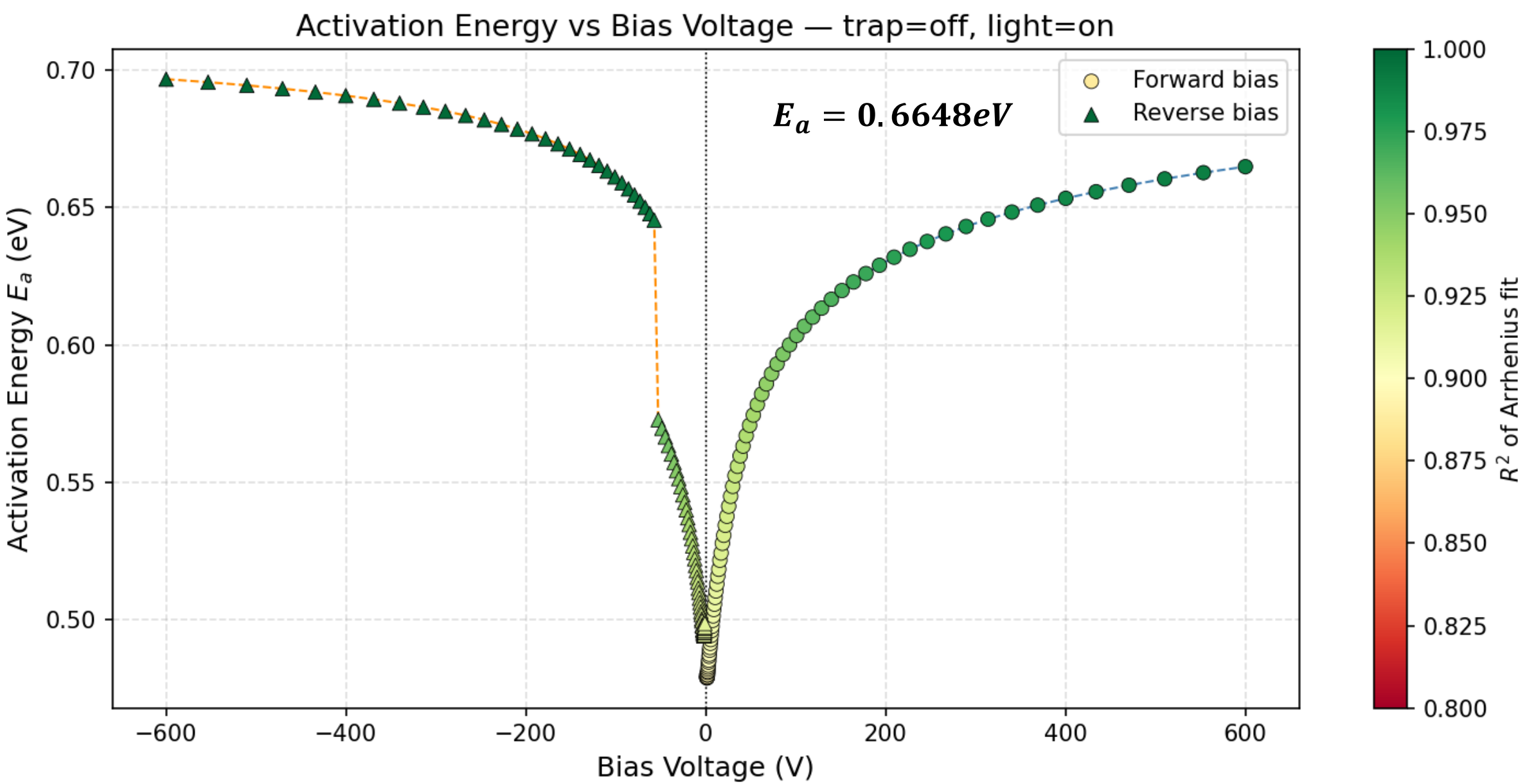
OF ENGINEERING
TY of HAWAI'I at MĀNOA

Log

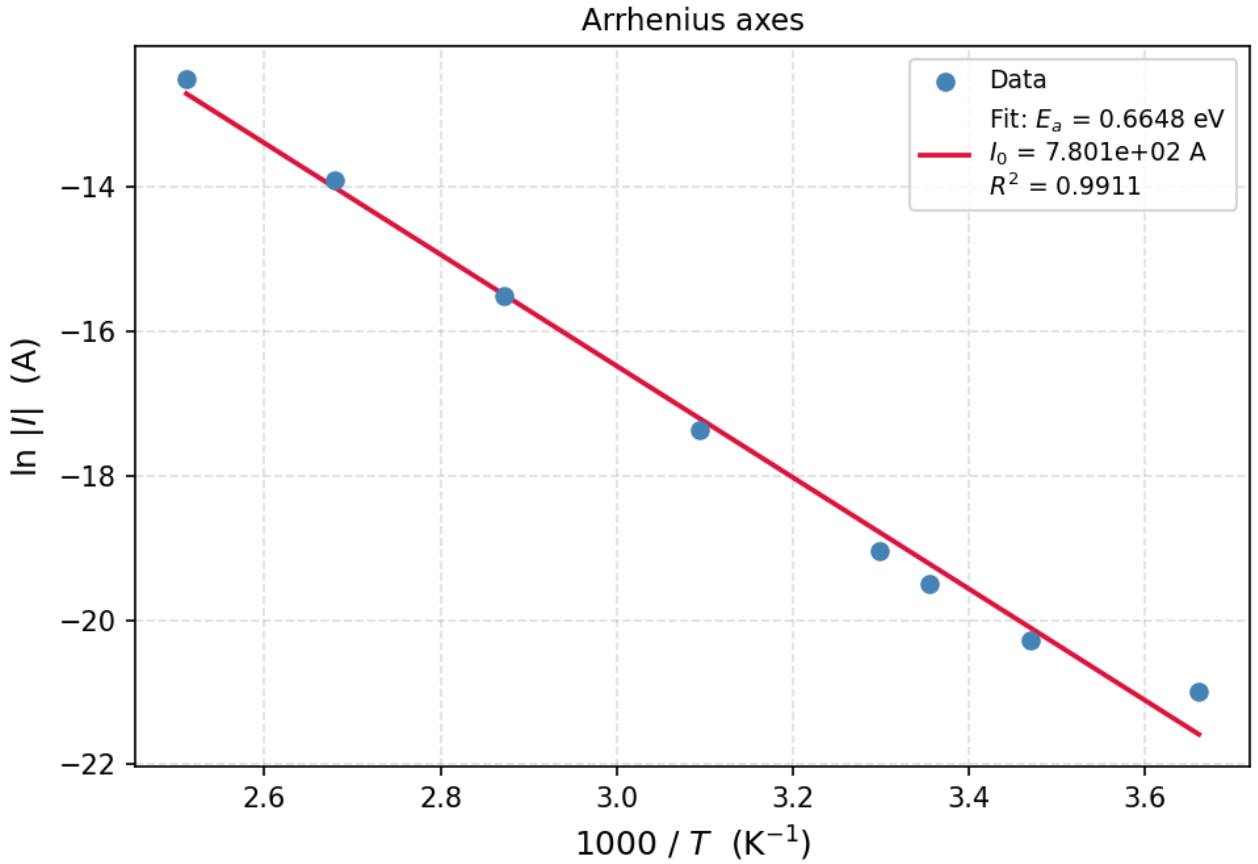
Trap Distribution Model On

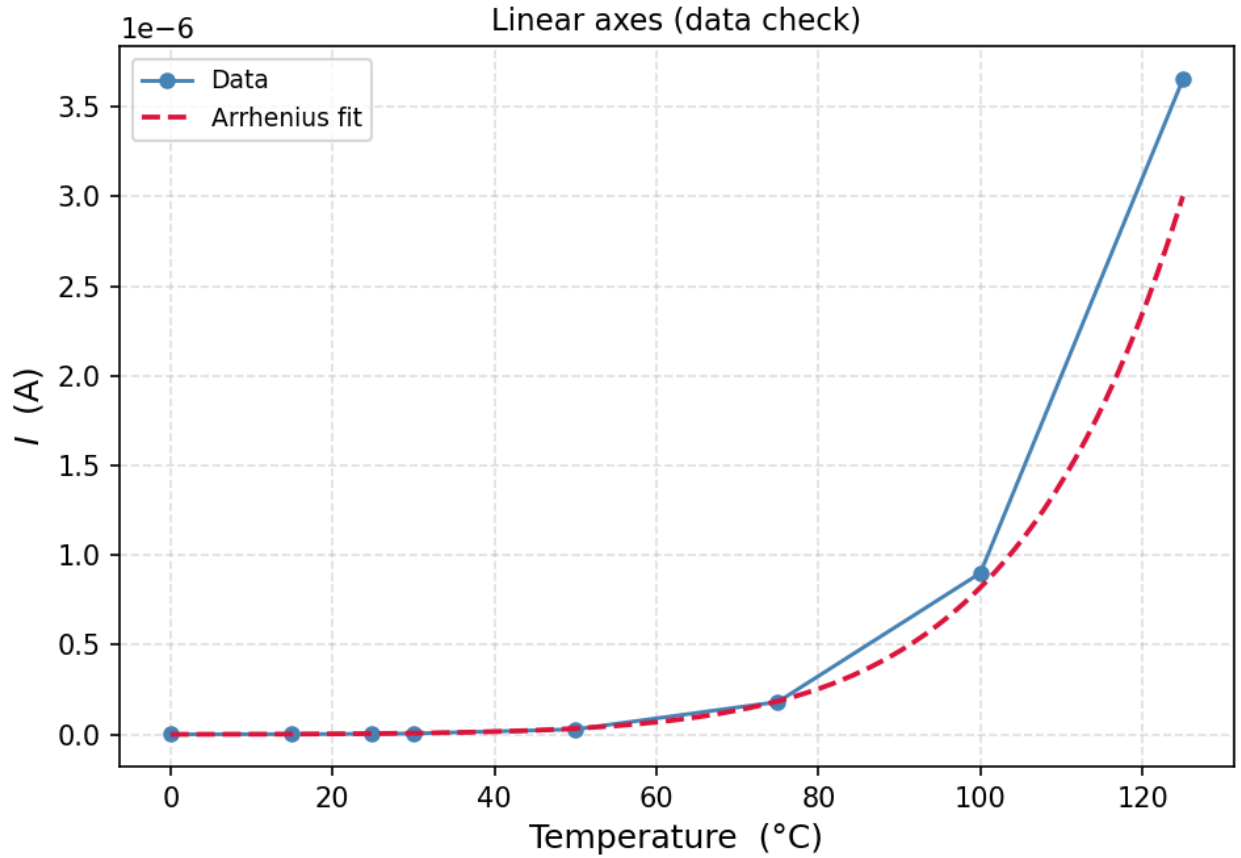
Arrhenius Plots for the IV Temperature Dependency Curves using Geant4 Energy Deposition Profiles for CLS and DLS profiles

Arrhenius Plot - CLS

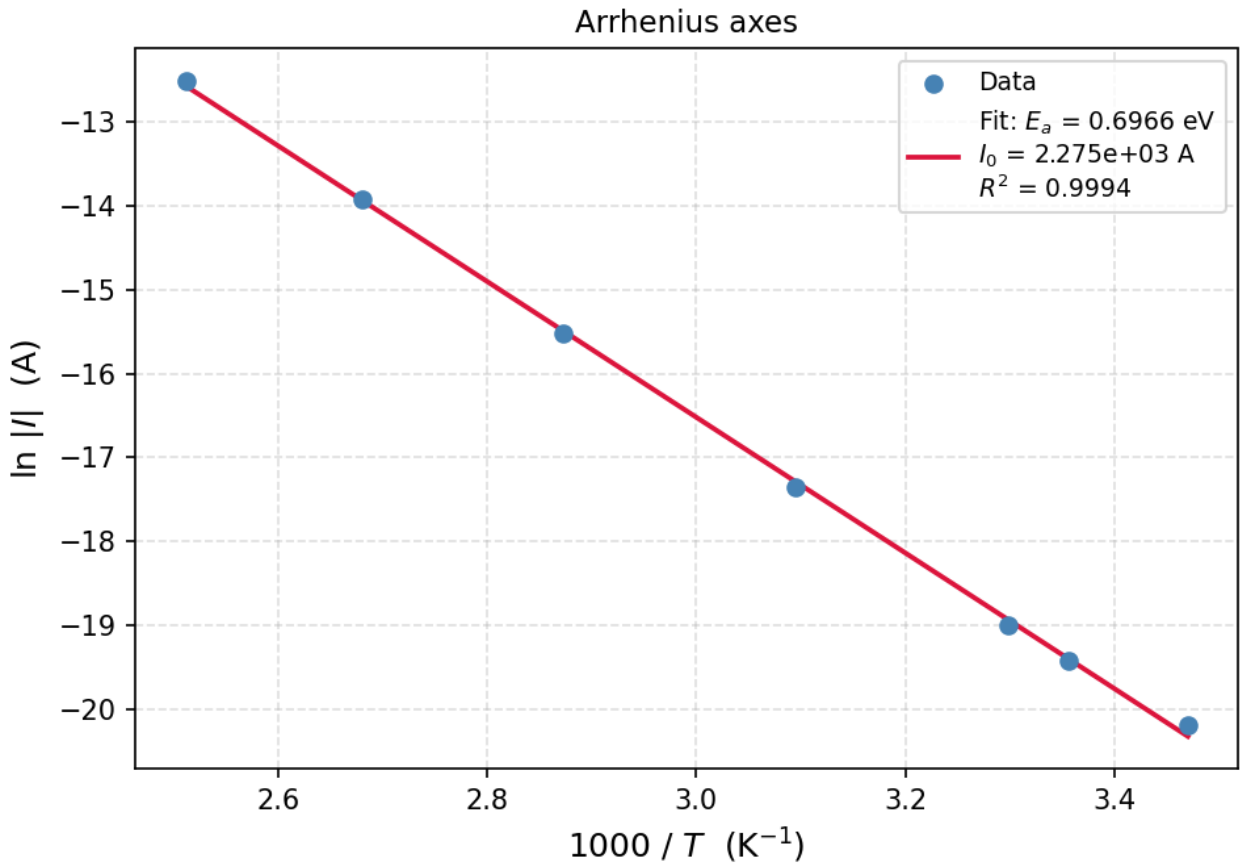

Activation Energy vs Bias Voltage — trap=off, light=on
$E_a = 0.6648eV$
Forward bias
Reverse bias
Activation Energy E_a (eV)
0.70
0.65
0.60
0.55
0.50
−600
−400
−200
0
200
400
600
Bias Voltage (V)
1.000
0.975
0.950
0.925
0.900
0.875
0.850
0.825
0.800
R^2 of Arrhenius fit

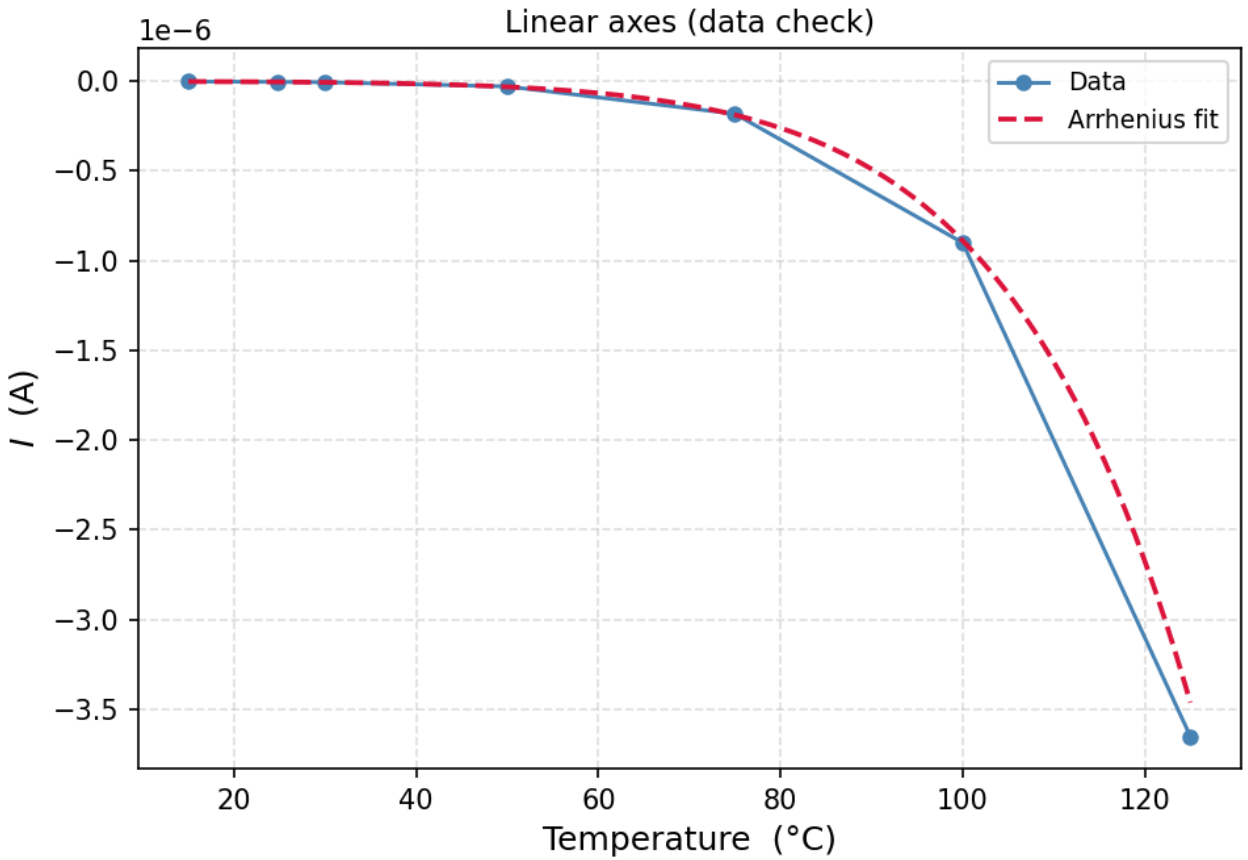
trap=off, light=on (bias = +600.0 V)

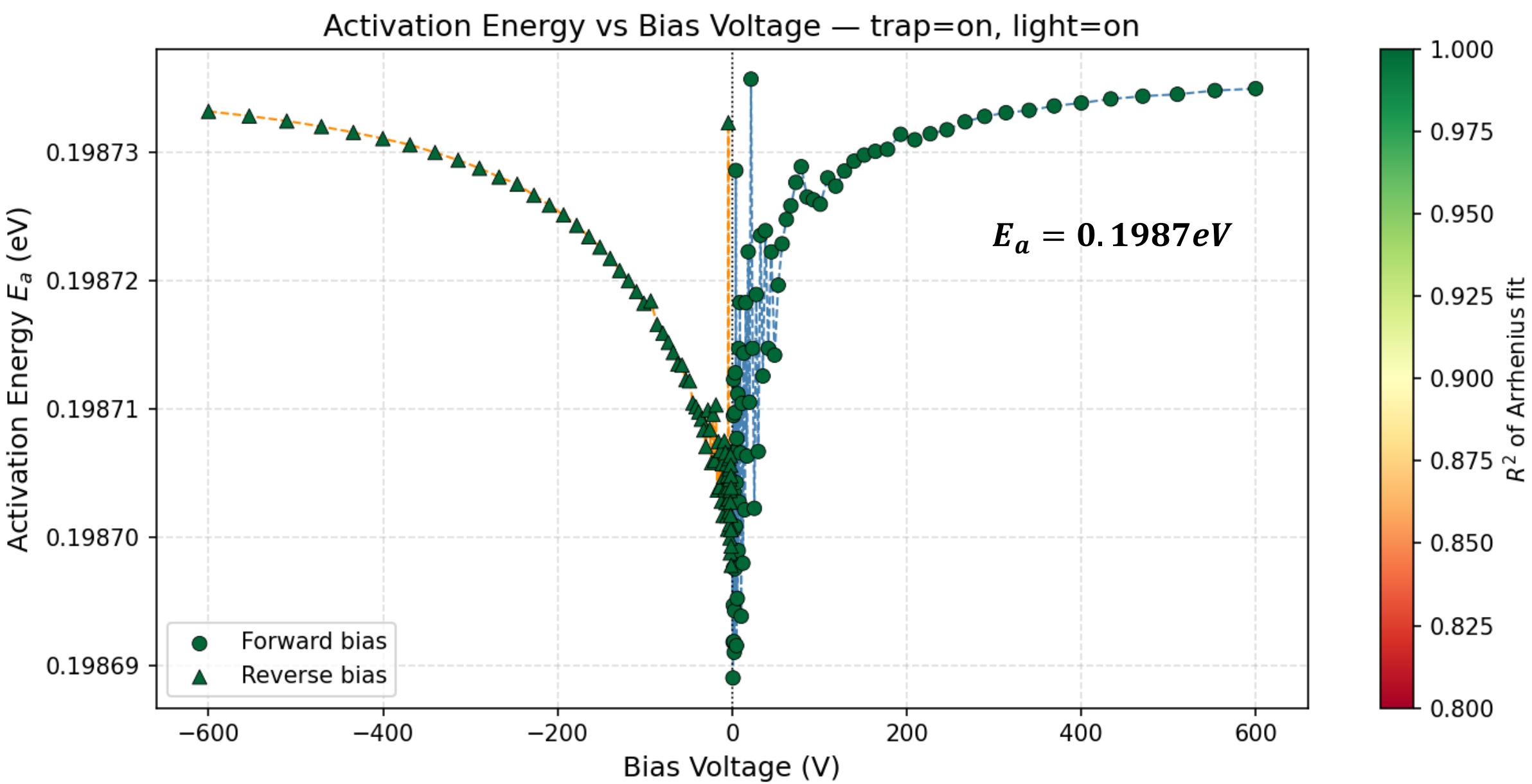




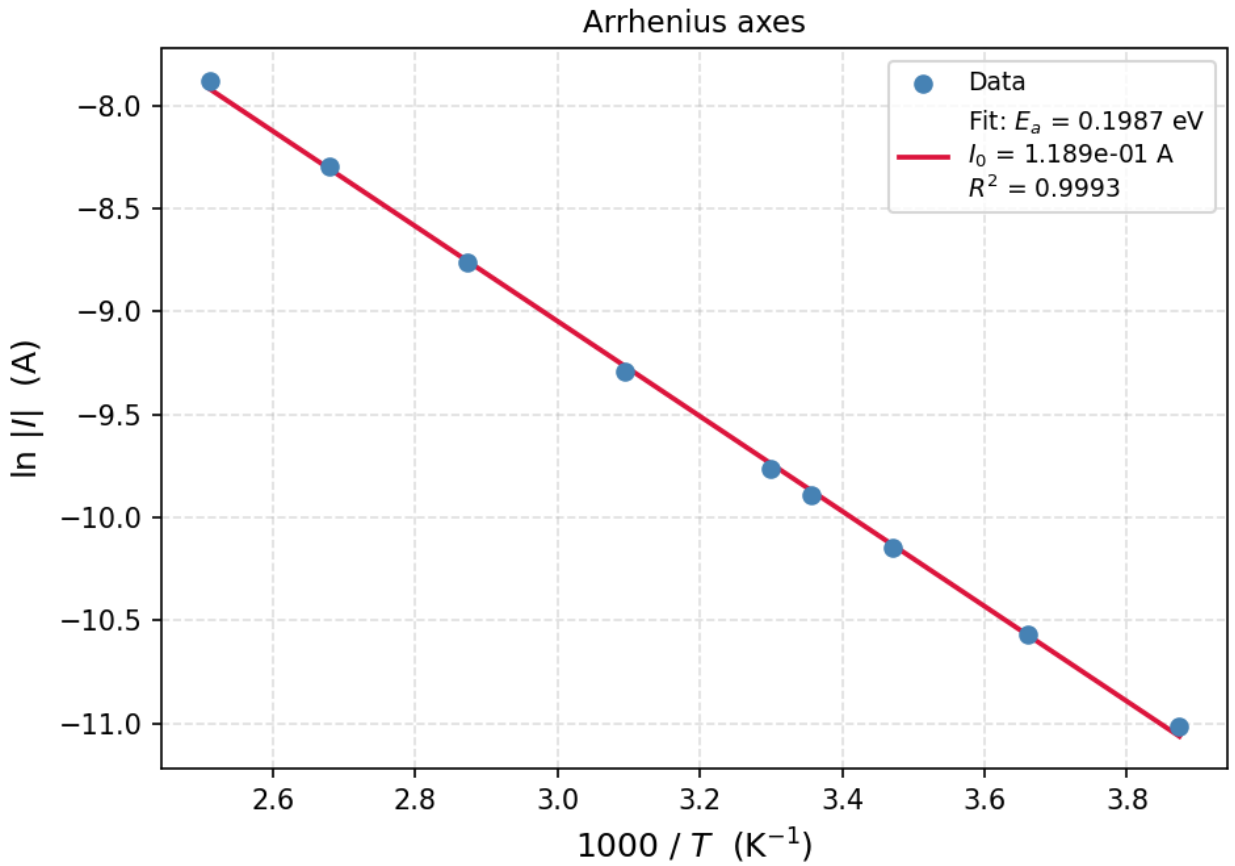
trap=off, light=on (bias = -600.0 V)

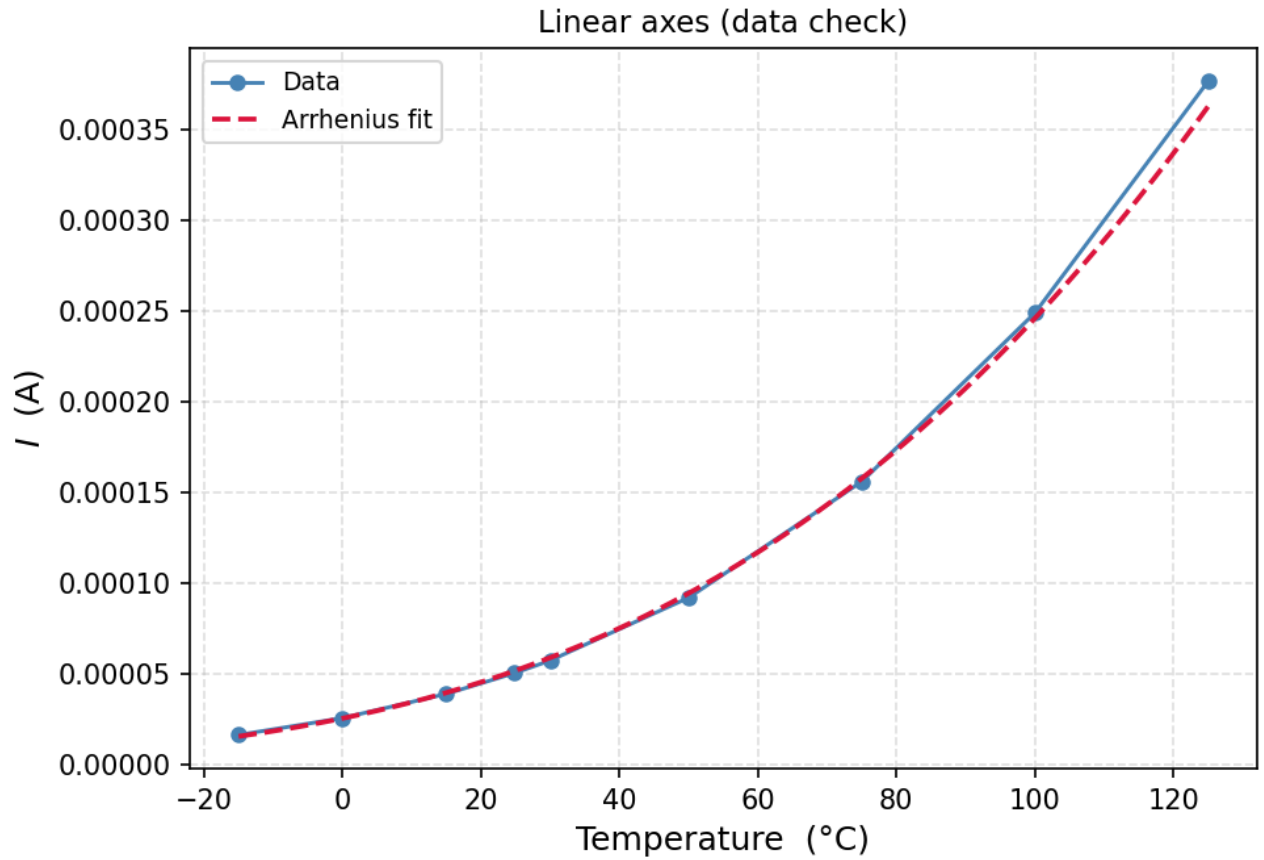




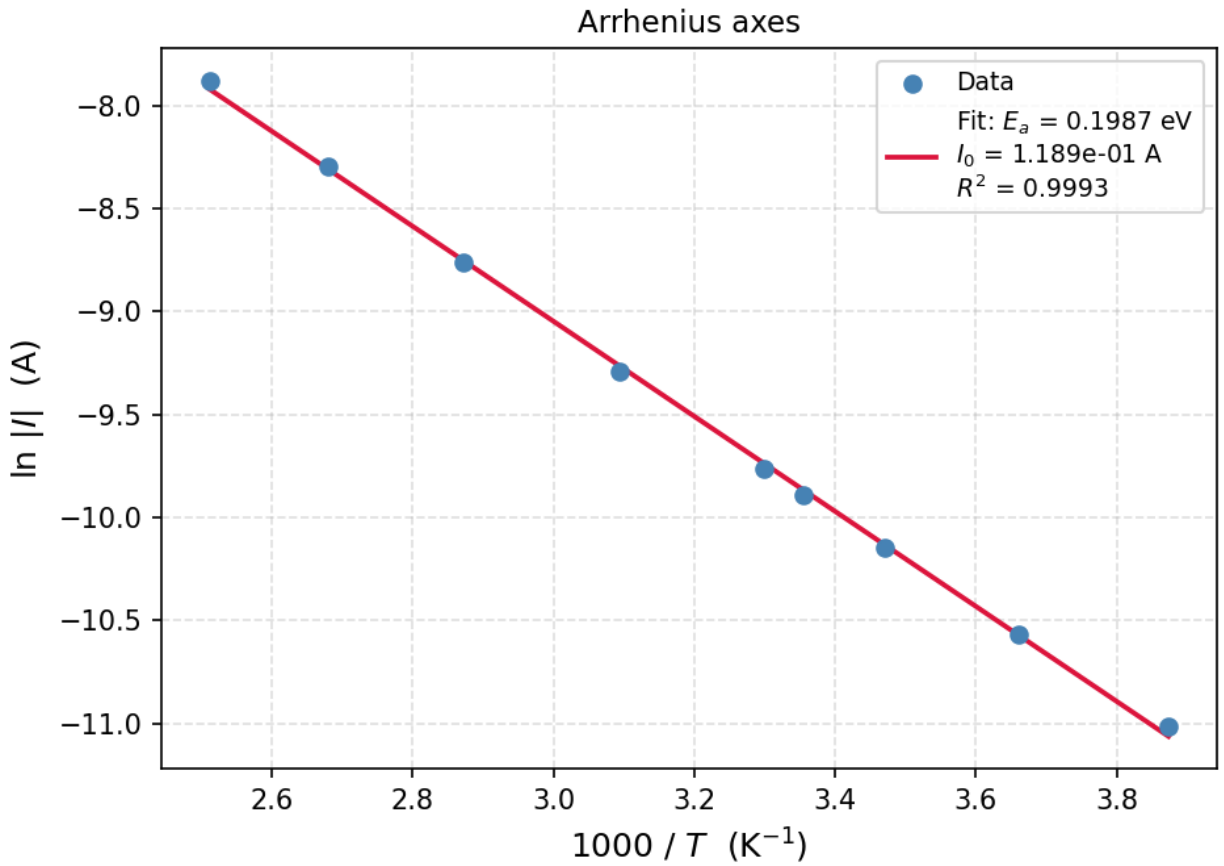

Activation Energy vs Bias Voltage — trap=on, light=on
Activation Energy E_a (eV)
0.19873
0.19872
0.19871
0.19870
0.19869
$E_a = 0.1987eV$
Forward bias
Reverse bias
−600
−400
−200
0
200
400
600
Bias Voltage (V)
1.000
0.975
0.950
0.925
0.900
0.875
0.850
0.825
0.800
R^2 of Arrhenius fit

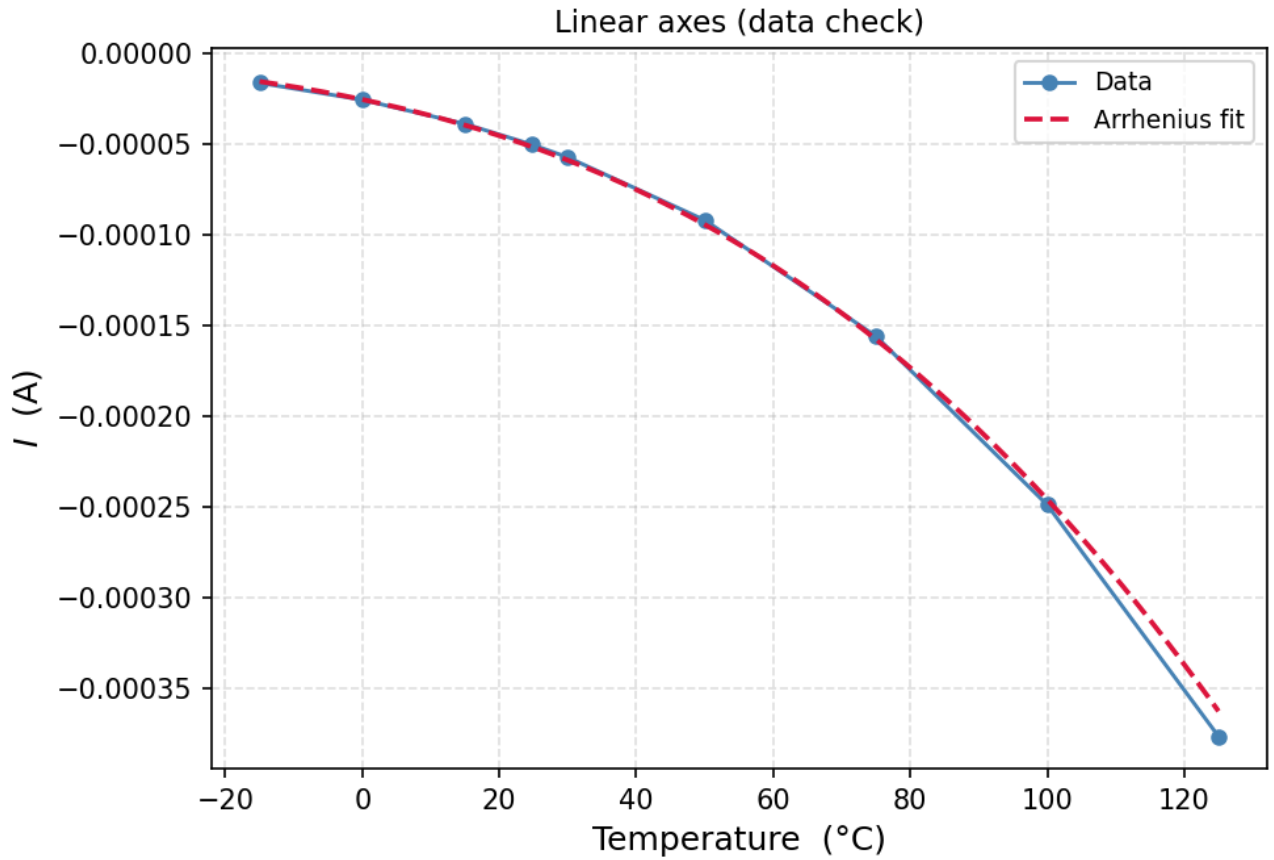
trap=on, light=on (bias = +600.0 V)



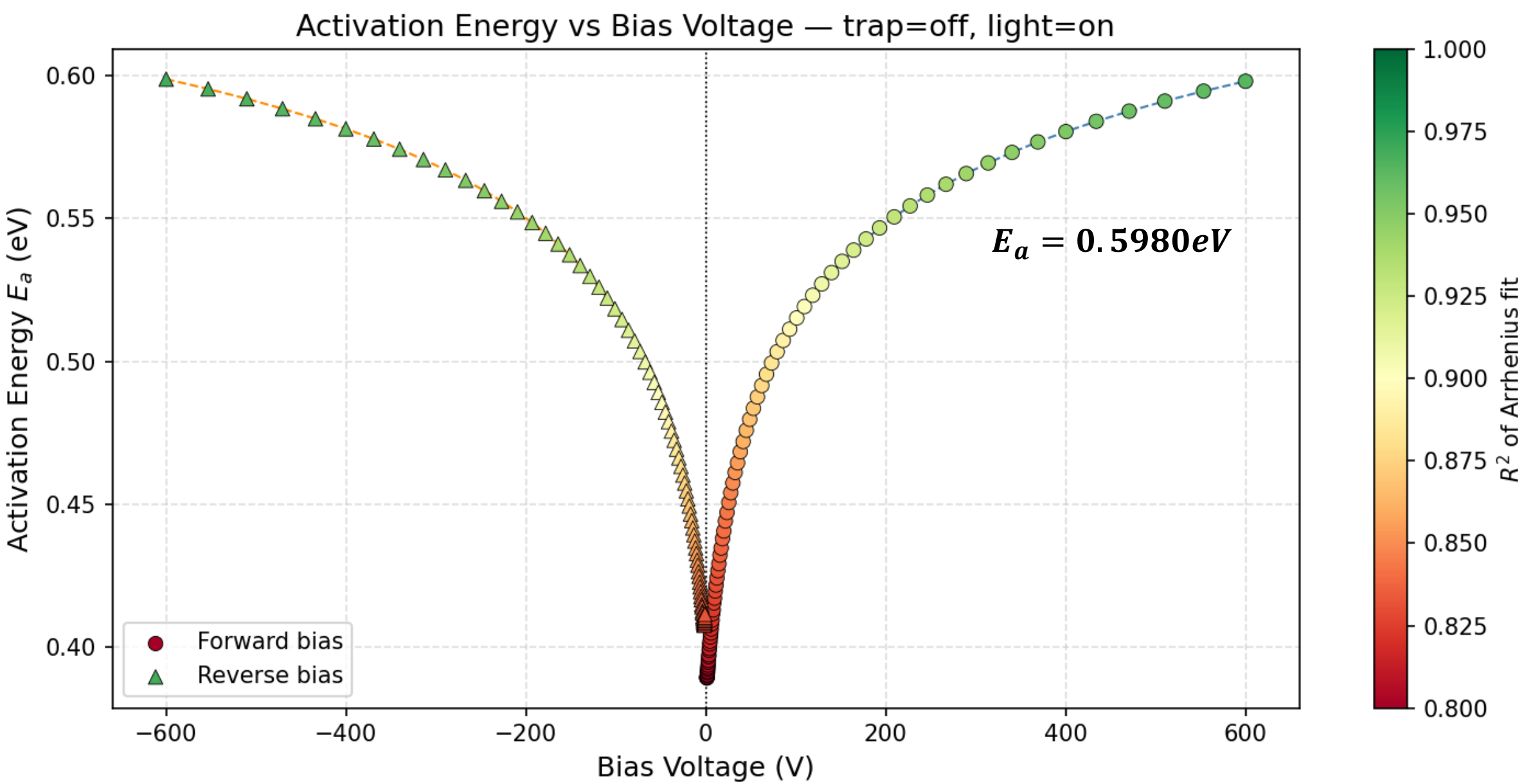


trap=on, light=on (bias = -600.0 V)

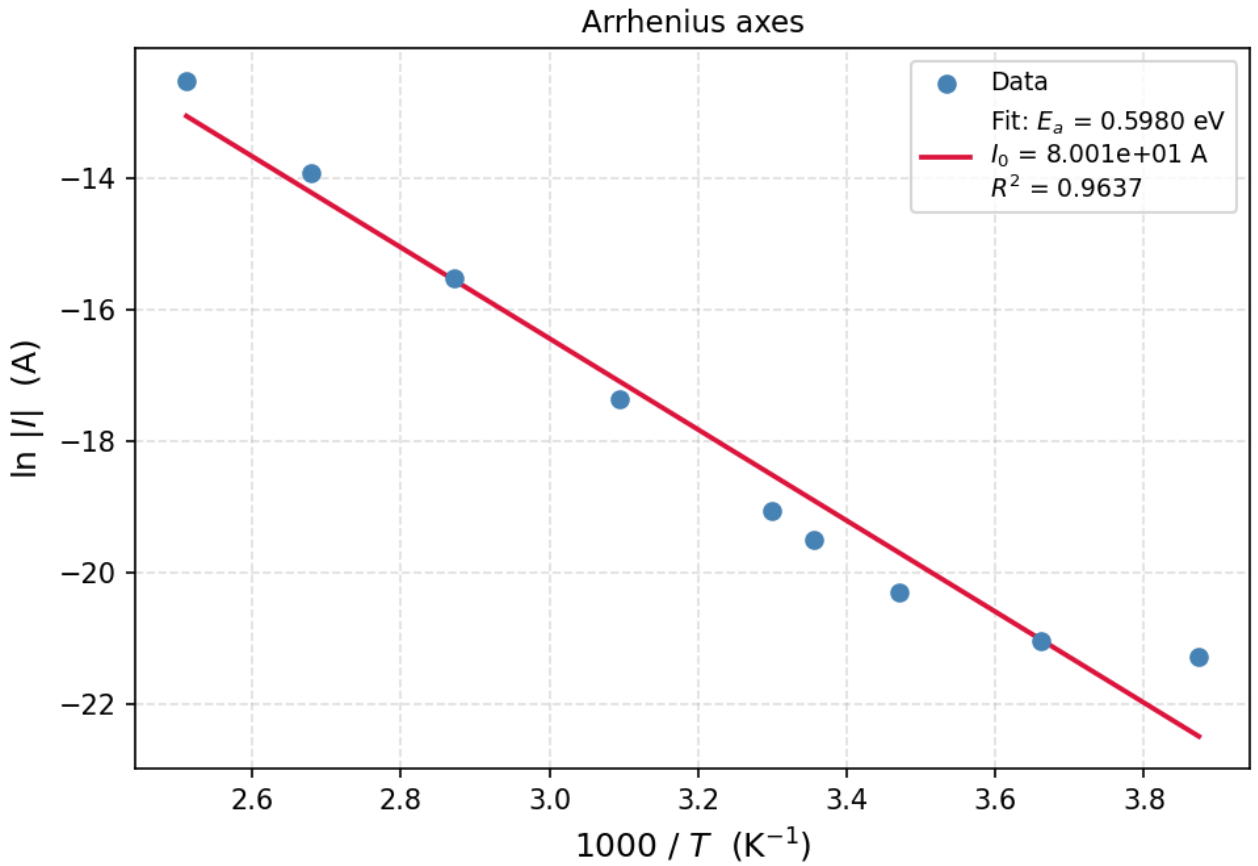


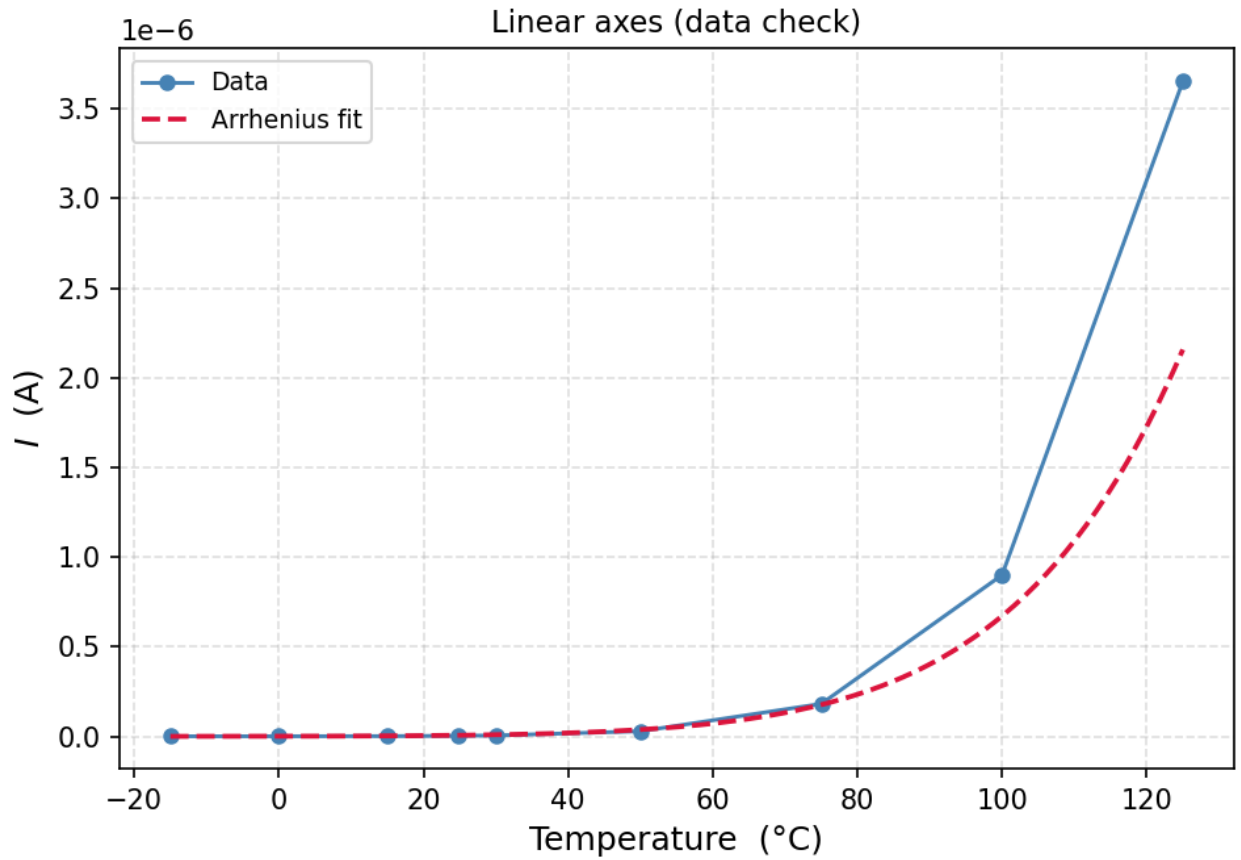


Arrhenius Plot - DLS

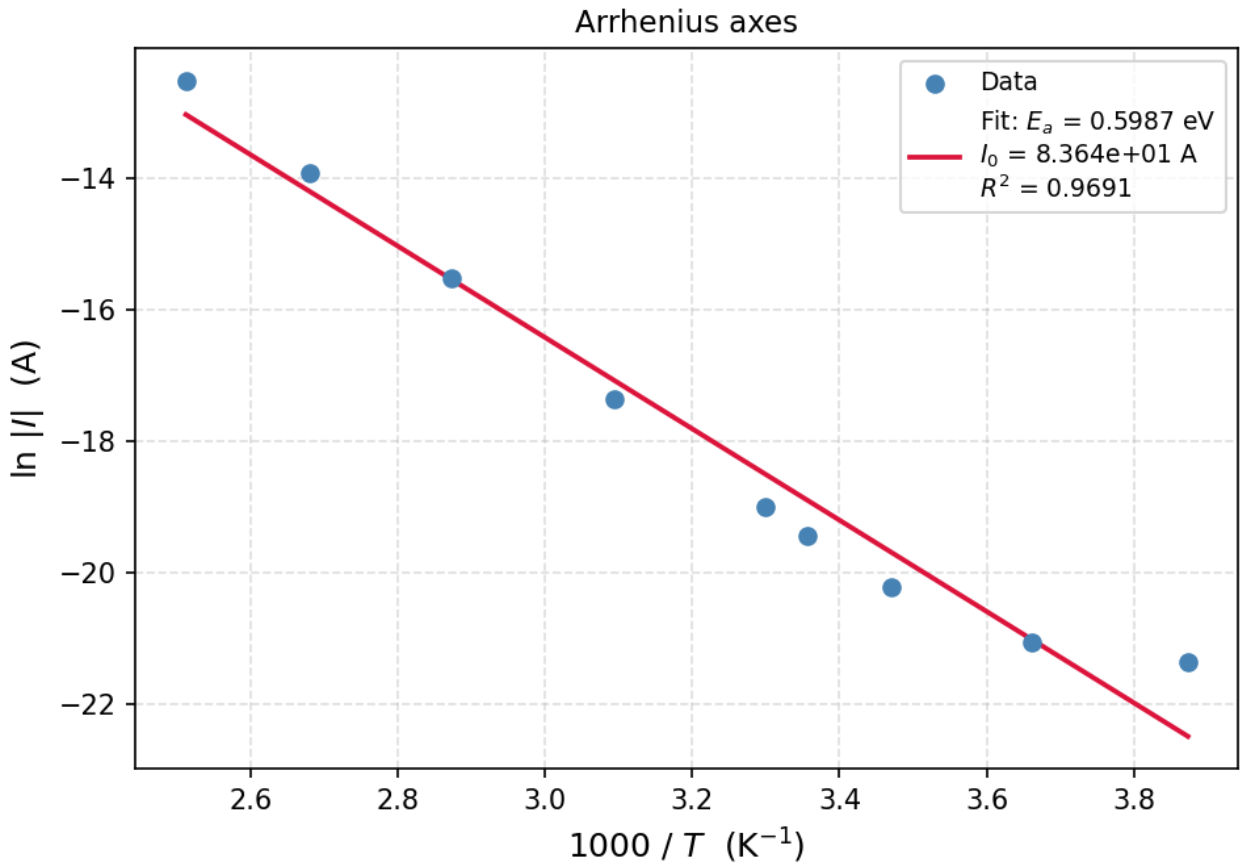

Activation Energy vs Bias Voltage — trap=off, light=on
Activation Energy E_a (eV)
0.60
0.55
0.50
0.45
0.40
−600
−400
−200
0
200
400
600
Bias Voltage (V)
Forward bias
Reverse bias
$E_a = 0.5980eV$
1.000
0.975
0.950
0.925
0.900
0.875
0.850
0.825
0.800
R^2 of Arrhenius fit

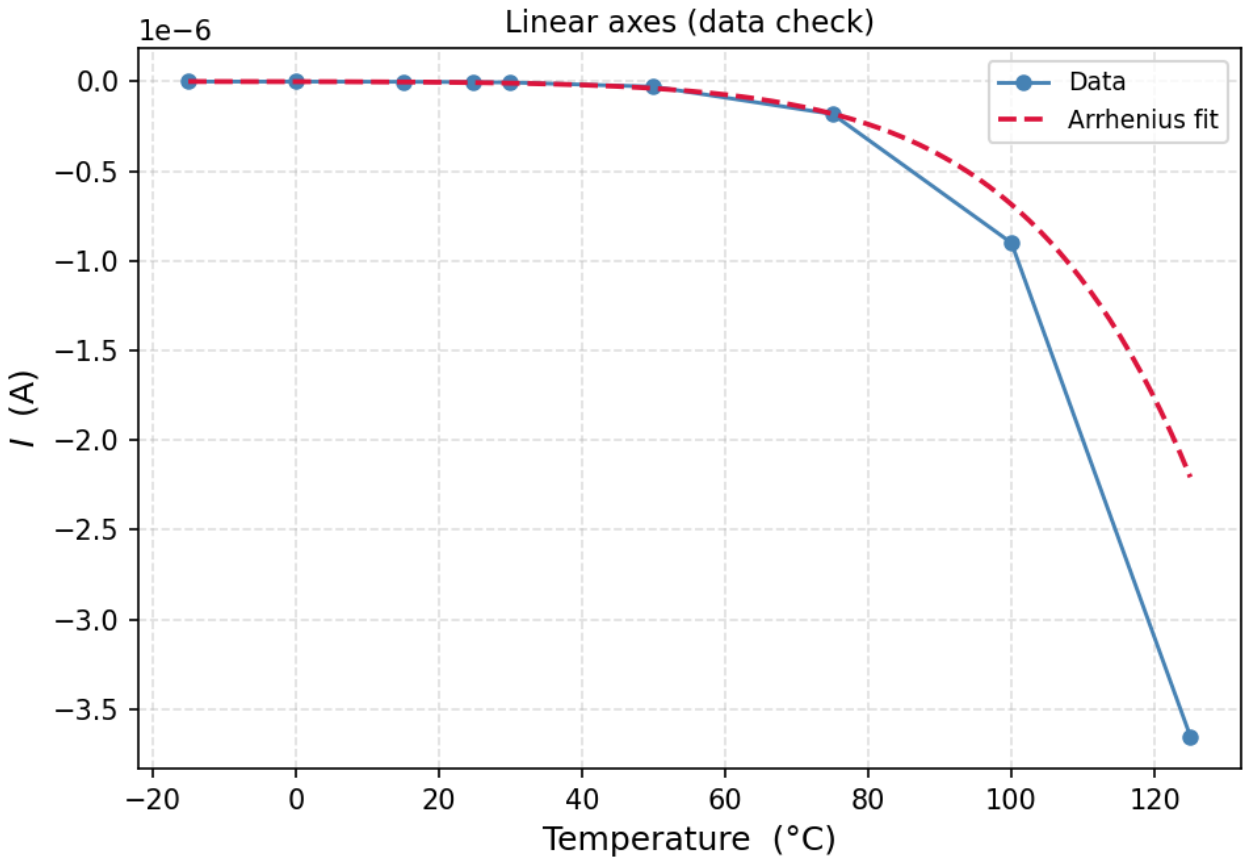
trap=off, light=on (bias = +600.0 V)

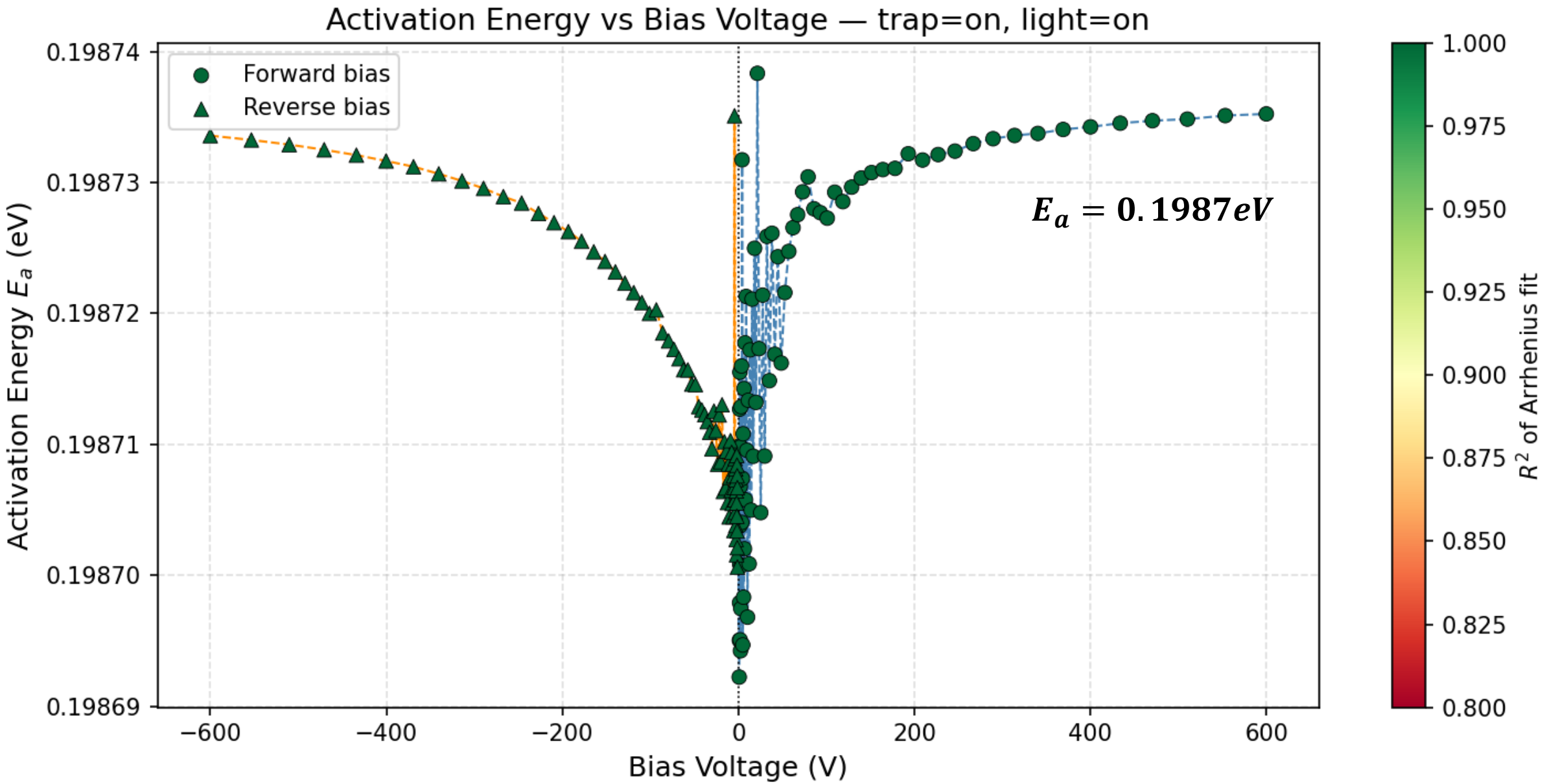




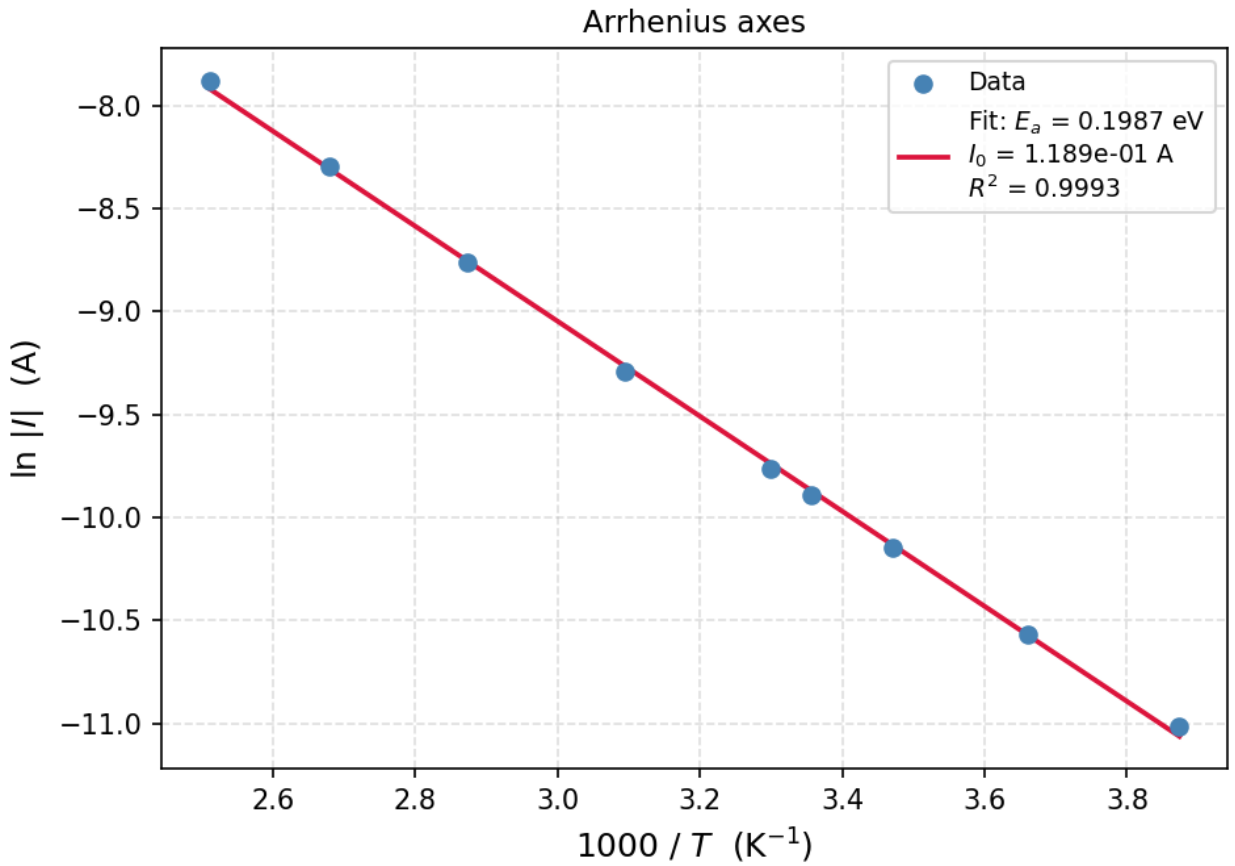
trap=off, light=on (bias = -600.0 V)

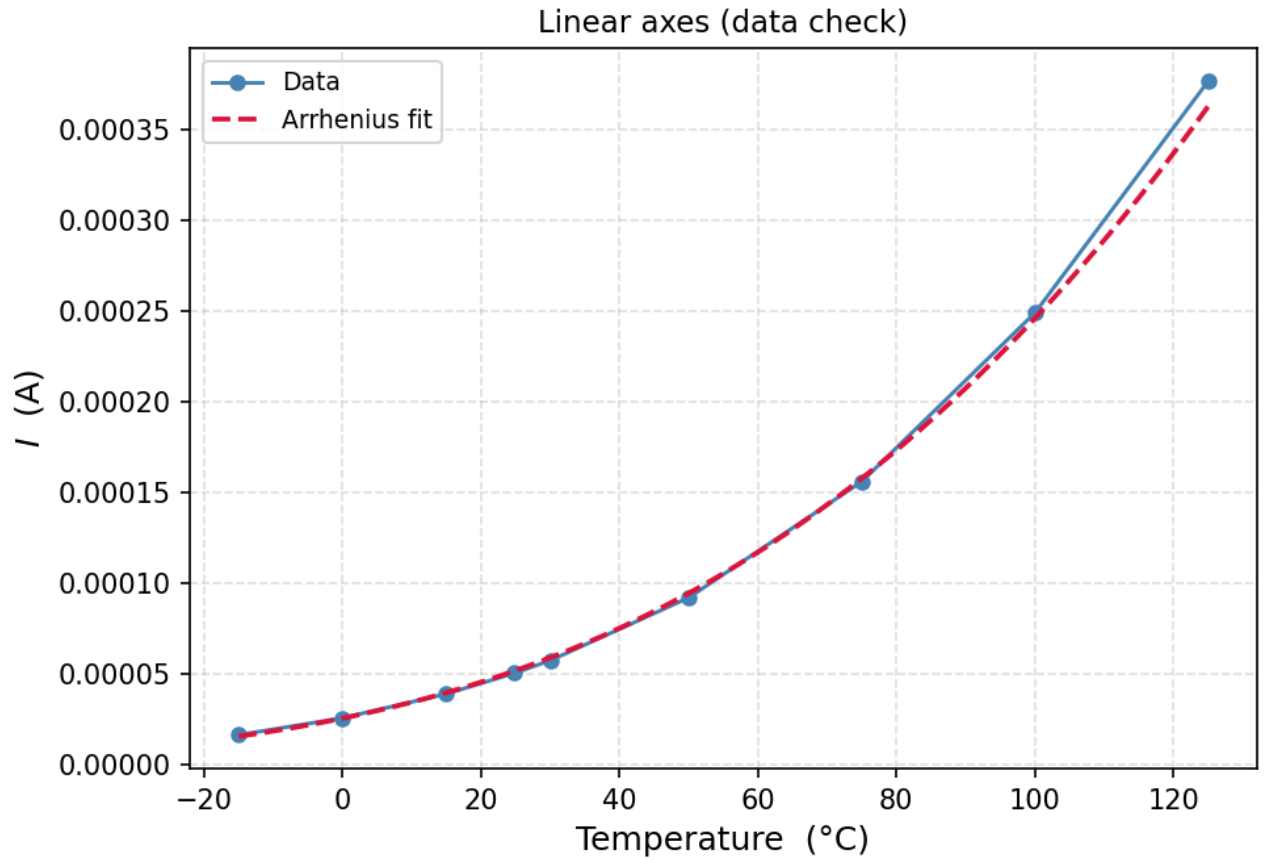





Activation Energy vs Bias Voltage — trap=on, light=on
Forward bias
Reverse bias
$E_a = 0.1987eV$
Activation Energy E_a (eV)
0.19874
0.19873
0.19872
0.19871
0.19870
0.19869
−600
−400
−200
0
200
400
600
Bias Voltage (V)
1.000
0.975
0.950
0.925
0.900
0.875
0.850
0.825
0.800
R^2 of Arrhenius fit

trap=on, light=on (bias = +600.0 V)





trap=on, light=on (bias = -600.0 V)

