EE788: Reliability Assignments

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Rel-2

We are given ΔN_{IT} vs time data for delays of 10s and 100s.
We first convert ΔN_{IT} to ΔV_T using the relation:

$$\Delta V_T = q\Delta N_{IT}/C_{ox}$$

For C_{ox}, we assume $T_{\text{IL, SiO2}} = 0.3nm$ and $T_{\text{HK, HfO2}} = 2.3nm$

We know that $V_T(EOS)$ follows power law, and is of the form $A \cdot t^{1/6}$, and the relation between $V_T(EOS)$ and V_T is given as follows:

$$\Delta V_T = \frac{\Delta V_T(EOS)}{1 + k \cdot (t_{rec}/t_{stress})^m}$$

This relation is used to fit both data sets with different ΔV_T such that they have the same $\Delta V_T(EOS)$ and k, m values.

Results

- $k = 0.9870$
- $m = 0.2413$
- $A = 0.0037$
- Slope of data with delay 10s before correction = 0.2432
- Slope of data with delay 100s before correction = 0.2704
- Slope of corrected data = 0.1667

The log-log plot of ΔV_T vs stress times is given below. The scatter plot is the given data, and the solid lines are the fitted lines.

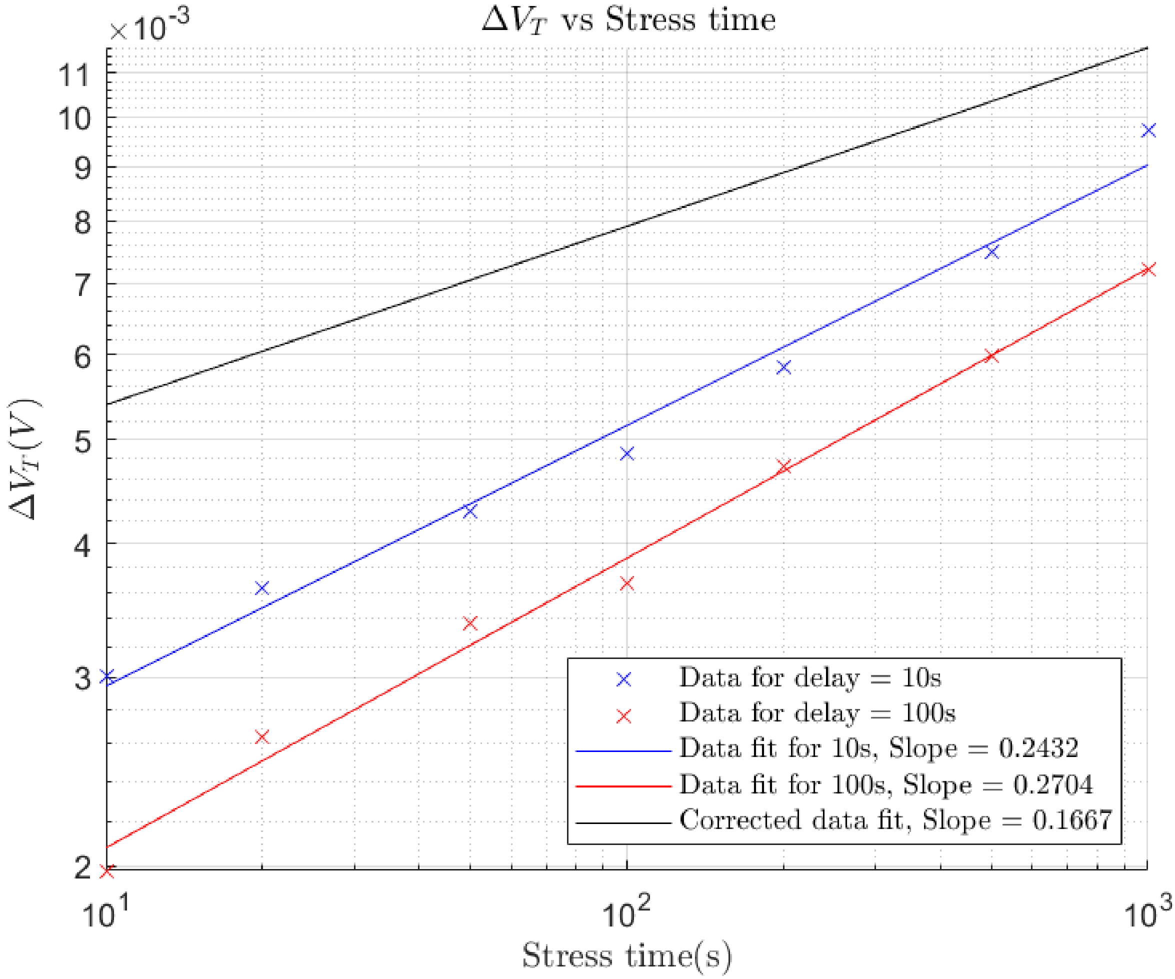


Figure 1: Fit of data to find k, m and $\Delta V_T(EOS)$

Rel-3

We are given ΔN_{IT} vs time data for delays of 10s and 100s.
We first convert ΔN_{IT} to ΔV_T using the relation:

$$\Delta V_T = q\Delta N_{IT}/C_{ox}$$

For C_{ox}, we assume $T_{\text{IL, SiO2}} = 0.3nm$ and $T_{\text{HK, HfO2}} = 2.3nm$

We have:

$$\Delta V_T = A \cdot {V_G}^{\Gamma} \cdot e^{-E_A/k_B T} \cdot t^n$$

The following steps are used to find the various parameters (n is fixed as 1/6):

- Take log of given ΔV_T data, and find slope of fit with x as $-q/k_B \cdot T$. This gives E_A in eV.
- Take log of given ΔV_T data, and find slope of fit with x as log of V_g. This gives γ.
- Using these values, run optimizer to minimine cost function and find A.

This relation is used to fit both data sets with different ΔV_T such that they have the same $\Delta V_T(EOS)$ and k, m values.

Results

(All in respective SI units unless otherwise mentioned)

- $n = 0.1667$
- $\gamma = 4.5597$
- $E_A = 0.0832$ (in eV)
- $A = 0.0123$

The log-log plot of ΔV_T vs stress times is given below. The scatter plot is the given data, and the solid lines are the fitted lines.

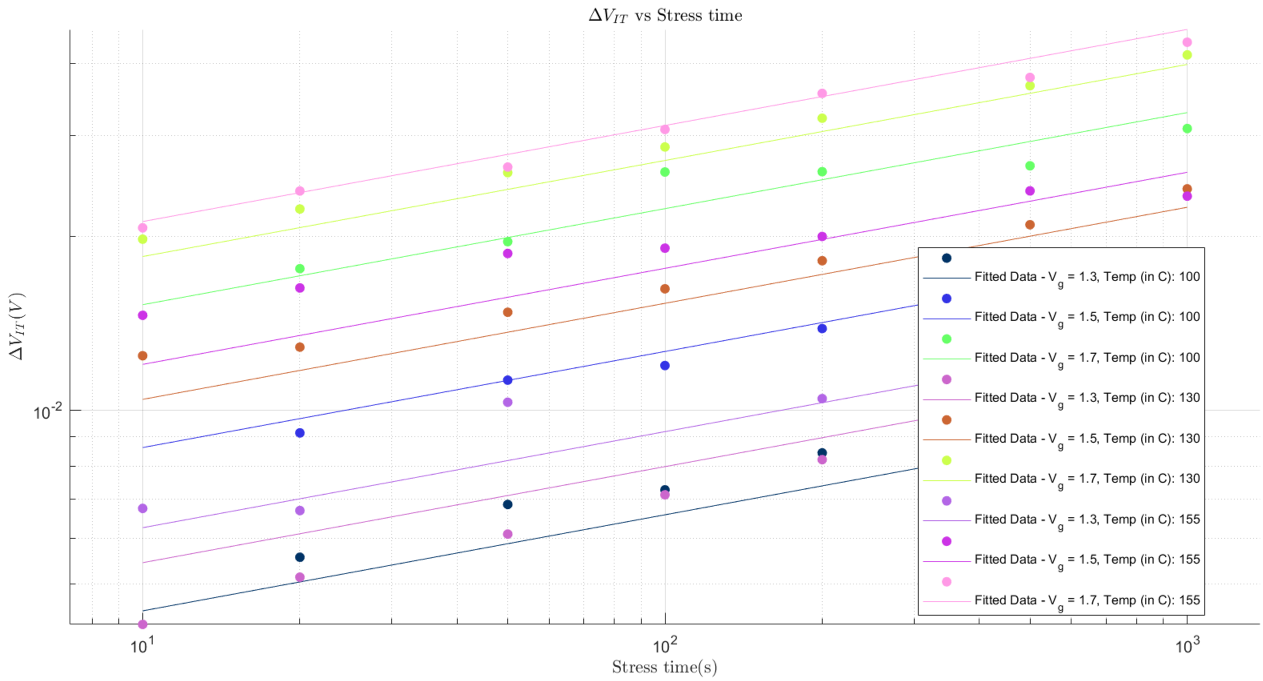


Figure 2: Fit of data to find γ, E_A, A

Rel-4

Stress Data

For the first part, we take the given data (Sheet 1) and fit the 7x16 data to find n, γ, E_A, A using stress times in the first column. We have:

$$\Delta V_T = A \cdot {V_G}^{\Gamma} \cdot e^{-E_A/k_B T} \cdot t^n$$

The following steps are used to find the various parameters:

- Take log of given ΔV_T data and find the slope of fit with x as stress times for n.
- Take log of given ΔV_T data, find slope of fit with x as $-q/k_B T$ to get E_A in eV.
- Take log of given ΔV_T data, and find slope of fit with x as log of V_g. This gives γ.
- Using these values, run optimizer to minimize cost function and find A.

Results

(All in respective SI units unless otherwise mentioned)

- $n = 0.1358$
- $\gamma = 4.6365$
- $E_A = 0.0881$ (in eV)
- $A = 0.0601$

The log-log plot of ΔV_T vs stress times is given below. The scatter plot is the given data, and the solid lines are the fitted lines.

Recovery Data

Now, we fix stress time as 1000s, which gives $\Delta V_T(EOS)$ as the last row data from Sheet 1.
This is used for data in Sheet 2 which represents ΔV_T. We want to find universal k, m for all voltages and temperatures.

Here first column represents the different delay values (we see that as delay increases, ΔV_T decreases in the log-log plot).

The relation between $V_T(EOS)$ and V_T is given as follows:

$$\Delta V_T = \frac{\Delta V_T(EOS)}{1 + k \cdot (t_{rec}/t_{stress})^m}$$

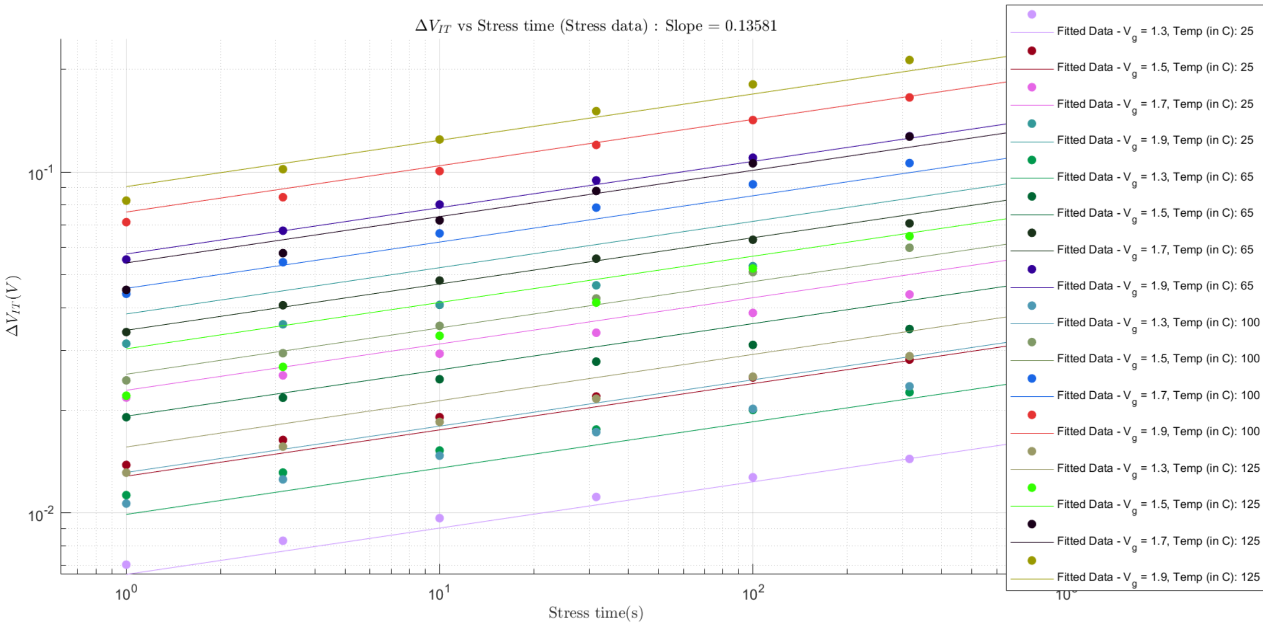


Figure 3: Fit of data to find n, γ, E_A, A

Results

- $k = 1.0661$
- $m = 0.1052$

The log-log plot of ΔV_T vs Recovery times is given below. The scatter plot with triangles pointing to left is the given data from sheet 2, and the points with triangles pointing to the right are the fitted values from calculated k, m values and $\Delta V_T(EOS)$ from Sheet 1's last row 1000s stress data.

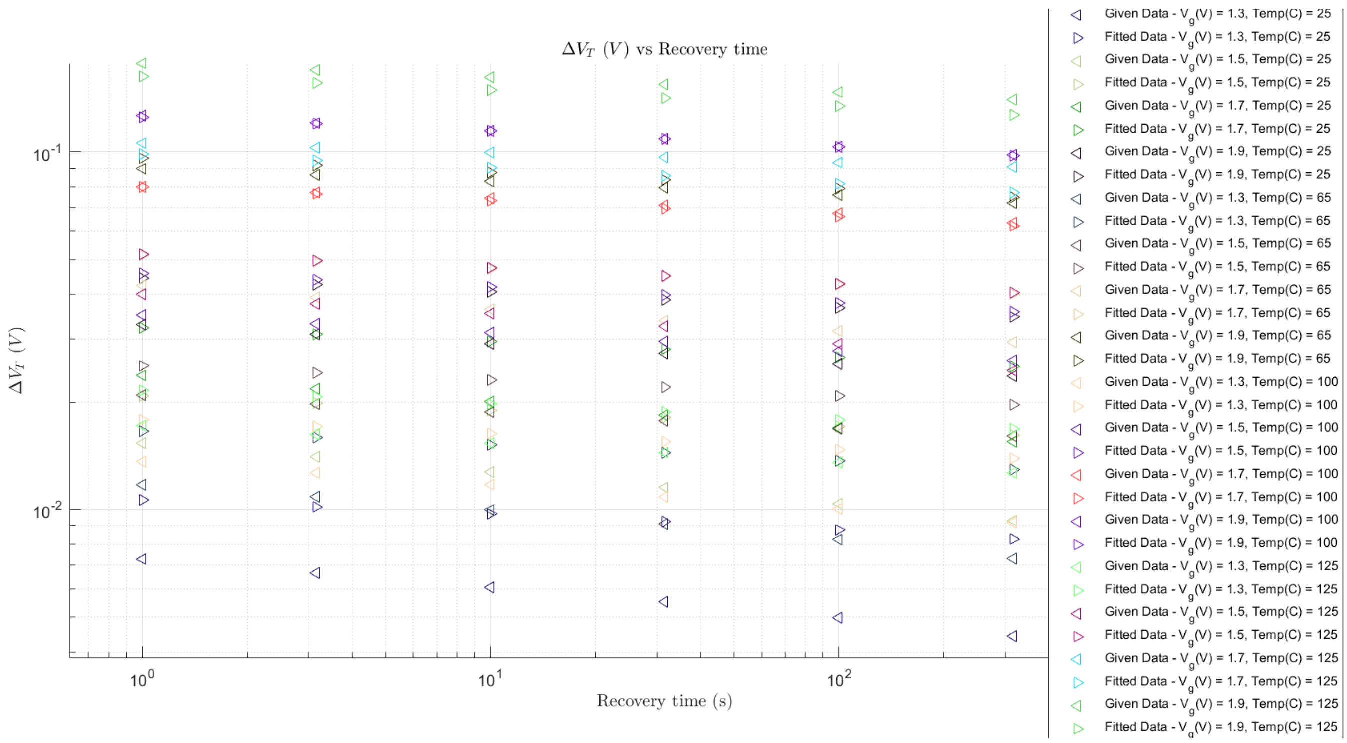


Figure 4: Fit of data to find k, m

Rel-5

We have:

$$\Delta V_T = A_{IT} \cdot {V_G}^{\Gamma_{IT}} \cdot e^{-E_{A_{IT}}/k_B T} \cdot t^{(1/6)} + A_{HT} \cdot {V_G}^{\Gamma_{HT}} \cdot e^{-E_{A_{HT}}/k_B T} \cdot t^{(0)}$$

An optimizer is run to find the 6 parameters with subscripts above, with the following initial guesses:

- $A_{IT} = 30$
- $\gamma_{IT} = 4.5$
- $E_{A_{IT}} = 0.08eV$
- $A_{HT} = 3$
- $\gamma_{HT} = 4.5$
- $E_{A_{HT}} = 0.05eV$

This relation is used to fit both data sets with different ΔV_T such that they have the same $\Delta V_T(EOS)$ and k, m values.

Results

(All in respective SI units unless otherwise mentioned)

- $A_{IT} = 0.055266$
- $\gamma_{IT} = 4.072905$
- $E_{A_{IT}} = 0.093317eV$

- $A_{HT} = 0.100569$
- $\gamma_{HT} = 4.117850$
- $E_{A_{HT}} = 0.100361eV$

The log-log plot of ΔV_T vs stress times is given below. The scatter plot is the given data, and the solid lines are the fitted lines.
The contributions of each component is given by the bar plot below.

We see that the contribution of the interface trap component is around 55% for all three temperatures/voltages, and the contribution of the hole trap component is around 45%.

- With increasing temperature and voltage, the contribution of the interface trap component decreases
- With increasing temperature and voltage, the contribution of the hole trap component increases

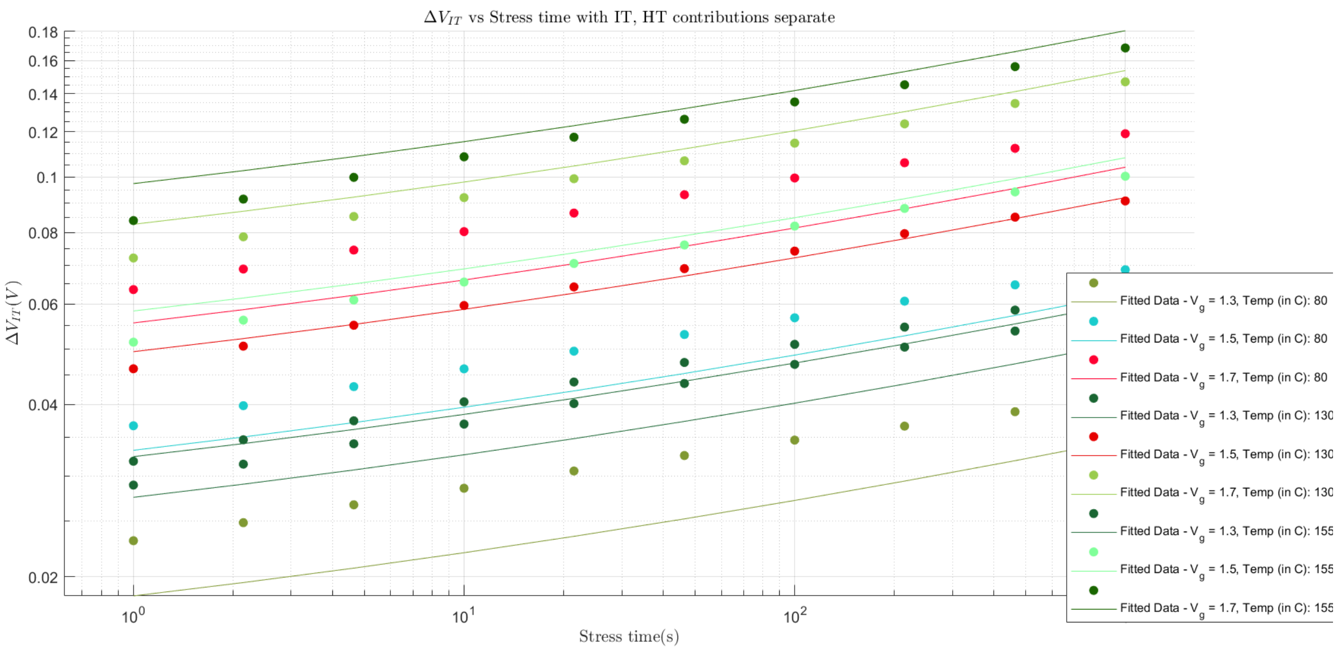


Figure 5: Fit of data to find A_{IT}, γ_{IT}, $E_{A_{IT}}$, A_{HT}, γ_{HT}, $E_{A_{HT}}$

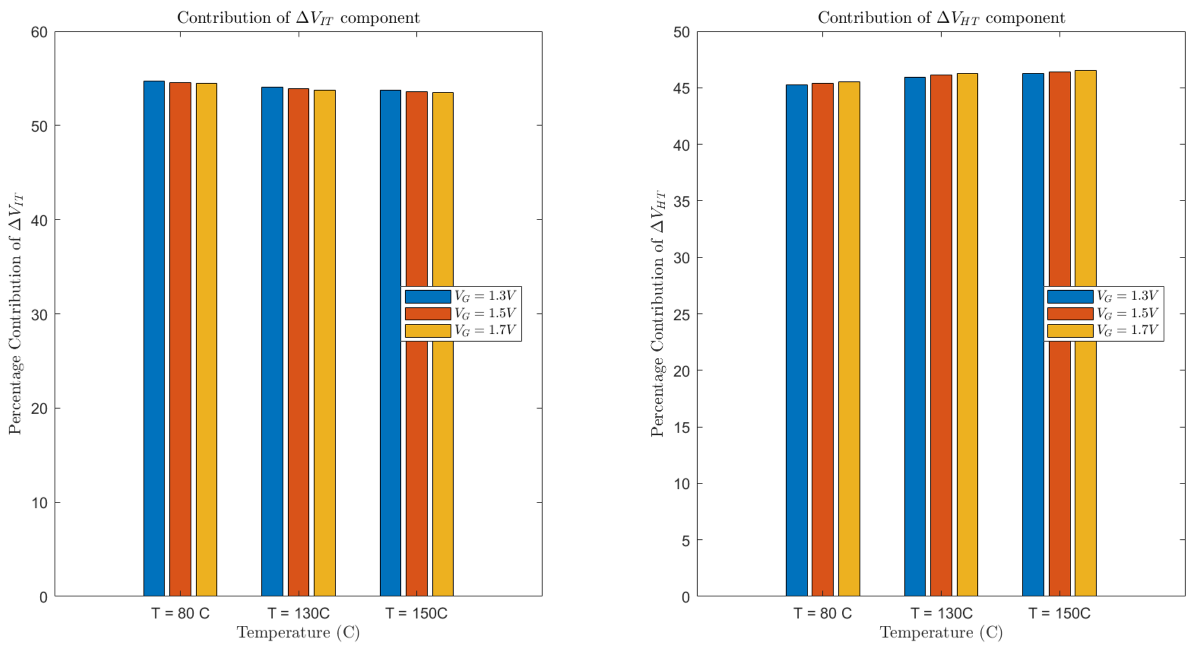


Figure 6: Contributions of each component

Rel-6

We have:

$$\Delta V_T = A_{IT} \cdot {V_G}^{\Gamma_{IT}} \cdot e^{-E_{A_{IT}}/k_B T} \cdot t^{(1/6)} + A_{HT} \cdot {V_G}^{\Gamma_{HT}} \cdot e^{-E_{A_{HT}}/k_B T} \cdot t^{(0)} + A_{OT} \cdot {V_G}^{\Gamma_{OT}} \cdot e^{-E_{A_{OT}}/k_B T} \cdot t^{(n_{OT})}$$

An optimizer is run to find the 6 parameters with subscripts above, with the following initial guesses:

- $A_{IT} = 30$
- $\gamma_{IT} = 4.5$
- $E_{A_{IT}} = 0.08eV$
- $A_{HT} = 3$
- $\gamma_{HT} = 4.5$
- $E_{A_{HT}} = 0.05eV$
- $A_{OT} = 20$
- $\gamma_{OT} = 9$
- $E_{A_{OT}} = 0.35eV$
- $n_{OT} = 0.3$

This relation is used to fit both data sets with different ΔV_T such that they have the same $\Delta V_T(EOS)$ and k, m values.

Results

(All in respective SI units unless otherwise mentioned)

- $A_{IT} = 0.043755$
- $\gamma_{IT} = 3.765638$
- $E_{A_{IT}} = 0.078282eV$
- $n_{IT} = 0.166667$

- $A_{HT} = 0.078120$
- $\gamma_{HT} = 3.856544$
- $E_{A_{HT}} = 0.094311eV$
- $n_{HT} = 0$

- $A_{OT} = 19.485833$

- $\gamma_{OT} = 5.485703$
- $E_{A_{OT}} = 0.464991 eV$
- $n_{OT} = 0.287573$

The log-log plot of ΔV_T vs stress times is given below. The scatter plot is the given data, and the solid lines are the fitted lines.
The contributions of each component is given by the bar plot below.

We see that the contribution of the interface trap component is around 60% for all three temperatures/voltages, and the contribution of the hole trap component is around 40%, with marginal contribution from oxide trap component.

- With increasing temperature, the contribution of the interface trap component decreases
- With increasing temperature, the contribution of the hole trap component increases
- With increasing temperature, the contribution of the oxide trap component increases
- With increasing voltage, the contribution of the interface trap component decreases
- With increasing voltage, the contribution of the hole trap component increases
- With increasing voltage, the contribution of the oxide trap component increases

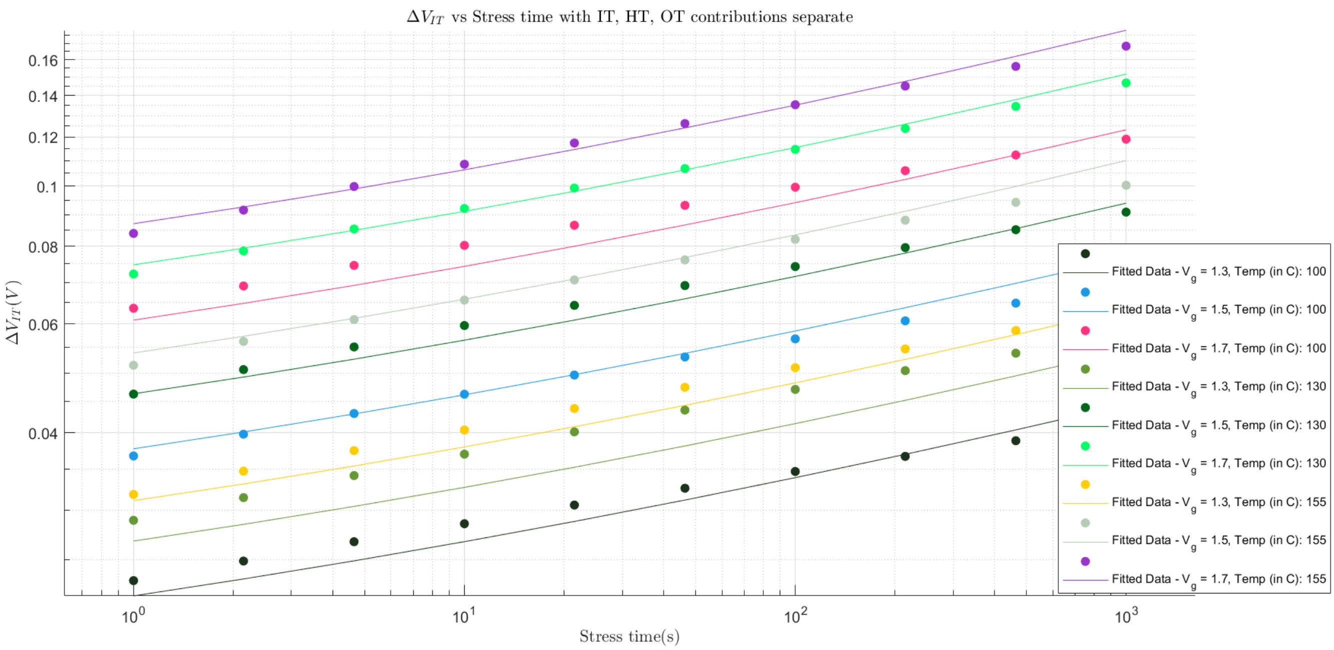


Figure 7: Fit of data to find A_{IT}, γ_{IT}, $E_{A_{IT}}$, A_{HT}, γ_{HT}, $E_{A_{HT}}$

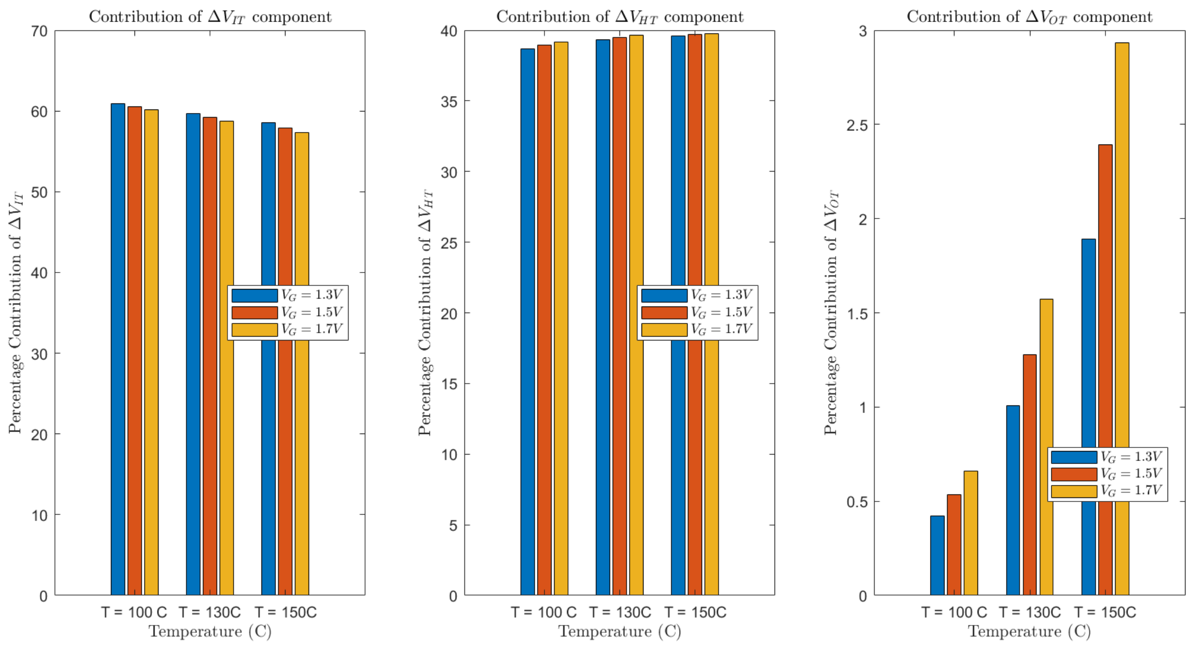
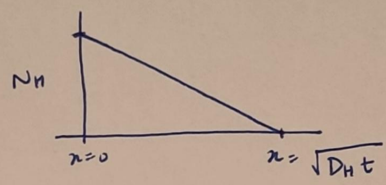


Figure 8: Contributions of each component

Rel-1

Diffusion of atomic H (no dimerization)



Using Fick's law,

$$\frac{dN_H}{dt} = D_H \frac{d^2 N_H}{dx^2}$$

$$\Rightarrow x = \sqrt{D_H t}$$

From area of graph,

$$N_{IT} = \frac{1}{2} \cdot N_H(x=0) \cdot (D_H t)^{1/2} \quad -①$$

Also, from the principle of detailed balance and $N_0 >> N_{IT}$

$$\frac{dN_{IT}}{dt} = k_F (N_0 - N_{IT}) - k_R N_H N_{IT} \sim 0$$

$$\Rightarrow N_H(x=0)\, N_{IT} = \frac{k_F}{k_R} N_0$$

$$N_H(x=0) = \frac{k_F}{k_R} \cdot \frac{N_0}{N_{IT}} \quad -②$$

Substituting ② in ①,

$$N_{IT} = \frac{1}{2} \cdot \left(\frac{k_F}{k_R} \cdot \frac{N_0}{N_{IT}}\right) \cdot D_H^{1/2} \cdot t^{1/2}$$

$$N_{IT}^2 = \left(\frac{1}{2} \frac{k_F}{k_R} D_H^{1/2}\right) \cdot t^{1/2}$$

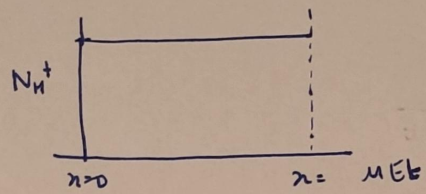
$$N_{IT} = \left(\frac{1}{2} \frac{k_F}{k_R} D_H^{1/2}\right)^{1/2} \cdot t^{1/4}$$

Time kinetics show power law with $\boxed{n = \frac{1}{4}}$

Figure 9: Case 1: Diffusion of atomic H (no dimerization)

Drift of ionic H^+

Profile can be approximated as :



We take drift distance $x =$ drift velocity $\times\, t$

$$x = (\mu E)\cdot t$$

N_{IT} is obtained as area under graph,

$$N_{IT} = N_{H^+}(x=0)\,.\,(\mu E t) \quad -(1)$$

Using detailed balance and considering $N_0 >> N_T$,

$$\frac{dN_{IT}}{dt} = k_F(N_0 - N_{IT}) - k_R N_{H^+} N_{IT} \sim 0$$

$$N_{H}^{+}(x=0) = \frac{k_F}{k_R}\cdot\frac{N_0}{N_{IT}} \quad -(2)$$

From (1) and (2),

$$N_{IT} = \frac{k_F}{k_R}\cdot\frac{N_0}{N_{IT}}\cdot \mu E t$$

$$N_{IT}^2 = \frac{k_F N_0}{k_R}\mu E\cdot t$$

$$N_{IT} = \left(\frac{k_F}{k_R}N_0 \mu E\right)^{1/2}\cdot t^{1/2}$$

Time kinetics show power law with $\boxed{n = \frac{1}{2}}$

Figure 10: Case 2: Drift of ionic H