High Frequency AC Electromigration Lifetime Measurements from a 32nm Test Chip

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Outline

- Motivation
- Proposed circuit based electromigration characterization technique
- AC and DC electromigration lifetime measurements from 32nm test chip
- Summary

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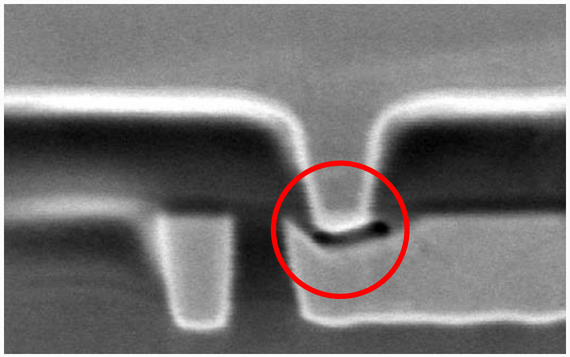
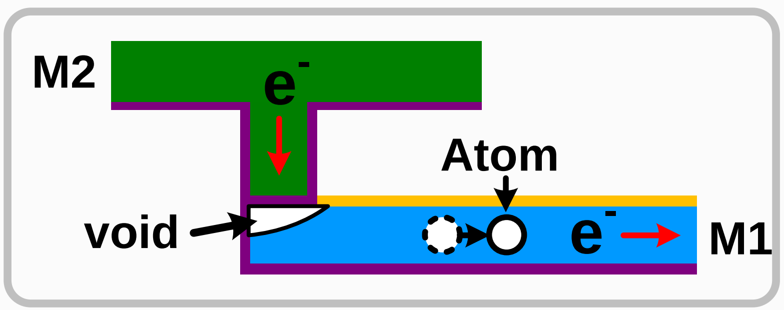
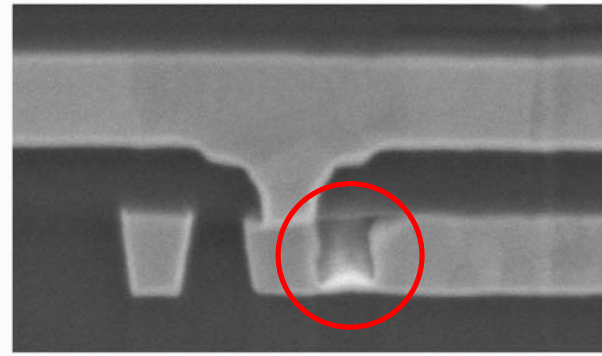
Wire Failure due to Electromigration

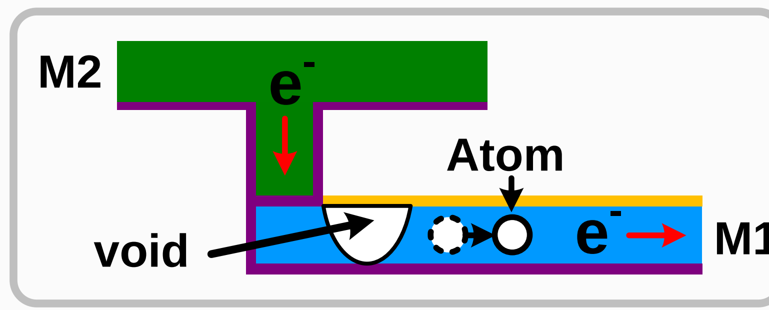
Abrupt failure





Progressive failure

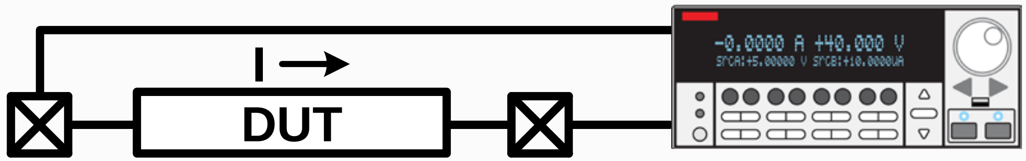




A.S. Oates, et al., TDMR, 2009

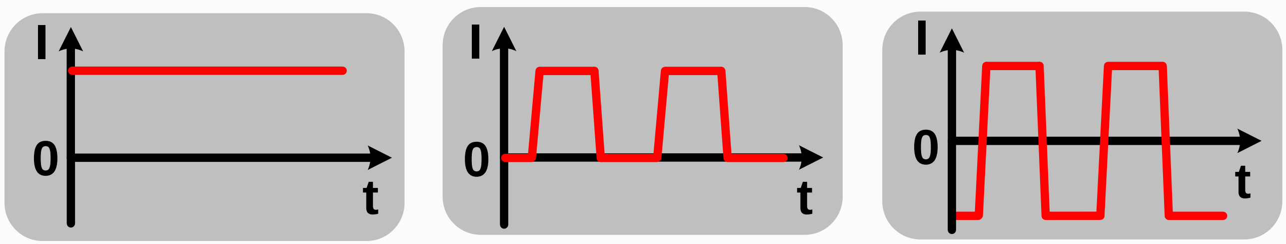
- **EM lifetime affected by current density/direction, temperature, and possibly switching frequency**

Previous EM Test Structure



Test
instrument

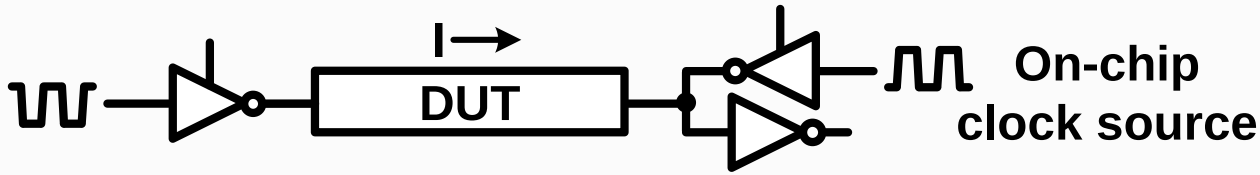
DC | Pulsed DC | Square AC

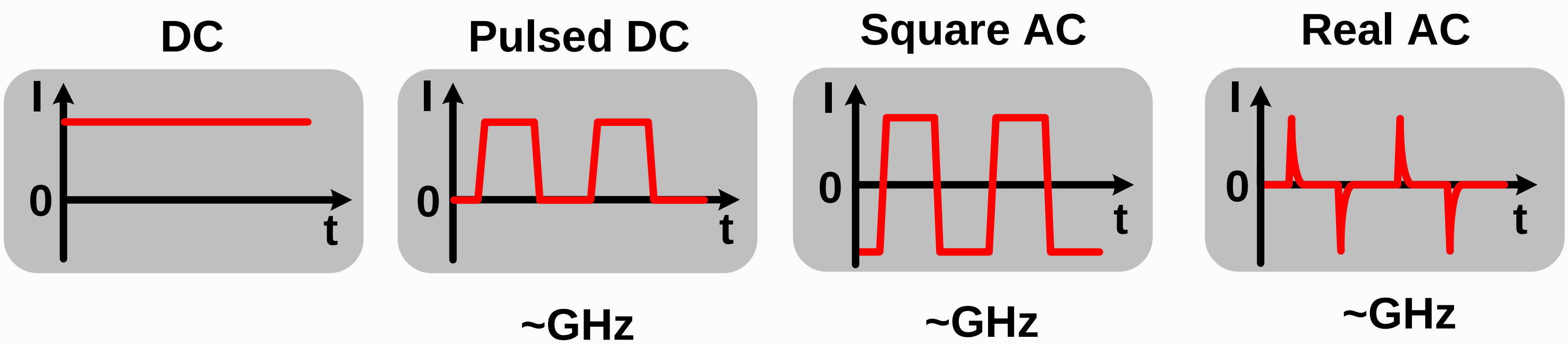


<5MHz | <5MHz

- **Limitations of traditional probing method**
  - Frequency (~5MHz) lower than actual chip clock freq.
  - Unable to generate realistic AC current
  - Large test area due to pads, long test time

Proposed Circuit based Approach





- **Advantages of proposed circuit based approach**
  - High operating frequency (~GHz)
  - Realistic AC current
  - Small test area due to shared pads, short test time
  - BTI and HCI effects in driver captured → closer to reality

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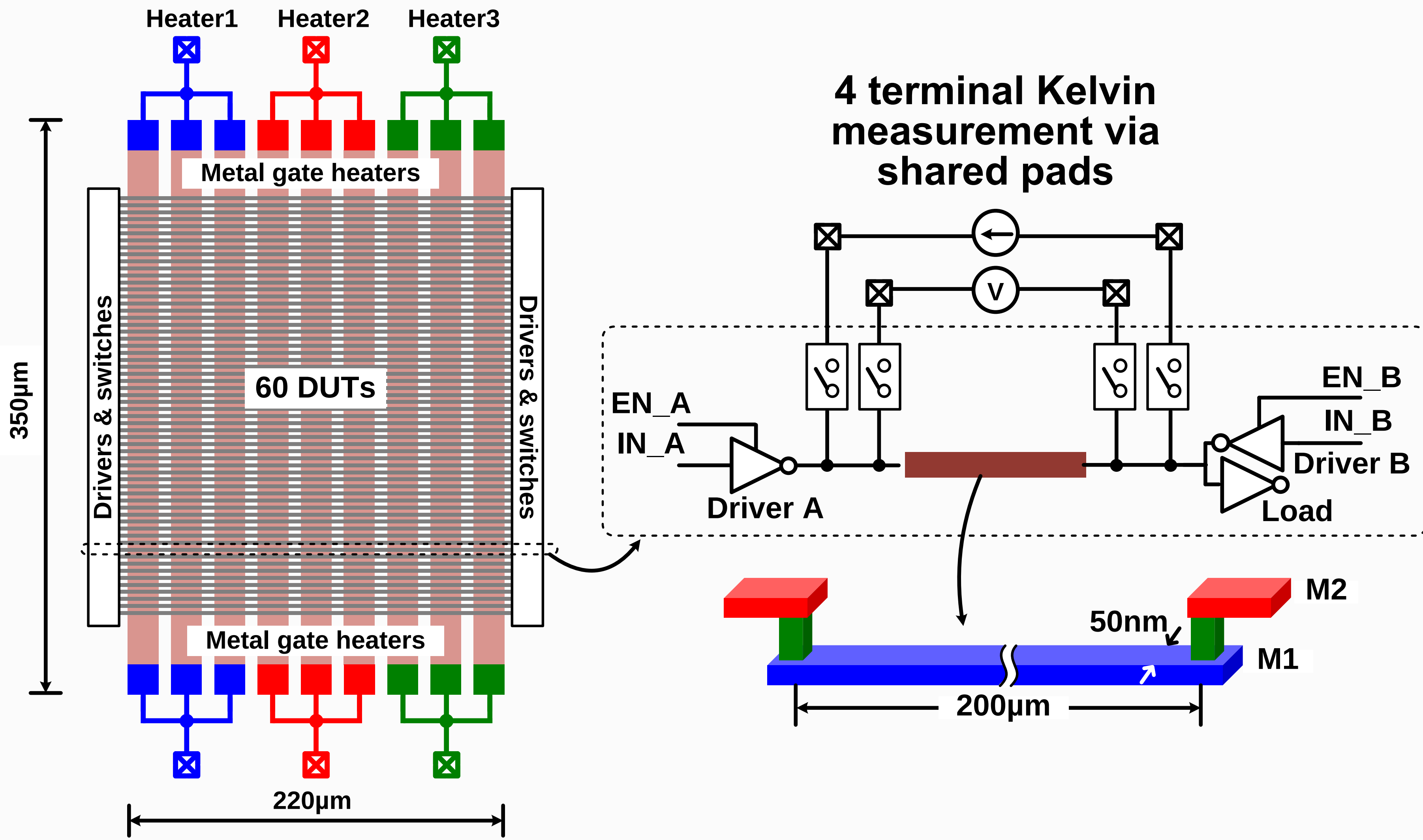
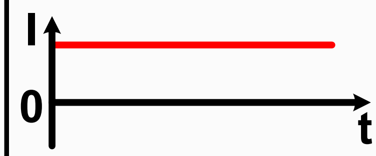
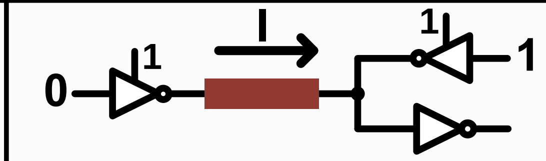
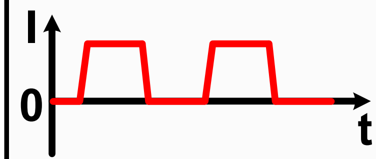
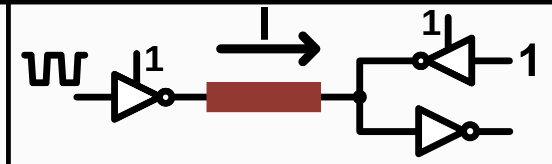
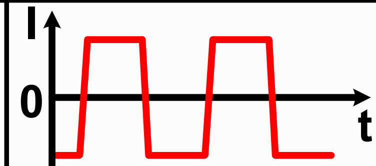
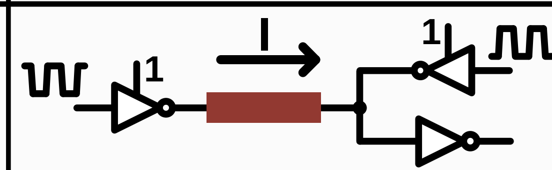
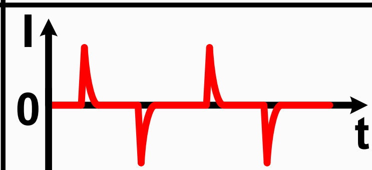
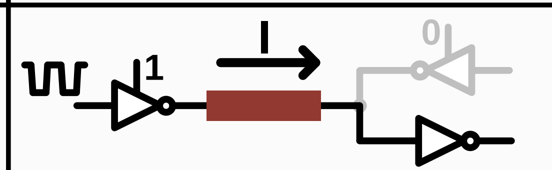
32nm Test Chip Overview

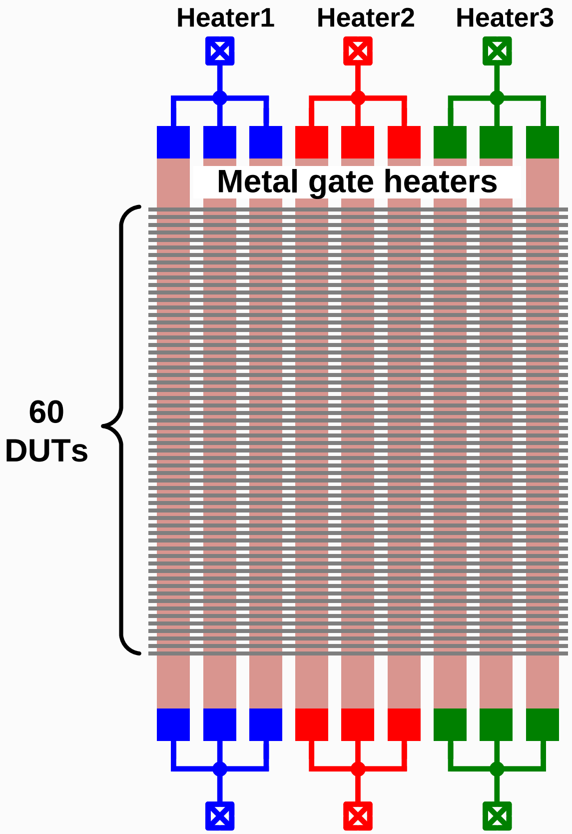


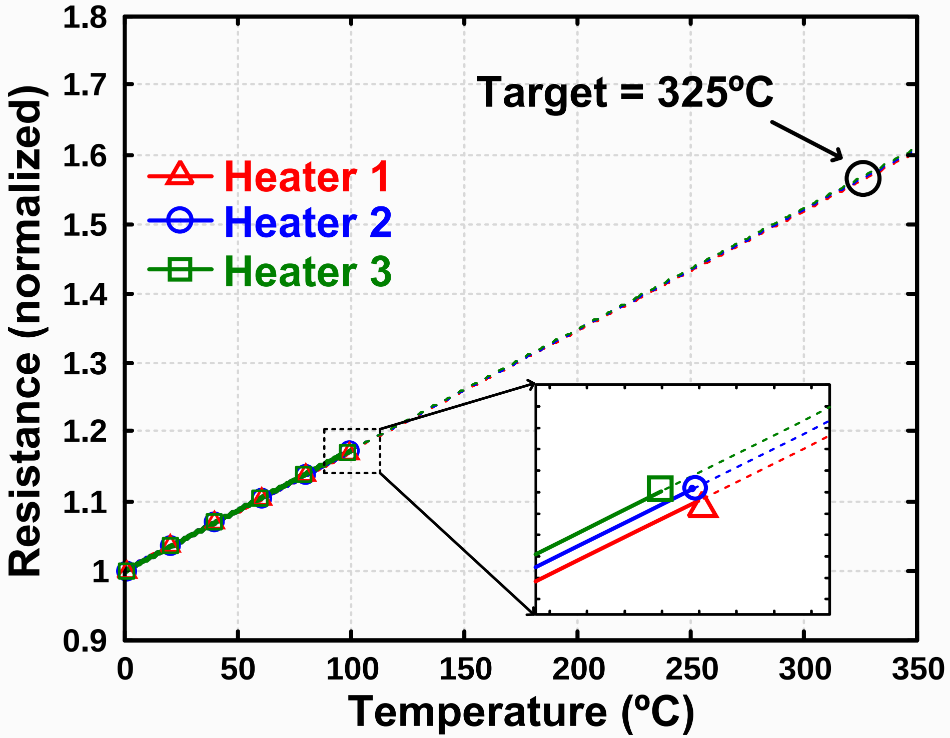
EM Stress Modes Supported

Stress Mode	Current Waveform	Driver Operation
DC		
Pulsed DC		
Square AC		
Real AC		

- Supports four different EM modes by configuring driver inputs

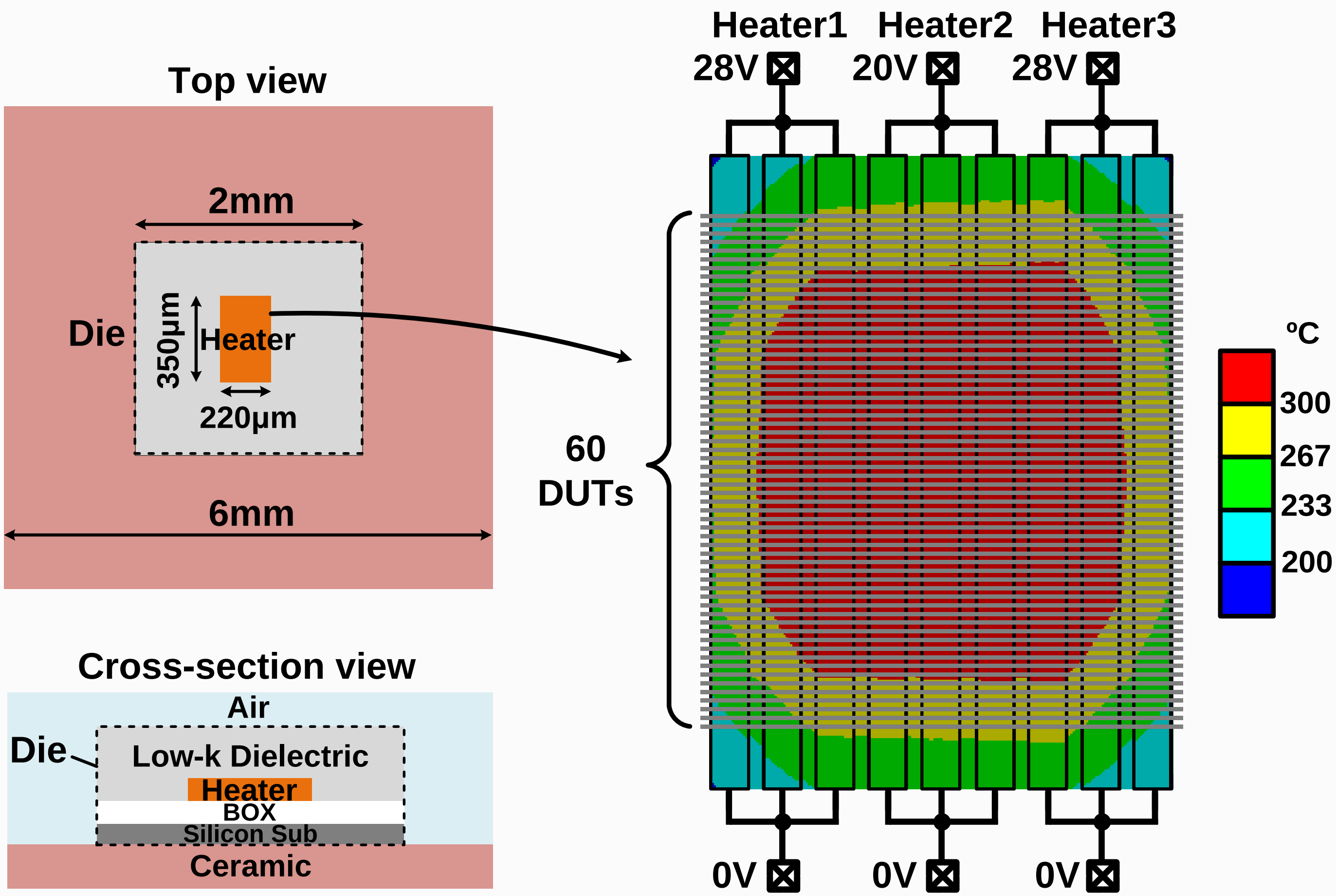
Local Metal Gate Heaters





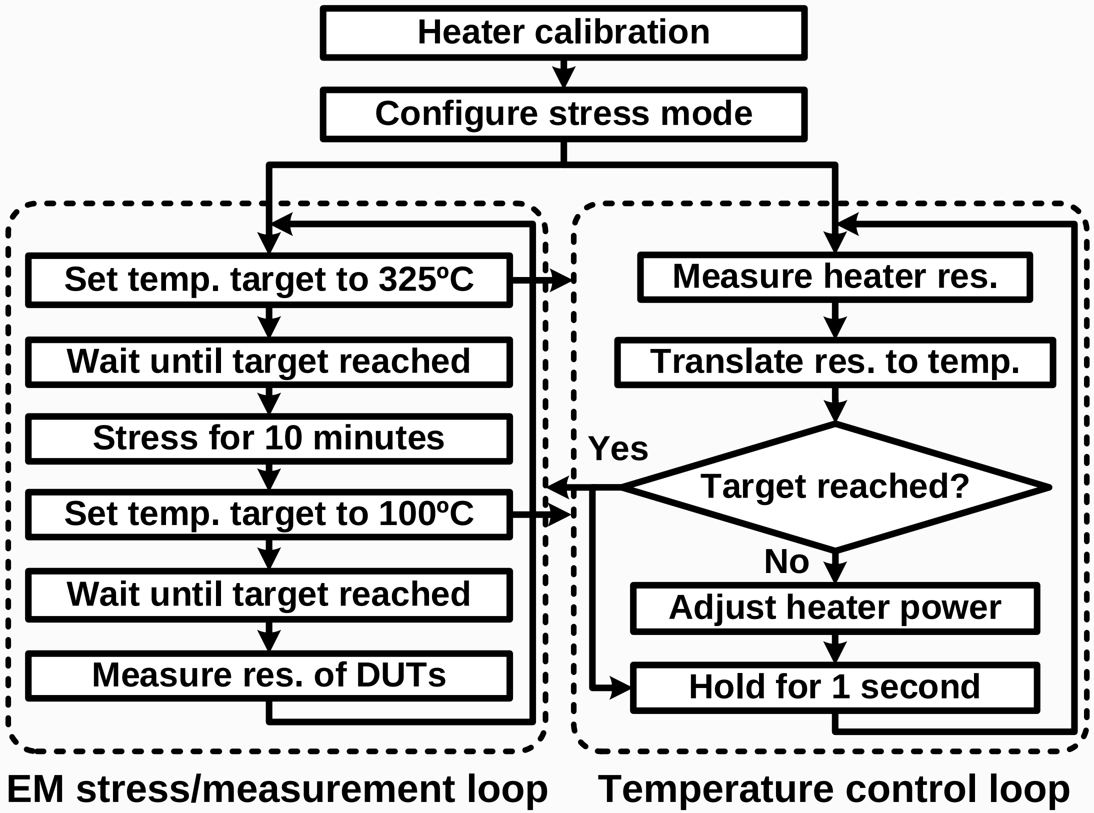
- Local heaters can raise DUT temp. to >350ºC
- Stress temperature is set by adjusting heater voltage until target resistance is reached

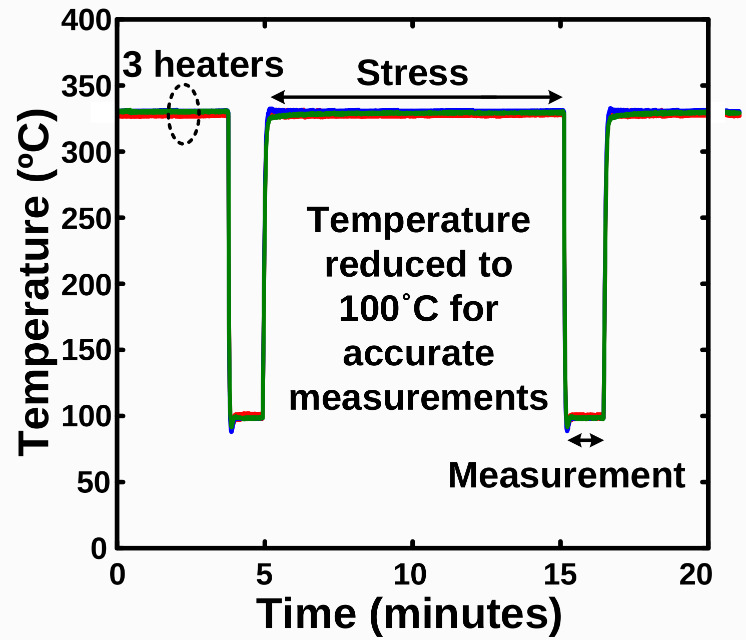
Heater Thermal Simulation Results



- **More uniform temperature can be obtained using multiple heater voltages (e.g. 28V, 20V, 28V)**

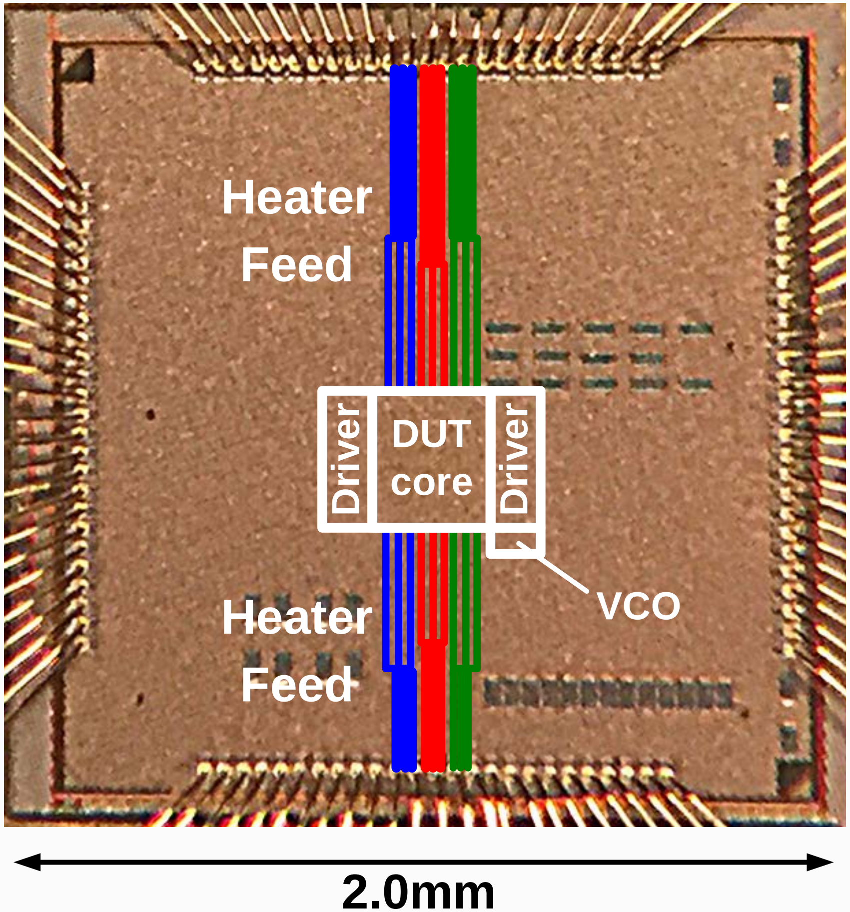
Automated EM Testing Flowchart





- **Script program with automatic temperature control enables accurate and efficient data collection**

32nm Test Chip Die Photo



Process	32nm HKMG
# of DUT	60
Stress modes	DC, pulsed DC, square AC, real AC
Stress current source	On-chip VCO and driver (>3GHz @ RT)
Stress driver VDD	<1.5V
Stress/measure temperature	325/100 ºC
Stress frequency	<900MHz @ 325ºC
Heat source	Metal gate heaters
Test approach	4 terminal Kelvin measurement

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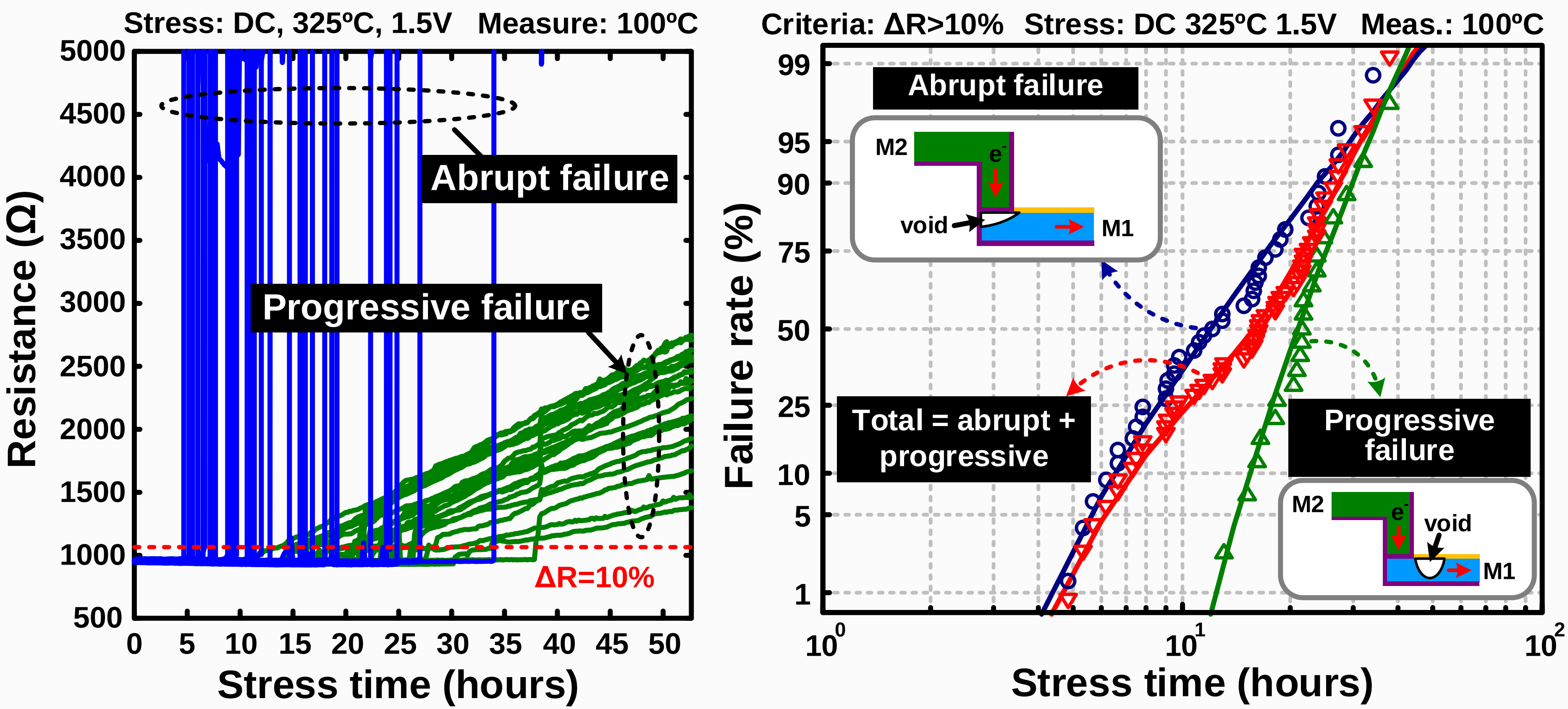
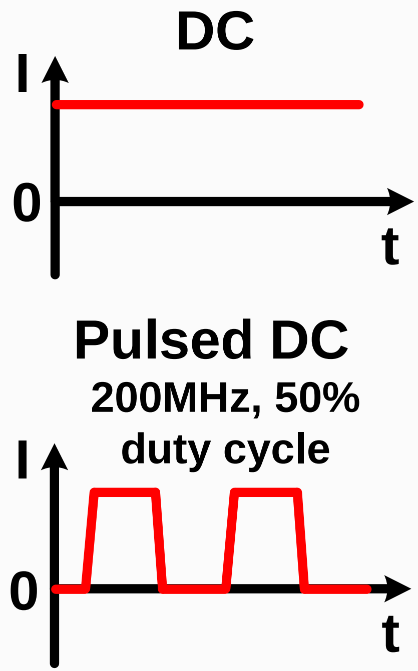
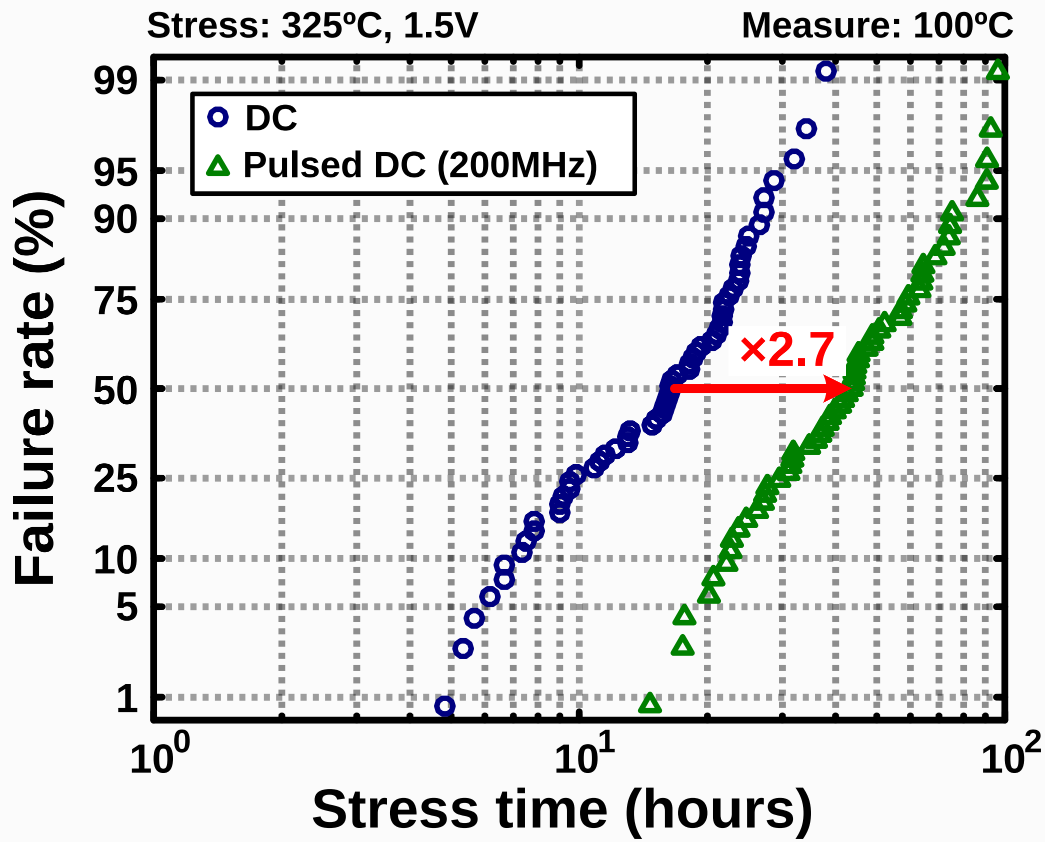
EM Lifetime under DC



- Results consistent with previously reported data
- Abrupt failure has smaller mean and larger variance

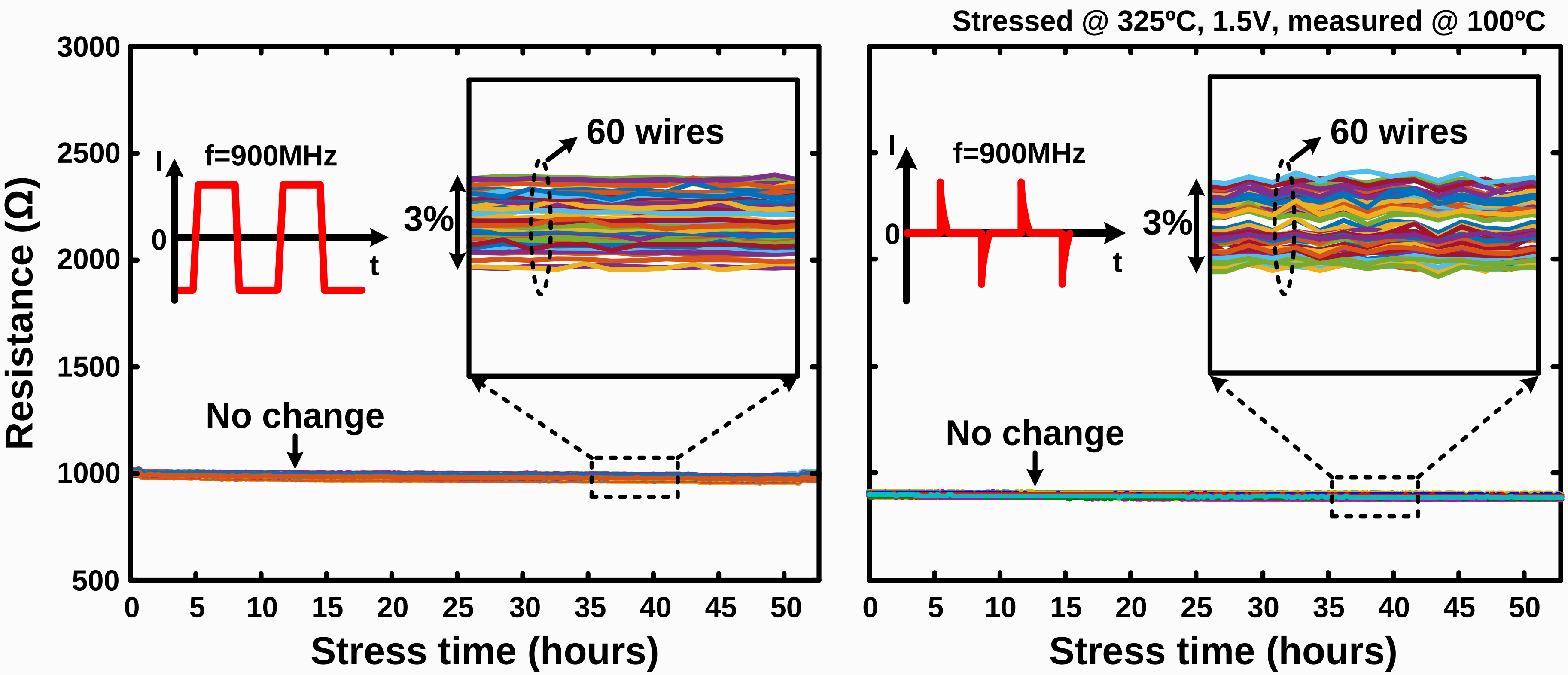
EM Lifetime under Pulsed DC





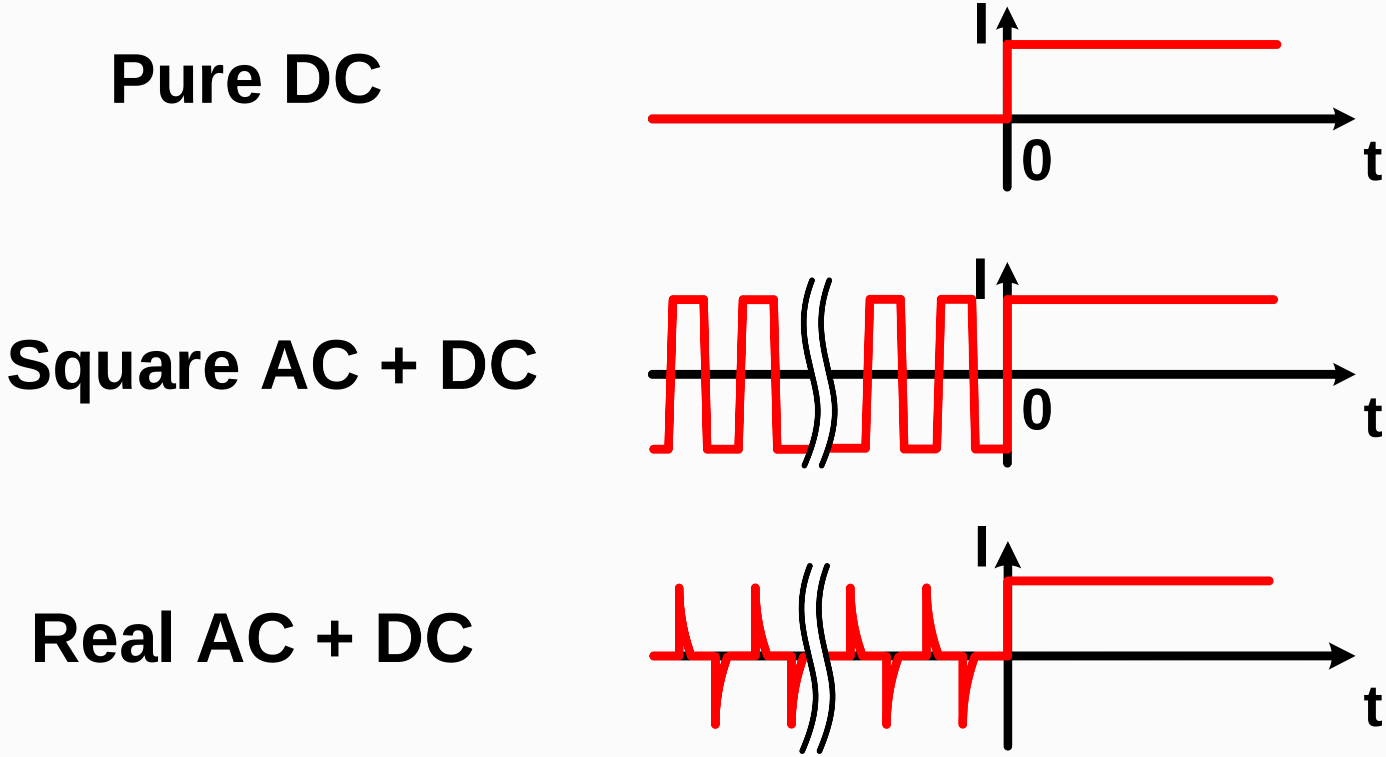
- **Possible reasons for ratio>2:**
  - **Lower $I_{average}$ → less Joule heating → lower temperature**
  - **EM self-recovery during off periods**
  - **BTI aging during off period reduces stress current**

EM Lifetime under Square/Real AC



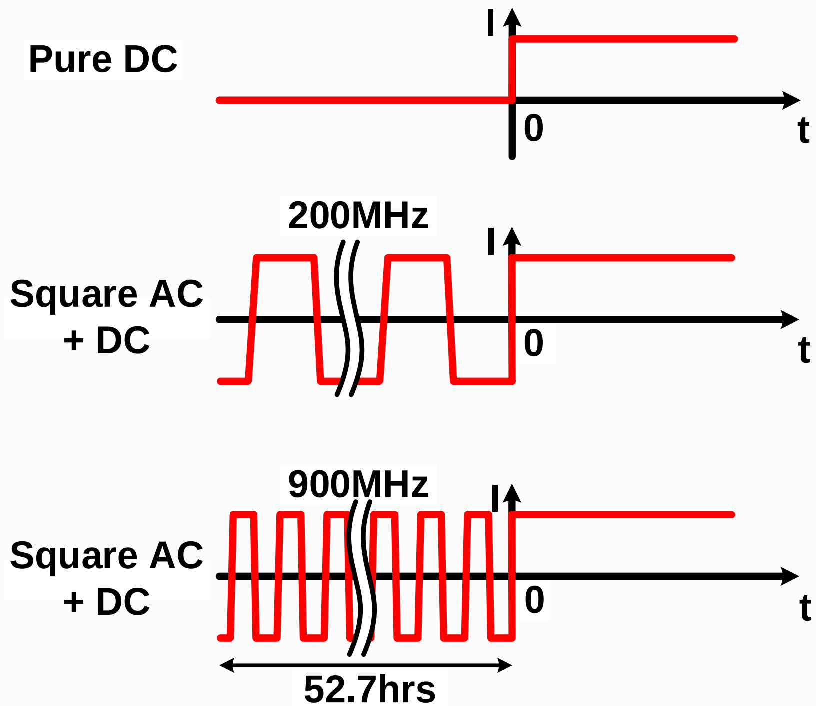
- **Negligible resistance change under both square AC and real AC current from 200 to 900MHz**

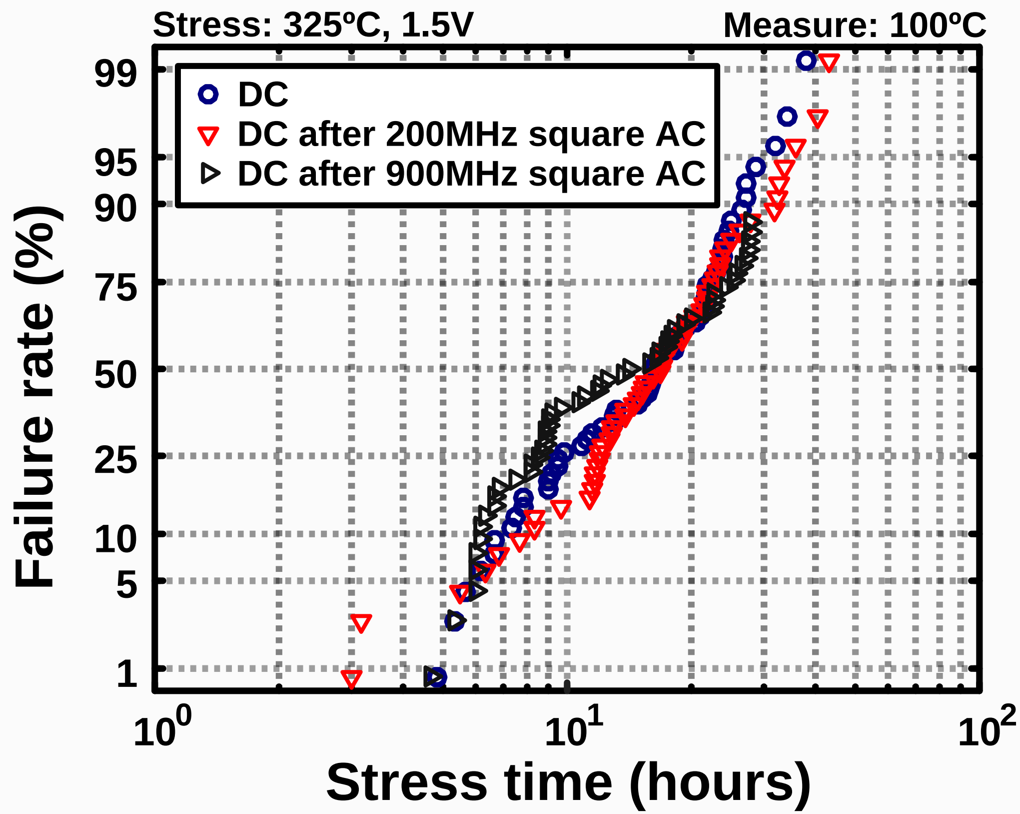
Alternative Testing Method: Two Phase Stress



- Apply AC stress first and then switch to DC stress*
- DC EM lifetime can reveal AC EM stress impact

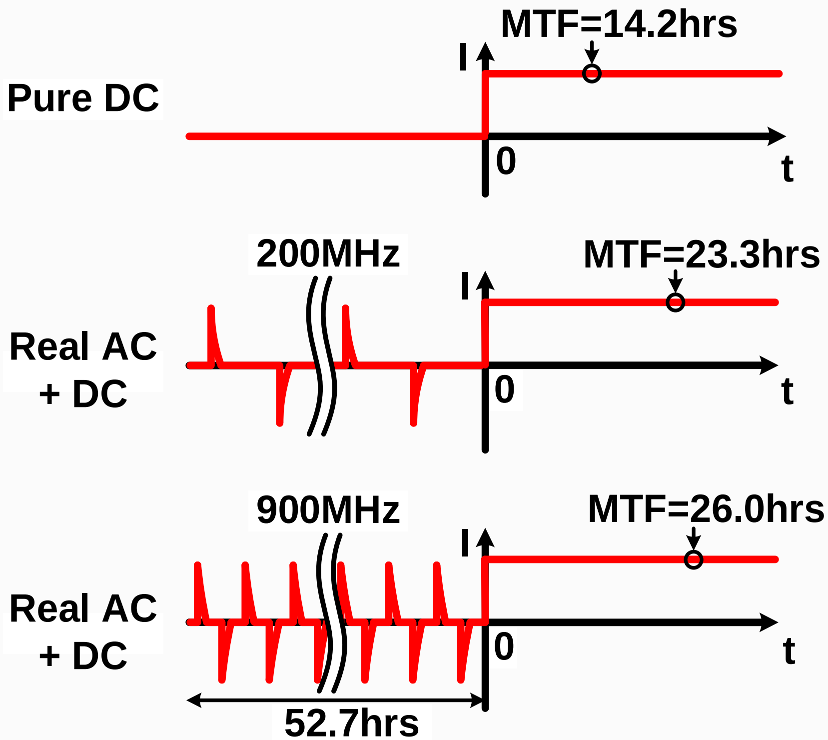
EM Lifetime under Square AC + DC

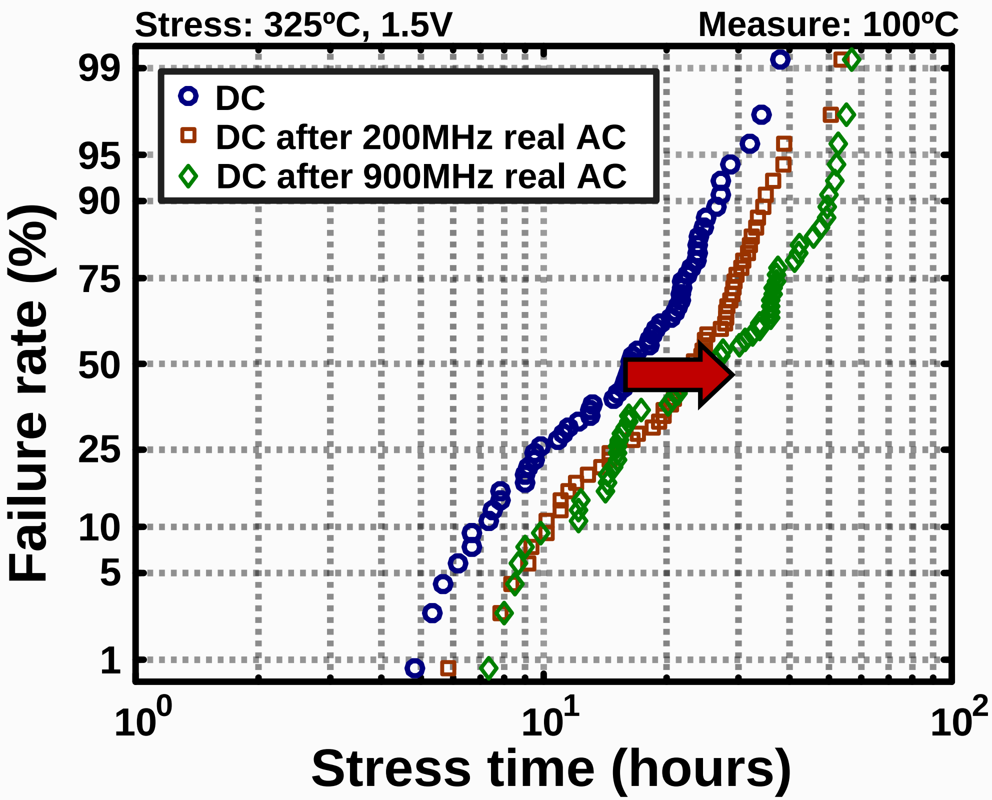




- No apparent difference between pure DC and square AC + DC
- Weak dependence on frequency

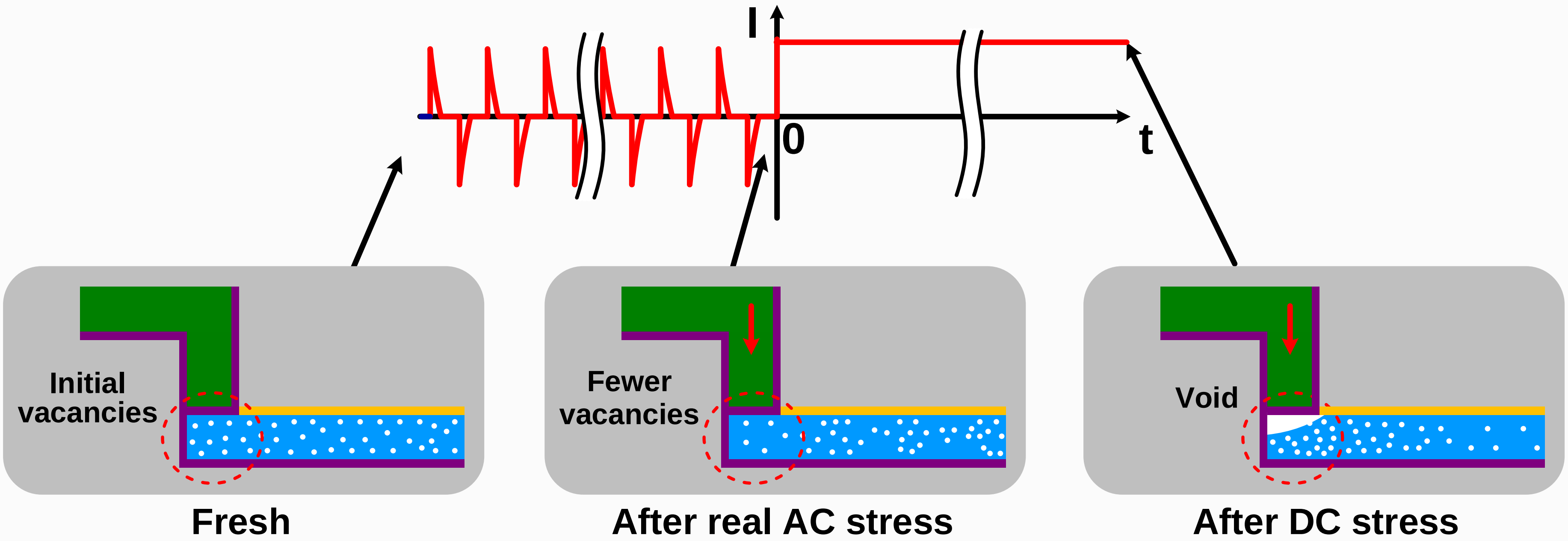
EM Lifetime under Real AC + DC





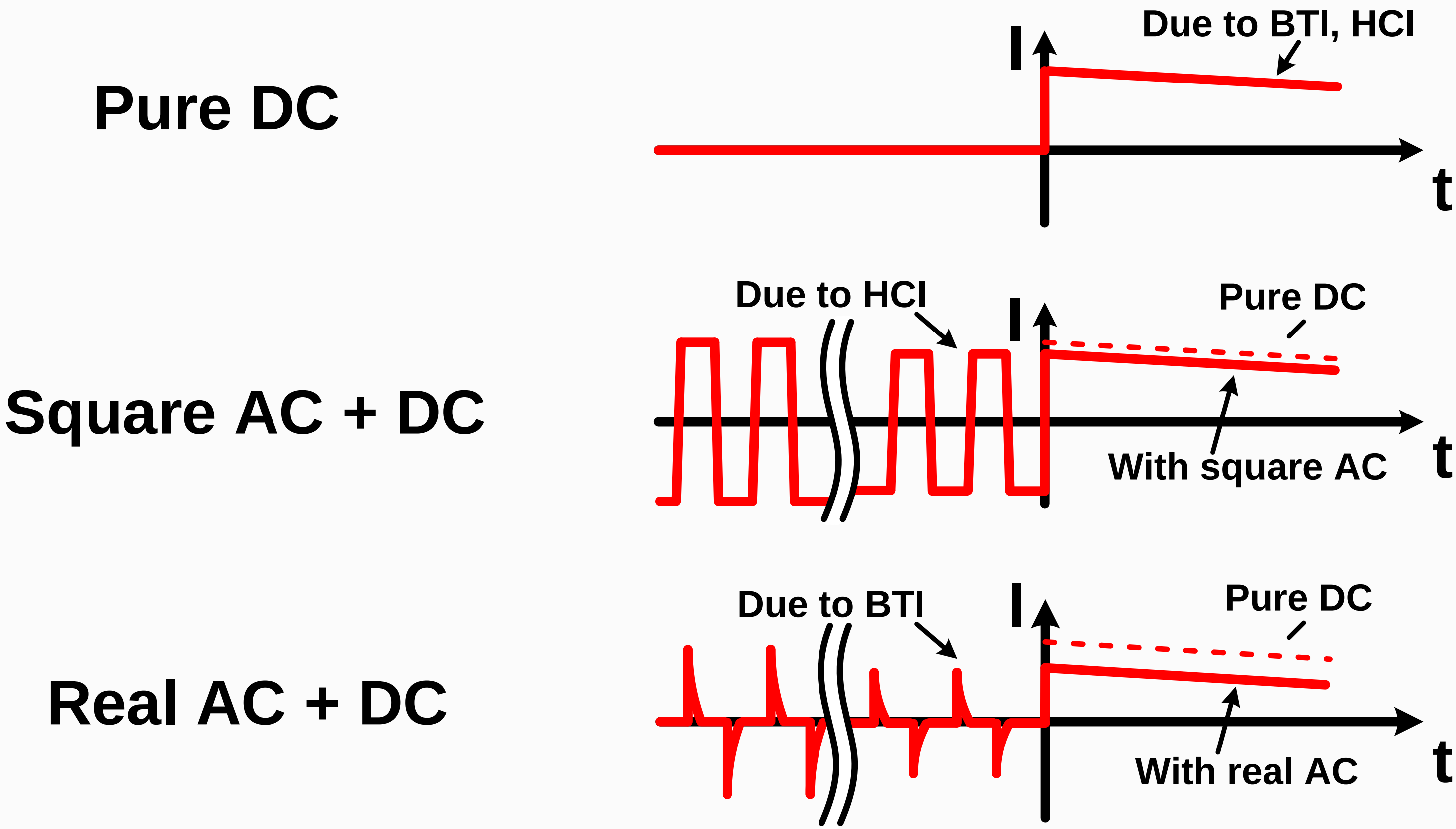
- Real AC pre-stress results in 64-83% longer DC EM lifetime
- Weak dependence on frequency

Possible Explanation for Longer EM Lifetime under Real AC



- Real AC stress may actually make wires more robust
- Additional time may be required for DC EM vacancies to nucleate and evolve

Another Explanation for Longer EM Lifetime under Real AC



- BTI in driver → lower stress current → longer DC EM lifetime

Summary

- EM lifetime measured up to 900MHz from a 32nm test chip
- Square AC did not change DC EM lifetime
- Real AC increased DC EM lifetime
  - Real AC could actually make wires more robust
  - Front end BTI aging may reduce EM stress current