Reliability Assessment of Single-Ended PCM in Automotive Microcontrollers Compliant with AEC-Q100 Standards

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  - Cell structure, read and write operation
  - Algo x write
- Failure Modes: Drift and Crystallization
- From Mission profile to Trial duration
- Double ended vs Xmemory
- Experimental data
- Conclusions

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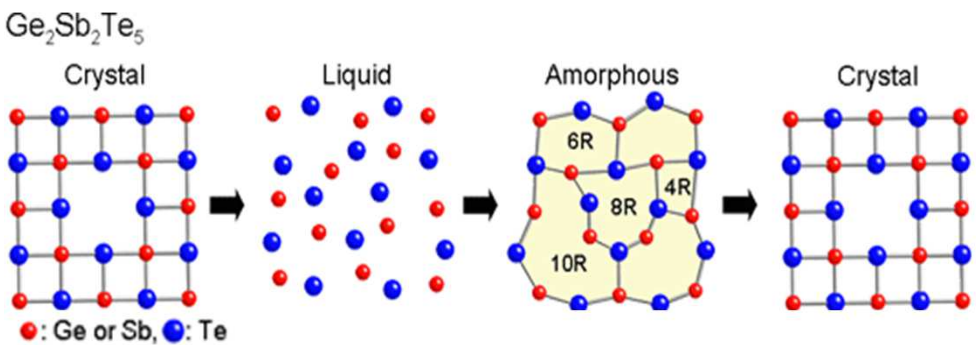
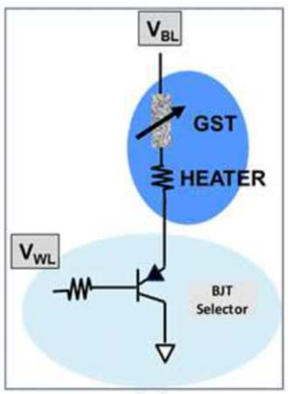
Phase Change Memory (PCM) storage mechanism

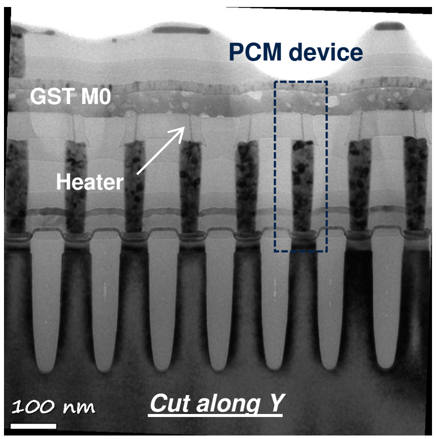
- PCM storage mechanism
  - Two phases of the chalcogenide alloy, $Ge_xSb_yTe_z$ (GST): Polycrystalline vs Amorphous
- Polycrystalline phase
  - High reflectivity / Low resistivity / High current
- Amorphous phase
  - Low reflectivity / High resistivity / Low current

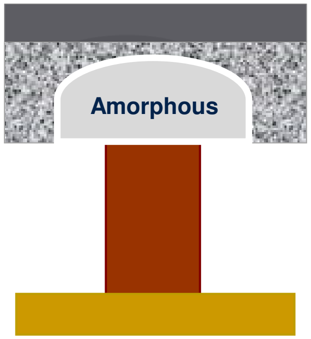


Read and Program Operation

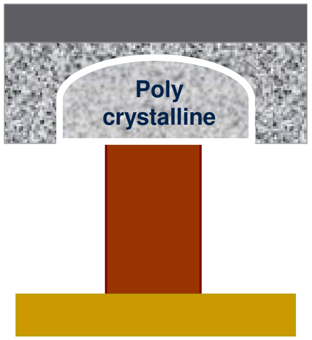
- Reading operation
  - Constant Voltage applied across GST gives high current when it is crystalline and low current when amorphous
- Program operation
  - Self-heating due to controlled current flow (Joule effect)







Low I_{read}
High resisitivity



High I_{read}
Low resisitivity

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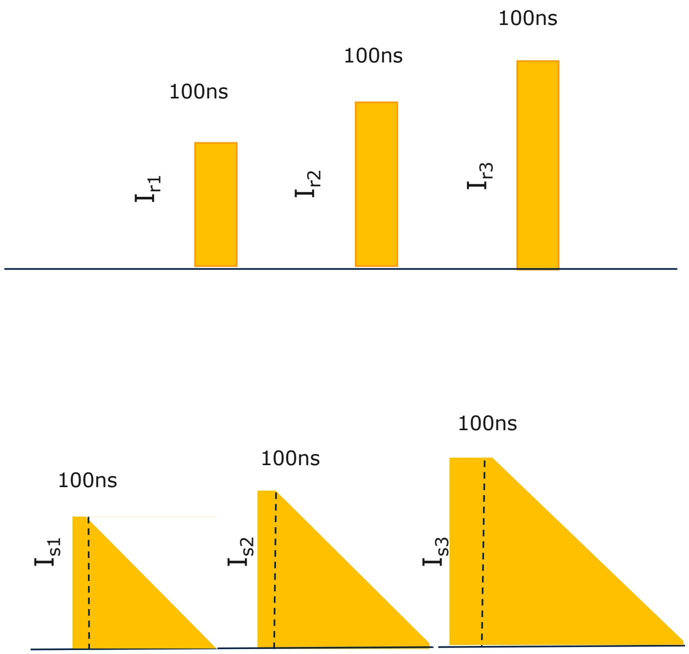
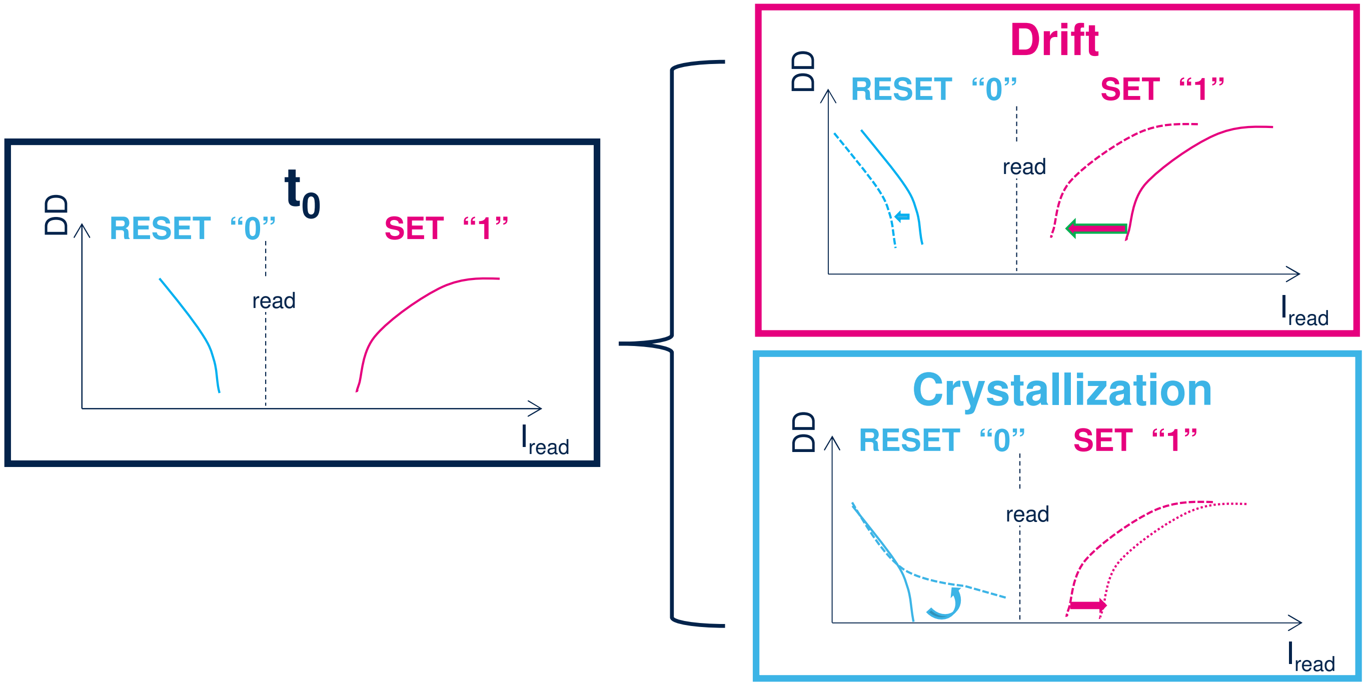
Reset and set state

- RESET (0) – Amorphous resistive phase
  - Fast cooling from melted state using fast and sharp
  - Rapid falling edge
  - $T > T_{melting}$
- SET (1) - Polycrystalline conductive phase
  - A long electric impulse allows the crystallization into an FCC structure
  - $t_{pulse} > t_{crystallization}$
  - $T_{crystallization} < T < T_{melting}$



PCM failure modes:
Drift and crystallization mechanisms



- **Drift mechanism**
  - Instability of crystalline state
  - Specific to Ge-rich alloys
  - Critical for SET
- Meyer Neldel power law

- **Crystallization mechanism**
  - Instability of amorphous state
  - Critical for RESET
- Arrhenius model

- Only one data retention trial is not enough to cover mission profile requirement due to two different failure modes
- The worst-case positioning of the distributions at the end of life for the Reset is retention post cycling, while for the Set is retention before cycling

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RESET: Ea evaluation of crystallization

E_a is used to evaluate mission profile for reset crystallization by translating every single profile into an equivalent time at a given T_{bake}

Arrhenius

$$A_f = \exp\left[\frac{E_a}{k_B} \bullet \left(\frac{1}{T_u} - \frac{1}{T_t}\right)\right]$$

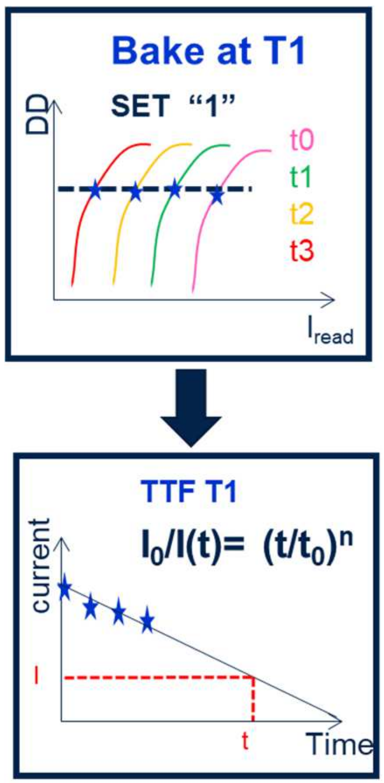
Ea [eV]	3.1		Example
k(J/K)	1.38065E-23		
k(eV/K)	8.61733E-05		
Tj char. [°C]	165		
	Profile B		Profile B
Tj [°C]	Time [h]		Time equiv. [h]
-40	500		0.00
40	500		0.00
85	1000		0.00
135	5600		13.35
150	1200		65.21
160	150		58.10
165	50		50.00
70	60000		0.00
40	70000		0.00
90	6200		0.00
110	1250		0.01
130	500		0.40
150	50		2.72
175	15.00		93.82
TOT			283.60

SET drift Mechanism: real use case

Considering a mission profile as an example, we can divide it by slices according to the trials on Set retention we want to perform.

	Prof. 2	Prof. 6
T_{bake}	Time [h]	Time [h]
90	108200	140105
105	30000	0
125	1250	1250
135	6100	6100
150	1250	1250
165	215	215

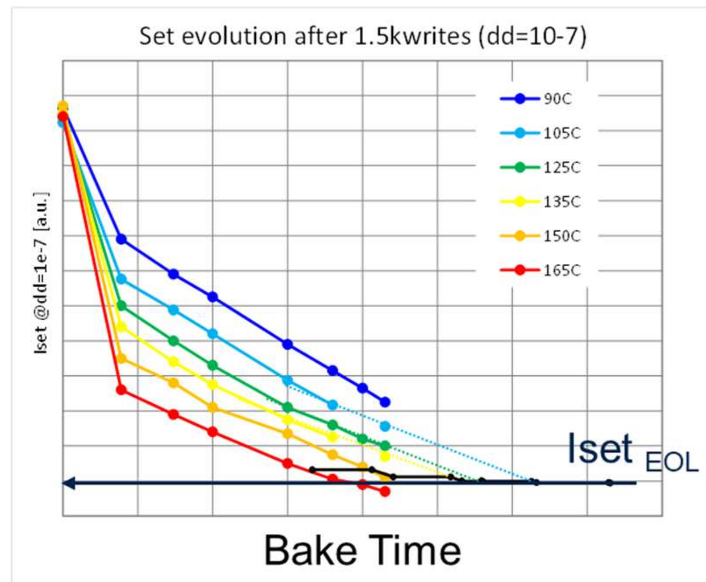
Table constructed by adding all the hours at $T<T_{bake}$ in the mission profile



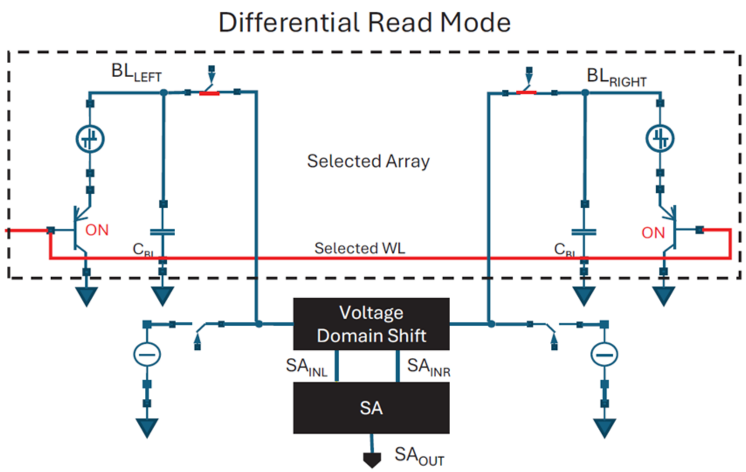
Each current distribution is taken at different times.

The value of the current of each distribution is taken at a given DD.

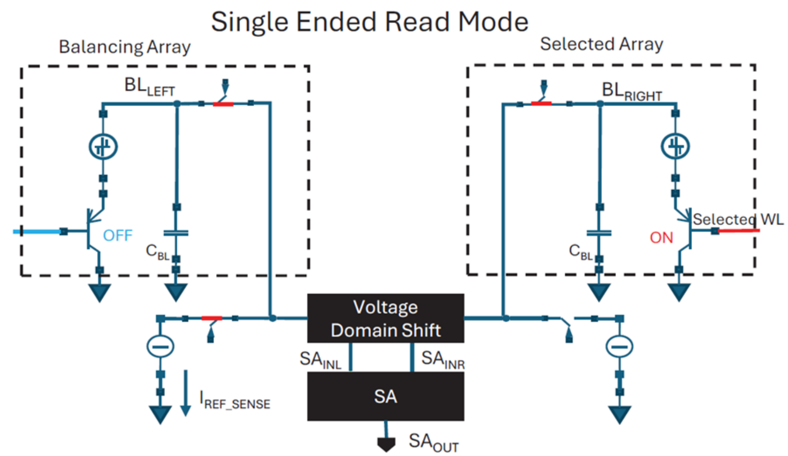
Each current value is plotted vs time of bake.



Double Ended vs Single Ended (Xmemory)



- The current in two cells with opposite state is compared. → Drift is mitigated



- The current of every cell is compared to a fixed reference value → Drift is NOT mitigated
- Memory capacity is doubled on demand via activation pulse.

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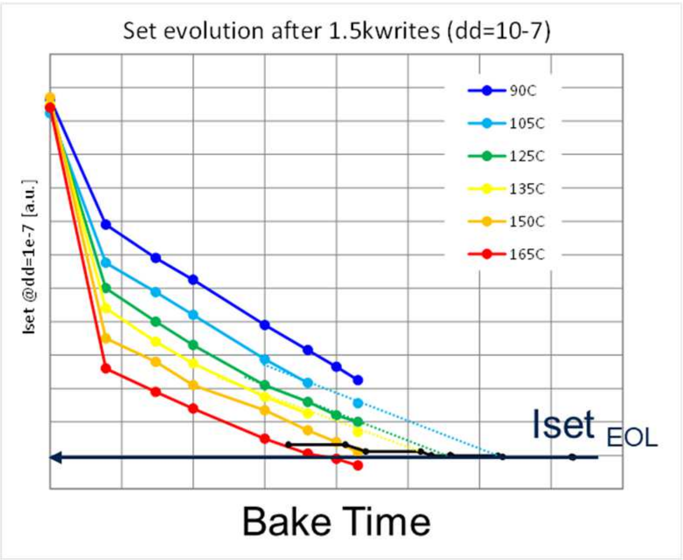
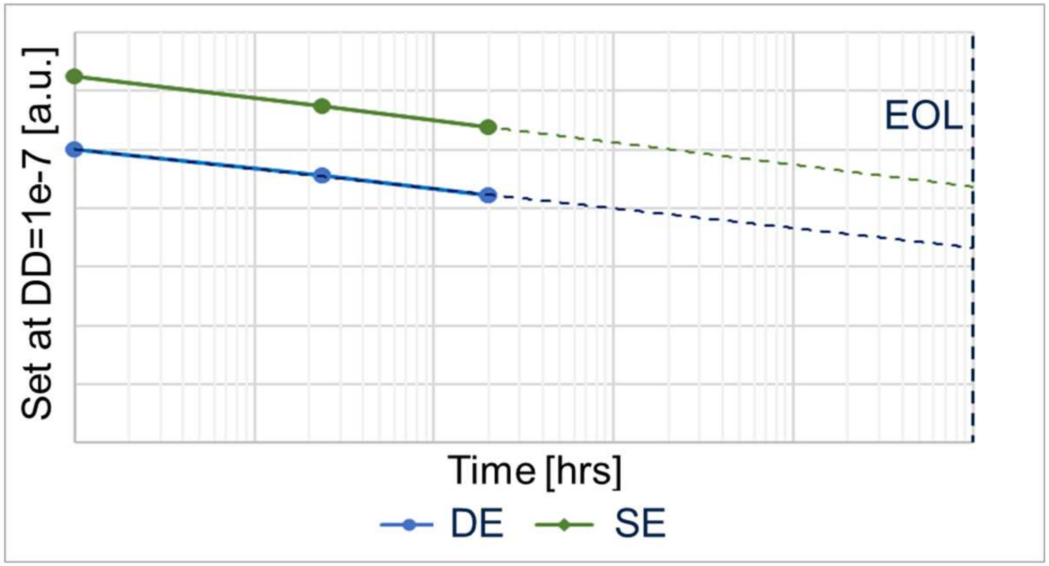
Experimental validation of SE



- Drift speed is the same after ~1hr bake time.



- Main contributor to higher EOL time is higher current at t0
- Activation pulse for SE increases t0 current allowing >1 decade margin at EOL

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Conclusion

- We characterized PCM’s Failure Modes allowing us to define qualification trial duration so that we can cover client’s mission profile on the field.
- We achieved Xmemory mode, effectively doubling memory density.
- By optimizing Xmemory activation impulse we increased EOL margin on data retention.

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Thanks for your Attention

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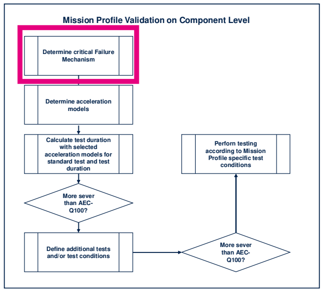
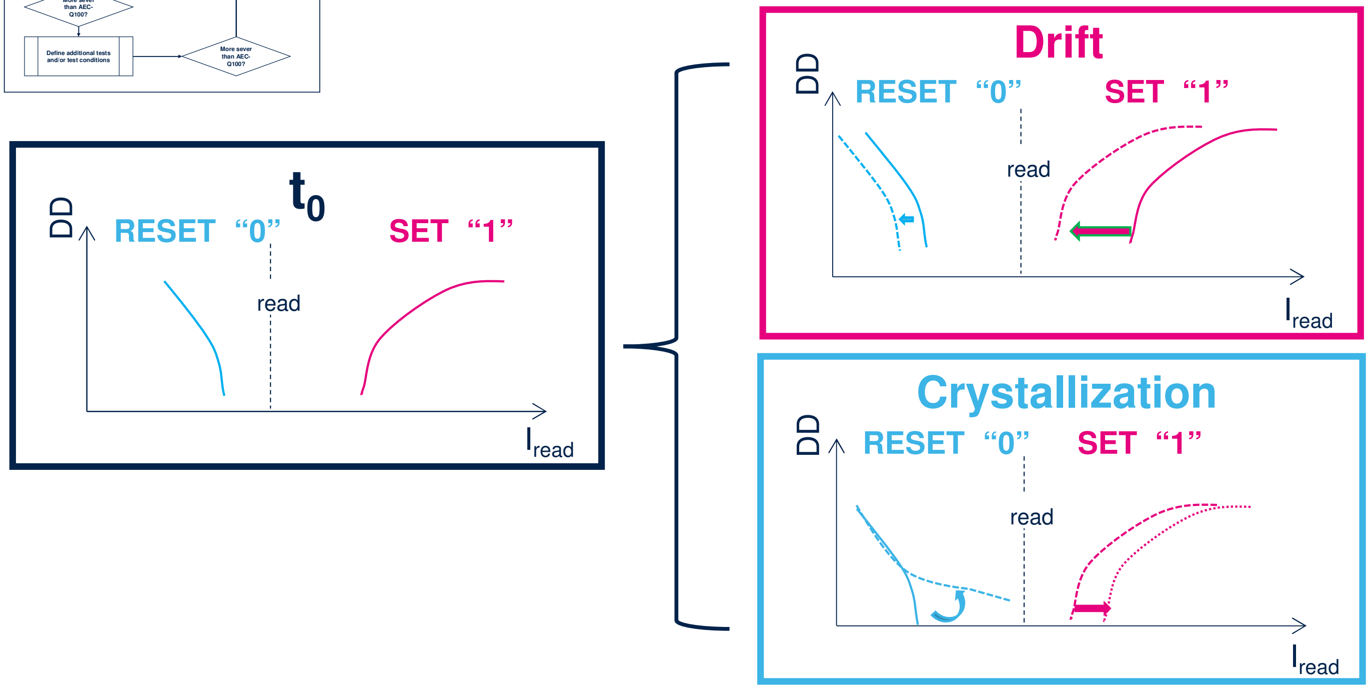
PCM failure modes: Drift and crystallization mechanisms





- **Drift mechanism**
  - Instability of crystalline state
  - Specific of Ge-rich alloys
  - Critical for SET
- Meyer Neldel power law

- **Crystallization mechanism**
  - Instability of amorphous vs crystalline state
  - Critical for RESET
- Arrhenius model

- Only one data retention trial is not enough to cover mission profile requirement due to two different failure modes
- New model to be considered with respect to flash data retention for drift mechanism

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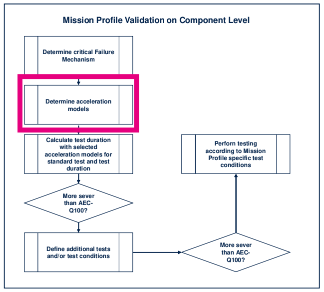
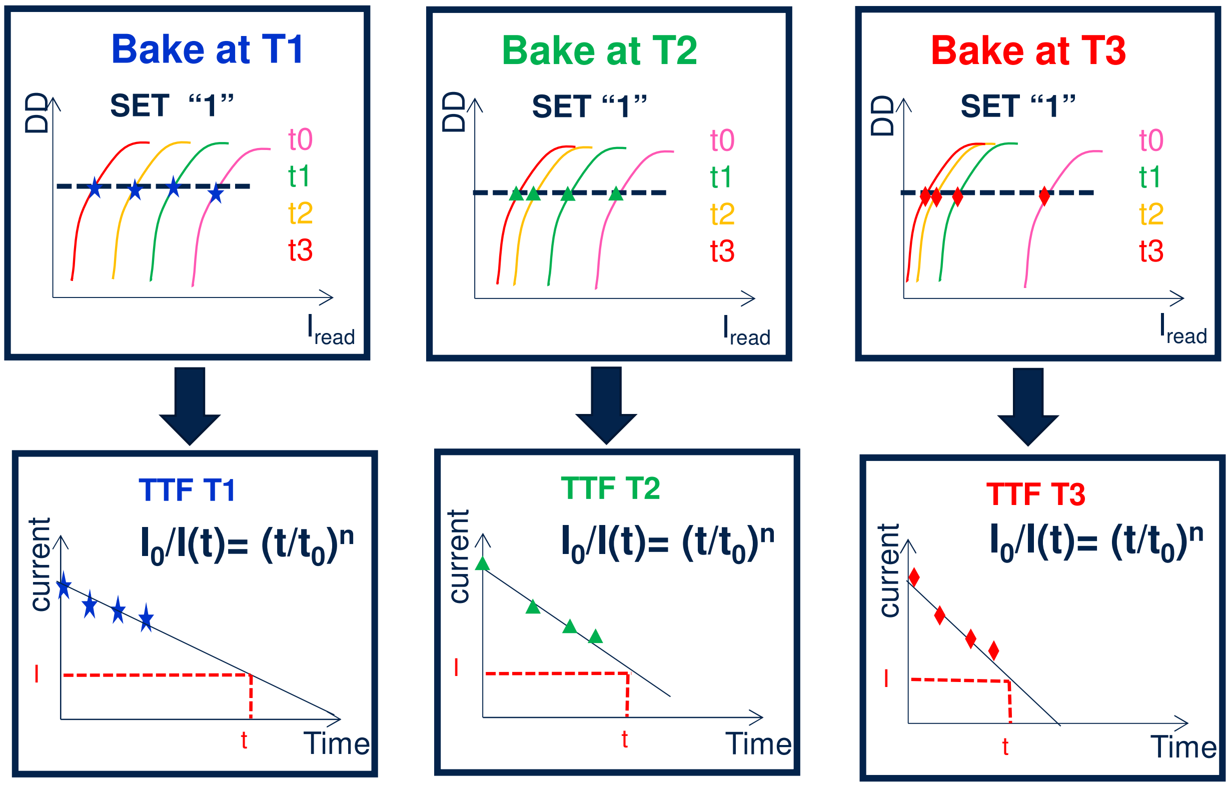
Spec evaluation: SET drift mechanism

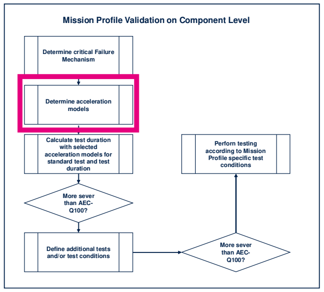


T1<T2<T3



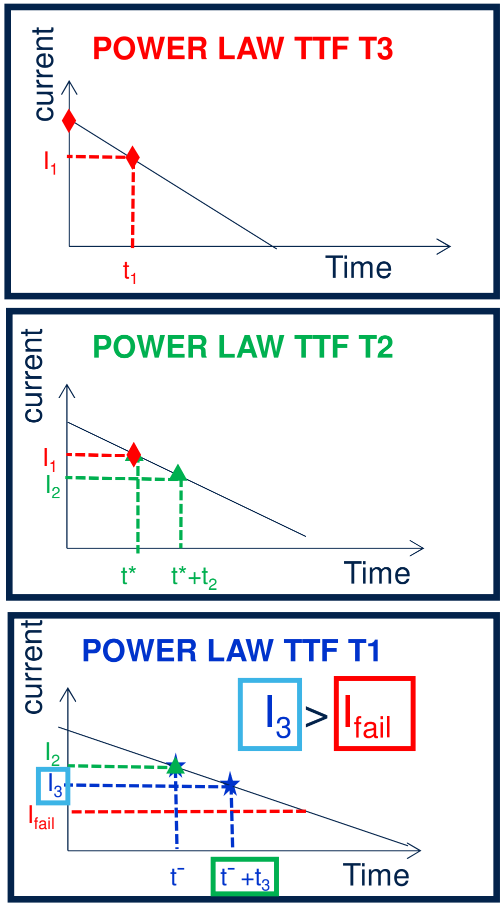
- Retention trials at different temperature without re-program
- Set Drift described by Meyer Neldel power law

Spec evaluation: SET drift mechanism



Mission Profile Example

T_{bake} [°C]	Time [hrs]
T1	t_3
T2	t_2
T3	t_1



t1@T3 + t2@T2 + t3@T1

- Once TTF is known for each T_{bake} we can evaluate I_3 (SET_{EOL}) at $t^{-}+t_3$, equivalent time (t1+t2+t3) at **T1**
- Qualification target: I_3 must be higher than I_{fail}

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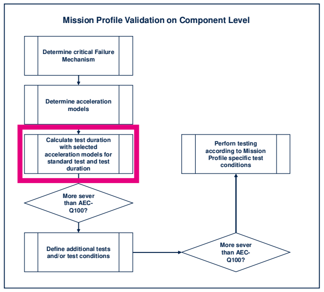

Spec evaluation: SET drift Mechanism - real use case

Considering one profile as an example (and considering half of the profile), we can divide it by slices according to the set experiments we have performed

	Profile 2
Tj [°C]	Time [h]
-40	500
40	500
85	1000
135	5600
150	1200
160	150
165	50
85	30000
95	30000
40	70000
90	6200
110	1250
130	500
150	50
175	15.00

	Profile 6
Tj [°C]	Time [h]
-25	260
0	450
20	550
60	700
90	800
105	900
115	1200
125	3100
135	2100
145	1600
155	330
165	10
-30	700
-20	15000
23	65000
30	35000
50	16000
90	3000
100	1700
120	500
130	100
150	25

	Prof. 2	Prof. 6
T_{bake}	Time [h]	Time [h]
90	108200	140105
105	30000	0
125	1250	1250
135	6100	6100
150	1250	1250
165	215	215

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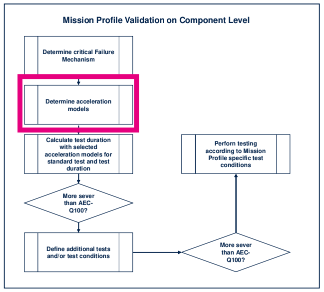
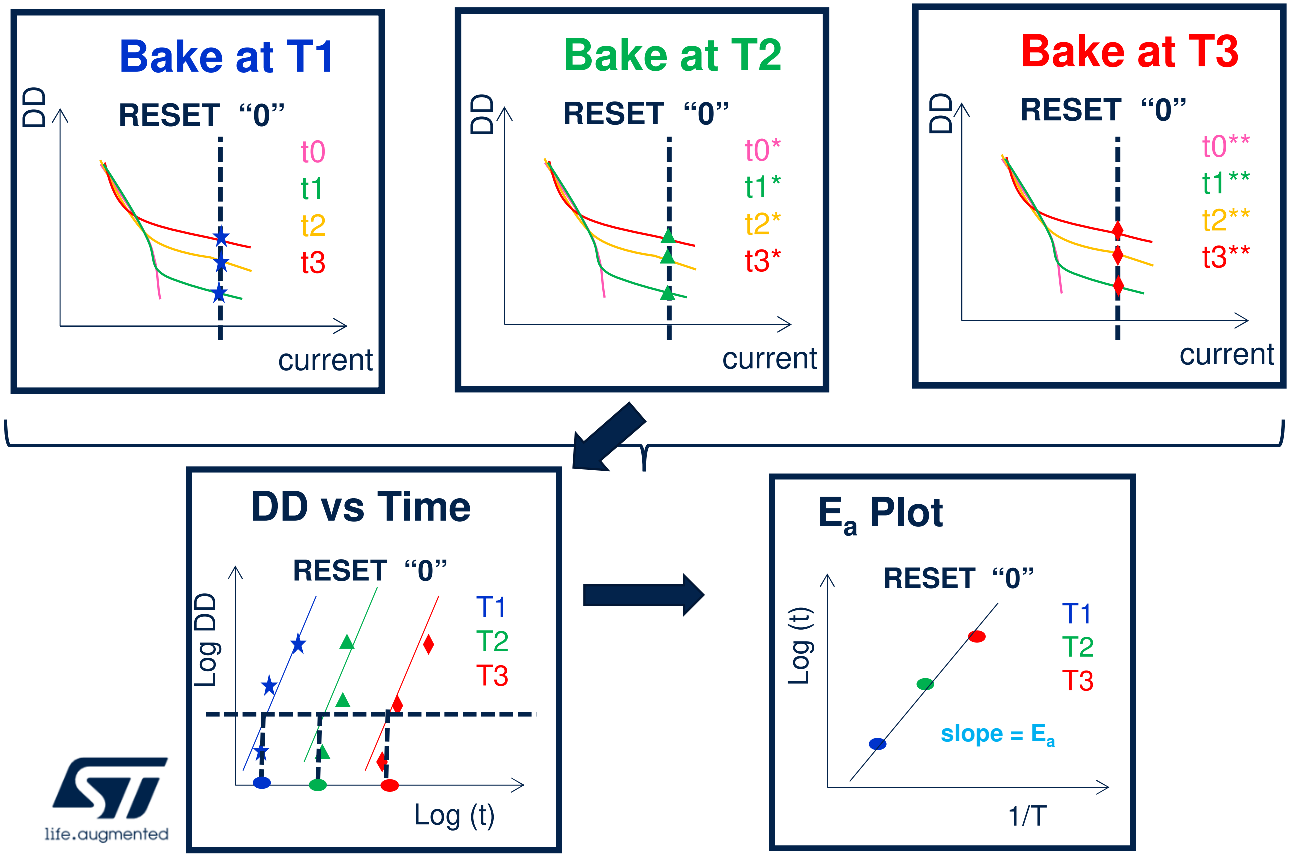
Spec evaluation: RESET crystallization mechanism

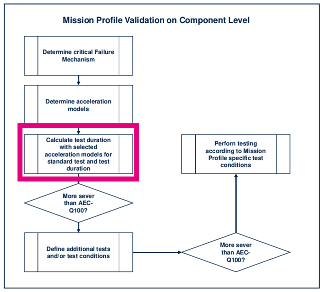


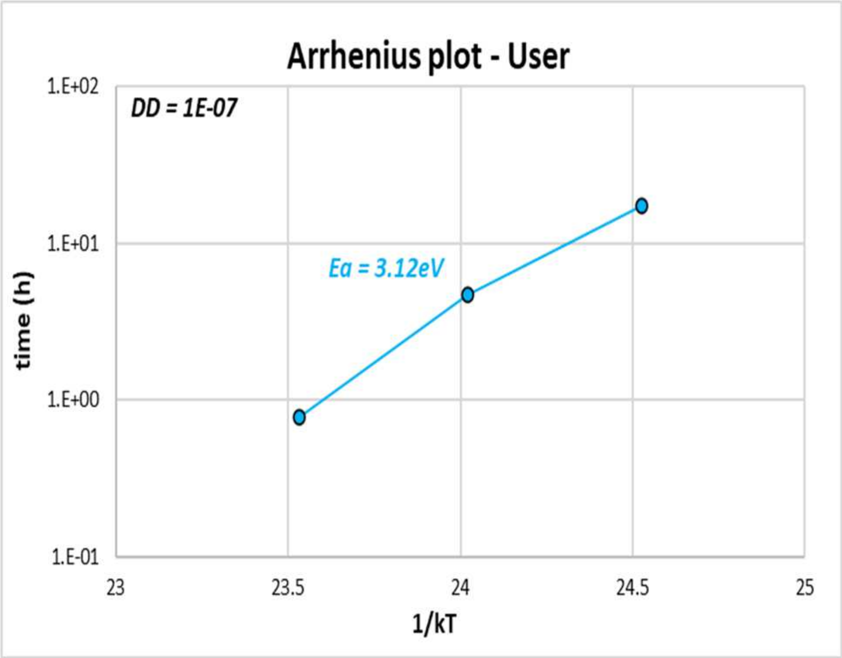
T1<T2<T3



- Retention trials at different temperature without re-program
- Reset crystallization described by Arrhenius model

Spec evaluation:
RESET Ea evaluation of crystallization





Even if reset crystallization is described by Arrhenius model, Ea value is quite different than flash data retention

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