Evaluation of constant power electromigration for Si Photonics heater applications

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Contributed:

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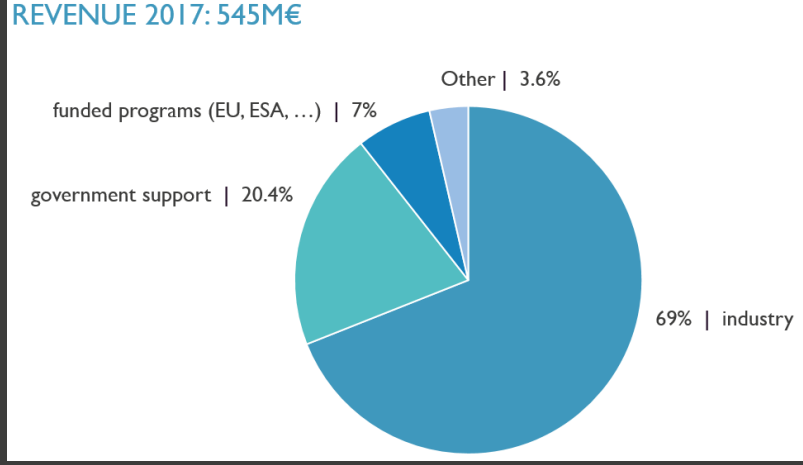
Eric Wilcox and Aaron Glabman, Reliability experts at FormFactor

Content

- *Introduction Interconnect Test and Reliability group@imec*
- *Overview of our collaborations with FormFactor*
  - Test activities
  - Electromigration activities
    - BEOL interconnects
    - MRAM
    - 3D interconnects
- *Today: Si Photonics interconnects*
- *Conclusions*



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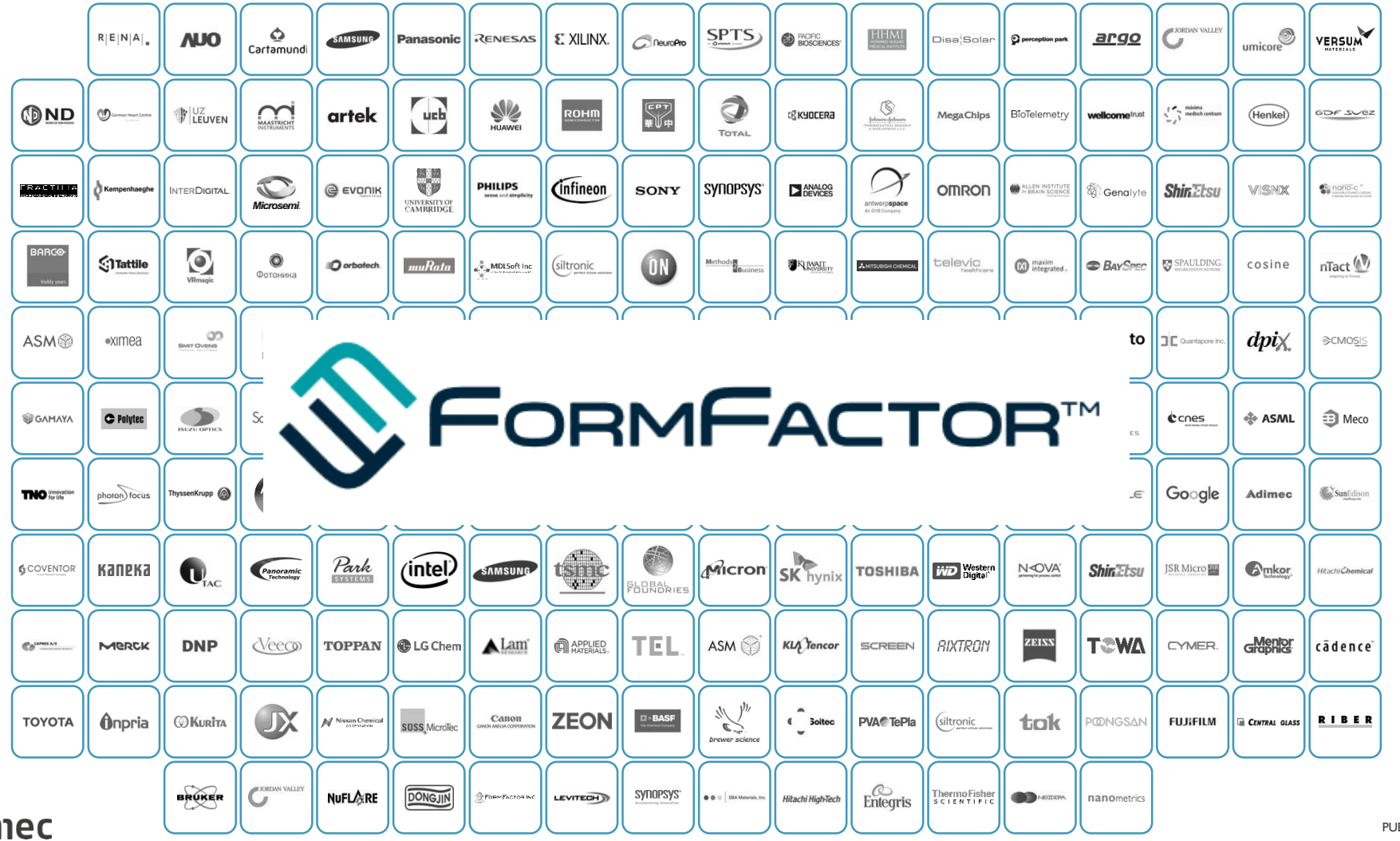
FormFactor™
RENA
AUO
Cartamundi
SAMSUNG
Panasonic
RENESAS
XILINX
neuroPro
SPTS
PACIFIC BIOSCIENCES
HHMI
Disa Solar
perception park
argo
JORDAN VALLEY
umicore
VERSUM MATERIALS
ND
German Heart Centre
UZ LEUVEN
MAASTRICHT INSTRUMENTS
artek
ucb
HUAWEI
ROHM
CPT
TOTAL
KYOCERA
Johnson & Johnson
MegaChips
BioTelemetry
wellcome trust
máxima medisch centrum
Henkel
GDF SUEZ
FRACTILIA
Kempenhaeghe
InterDigital
Microsemi
EVONIK
UNIVERSITY OF CAMBRIDGE
PHILIPS
Infineon
SONY
Synopsys
ANALOG DEVICES
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VISNX
nanoc
BARCO
Tattile
VRmagic
Фотоника
orbotech
muRata
MDLSoft Inc
siltronic
ON
Methods Business
KIWATT UNIVERSITY
MITSUBISHI CHEMICAL
televic healthcare
maxim integrated
BaySpec
SPAULDING
cosine
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ASM
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Quantapore Inc.
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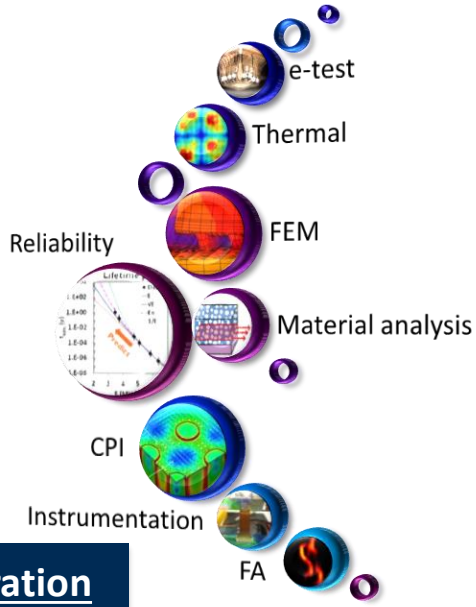
KURITA
JX
Nissan Chemical CORPORATION
SUSS MicroTec
Canon CANON ANELVA CORPORATION
ZEON
BASF
brewer science
Boitec
PVA TePla
siltronic
tok
POONGSAN
FUJIFILM
CENTRAL GLASS
RIBER
BRUKER
JORDAN VALLEY
NuFLARE
DONGJIN
FORM FACTOR INC
LEVITECH
Synopsys
SBA Materials, Inc.
Hitachi High-Tech
Entegris
ThermoFisher SCIENTIFIC
NEXDIA
nanometrics

Imec's interconnect test and reliability group

"Electrical" reliability	"Thermo/thermomechanical" reliability	E- and O-Test Instrumentation	FA
Electromigration Stressmigration TDDB	Material characterization ↓ FEM ↓ CPI		



(f)BEOL reliability and CPI expertise center supports, drives and enables

- Understanding of failure mechanisms and development **reliability test methods**
- Mechanical, thermal and thermo-mechanical modelling and characterization
- **Development of advanced e- and o-test systems/methods**
- Failure Analysis

with main focus on advanced interconnects and packaging (2D, 3D and OIO)

➔ Focus of collaboration with FormFactor: E- and O-test and electromigration

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Probing of 3D-Stacked ICs

FORMFACTOR – IMEC JDP COLLABORATIONS

JDP1: June 2010 – June 2013

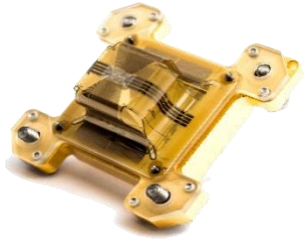
CM300 + MHU

Pyramid RBI probe cores

Technical marketing:
2011: SWTW, ITC, SEMICON Europe;
2012: 3D-TEST;
2013: SWTW, Compass;
2014: Chip Scale Review

JDP2: January 2014 – April 2017

CM300 + NI PXI test head



Pyramid RBI probe cores

Technical marketing:
2014: Compass, ITC;
2015: ETS, SEMICON West, Compass, ITC;
2016: ETS, SWTW;
2017: NI Week, SWTW, ITC-Asia, Chip Scale Review, NI Engineering Impact Award 2017;
2018: ITC, chapter in 3D Handbook

ENIAC JOINT UNDERTAKING

ESiP

ESiP INNOVATION AWARD 2013

Funded by the European Union

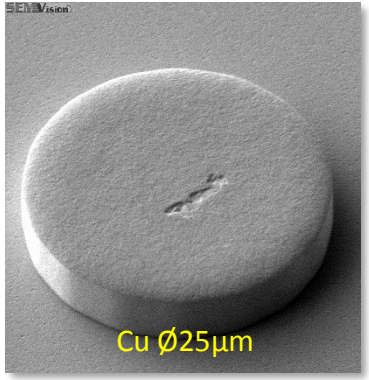
SEA4KET
EC-FUNDED PROJECT
Semiconductor Equipment Assessment for Key Enabling Technologies

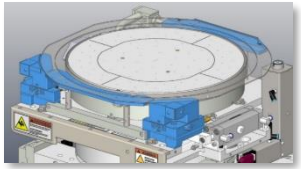
Solutions for Probe Challenges in (3D-)Test

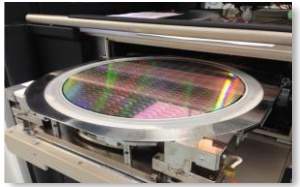
imec

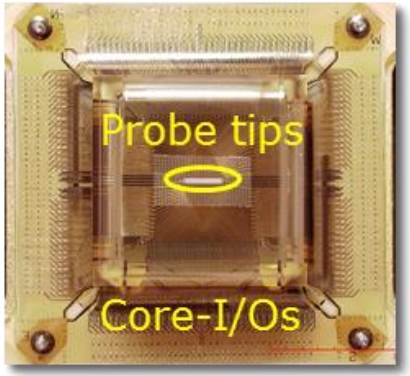
FORMFACTOR – IMEC JDP COLLABORATIONS

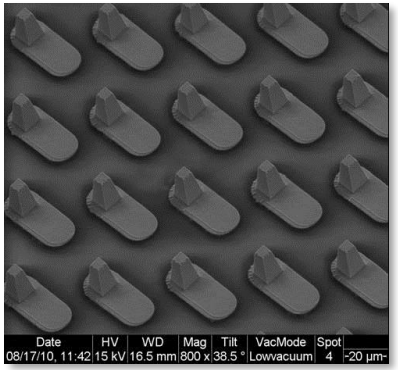
Probing Challenges	imec-FormFactor Solutions
1. Large tape frames	Adapted CM300 probe station
2. Ultra-thin wafers on tape	Pyramid RBI low-force probes
3. Dense arrays of micro-bumps	Advanced probe card + station
4. Singulated die (stacks) on tape	Velox *AlignChip* + *PreMapWafer*

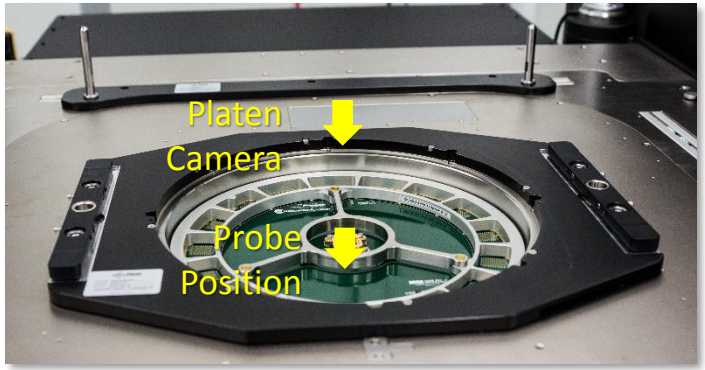












Electro-Optical Wafer Probing

FORMFACTOR – IMEC JDP COLLABORATIONS

JDP3: December 2014 – April 2016

PA300 semi-auto prober

imec-built optical positioners on top

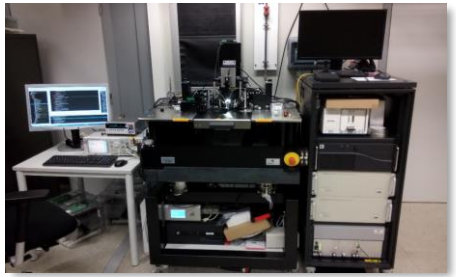
Technical marketing:
2016: ETS;
2017: SEMI Best ATE Paper 2016;
2018: Photonics Online, imec Magazine

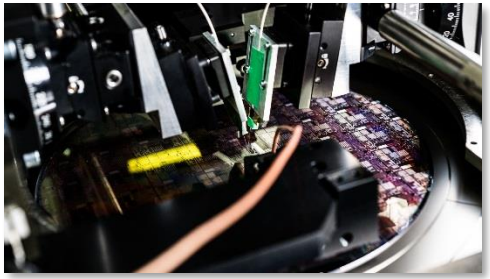
BEST ATE PAPER of 2016
Awarded to
J. De Coster, P. De Heyn, M. Pantouvaki, H. Ingelen, H. Chen, EJ Marchiness, F. Abid, J. Van Campenhout – imec
R. Dok – Cascade Microtech
For their paper published at the 2016 IEEE European Test Symposium
Test station for flexible semi-automatic wafer-level silicon photonics testing
semi
TEST VISION 2020
SEMICON WEST

JDP4: October 2017 – November 2019

CM300xi + MHU + PI hexapods

Technical marketing:
TBD





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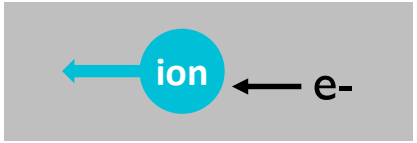
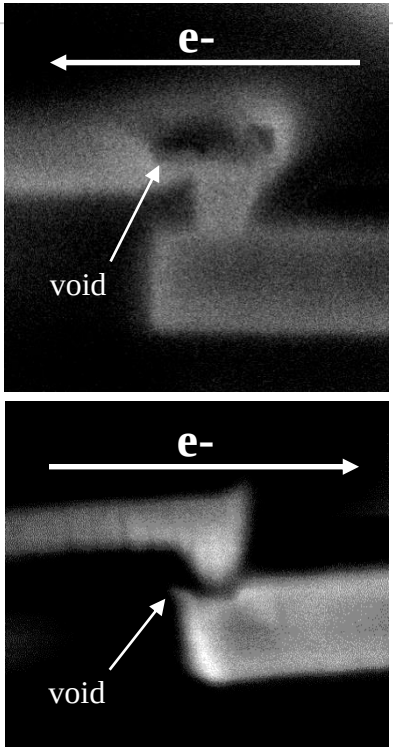
What is electromigration?

Electromigration fundamentals



- Mass transport of metal ions by momentum exchange with conduction electrons
- Leads to resistance increase

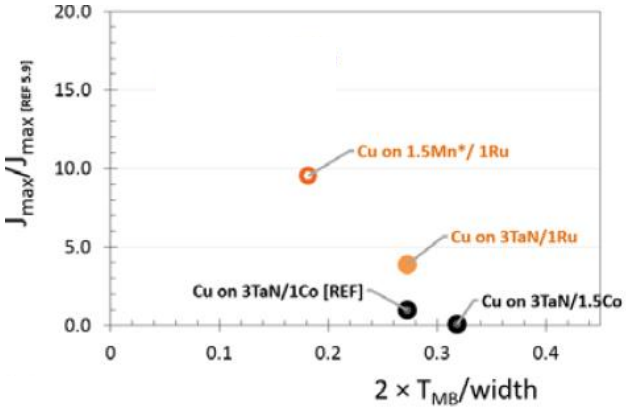


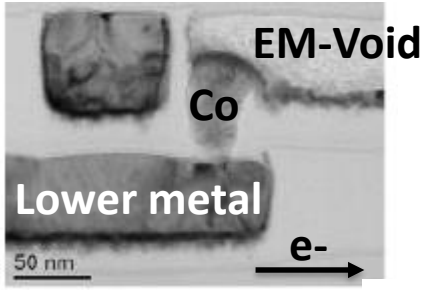
Electromigration = Metal migration induced by electron wind

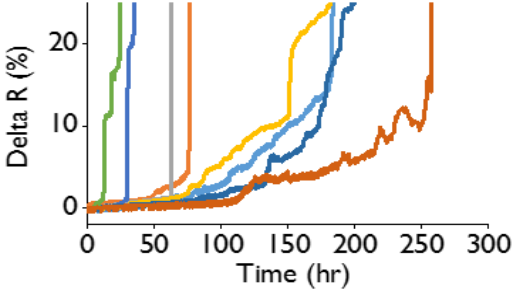
BEOL Interconnects

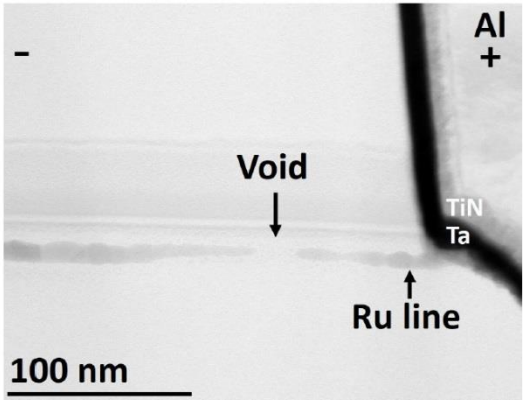
- **Reliability system of FormFactor heavily used in imec to test reliability of advanced BEOL interconnects**

Cu van der Veen et al, IITC'18	Co Via Varela Pedreira et al, IITC'18	Ru Beyne et al, IRPS'18





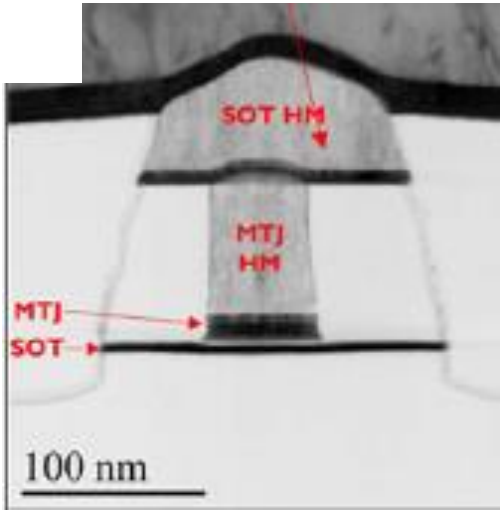


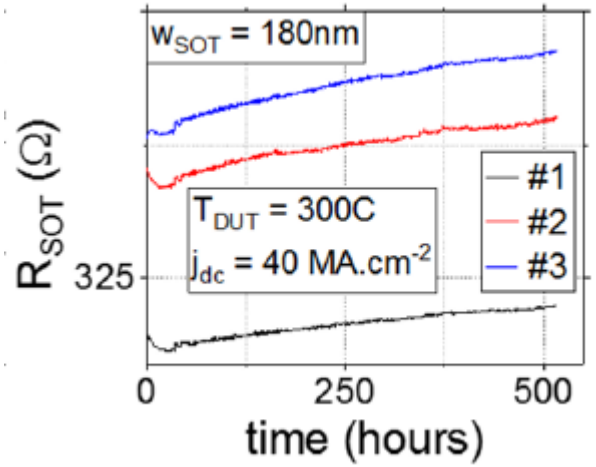


Hole wind?

SOT-MRAM

- **Electromigration in ultra-thin (<4nm) SOT-layers could a concern for Magnetic RAM**
- **K. Garello et al, VLSI'18**



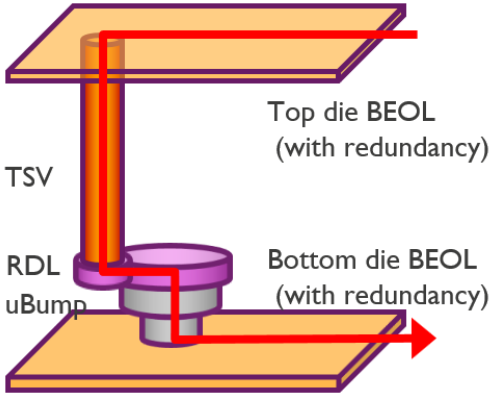


1st data suggest thin SOT layer survives high current densities

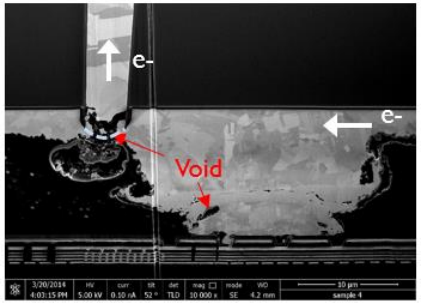
3D interconnects

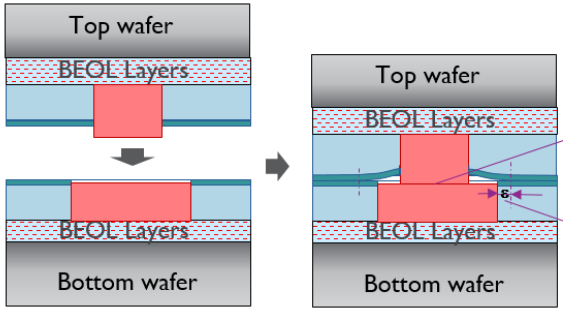
- **Reliability system of FormFactor heavily used in imec to test reliability of advanced 3D interconnects**

TSV Oba et al, Admeta	Hybid bonds De Messemaeker et al, SSDM'18

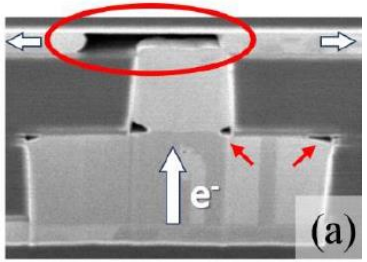


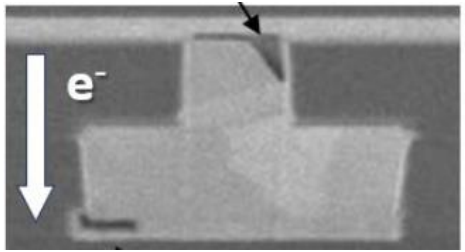
After EM test (SEM)





Pads are big➔ high I required





TSVs are big➔ high I required

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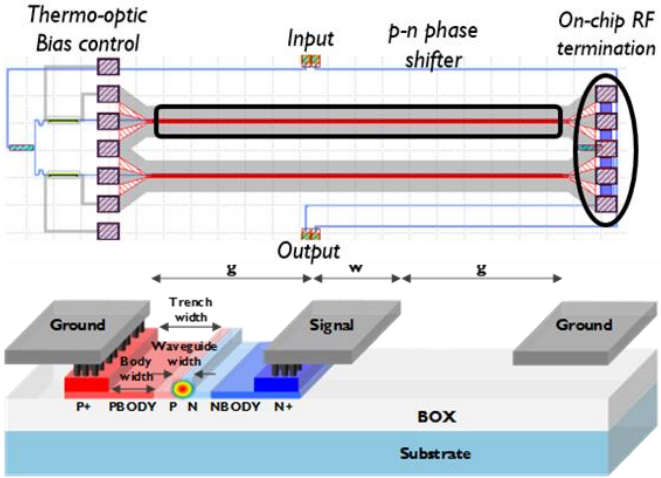
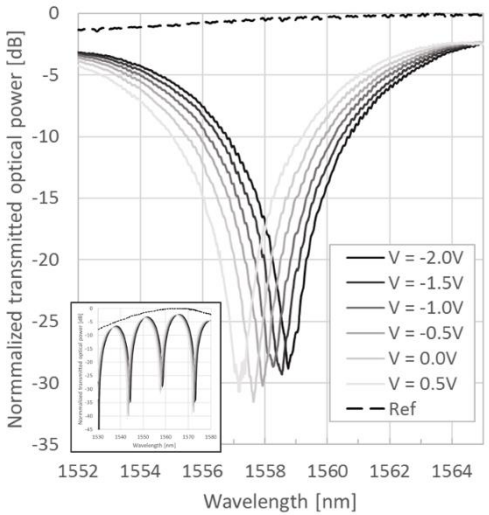
Application - Modulators

- *Si Photonics modulators modulate light by applying external modulation voltage*
  - Absil et al, IEDM'17 "Reliable 50Gb/s Silicon Photonics Platform for Next-Generation Data Center Optical Interconnects"

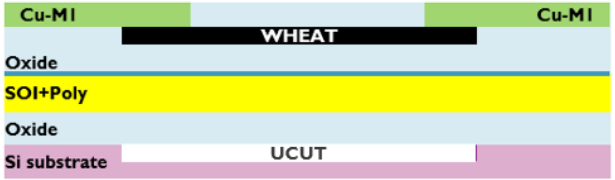




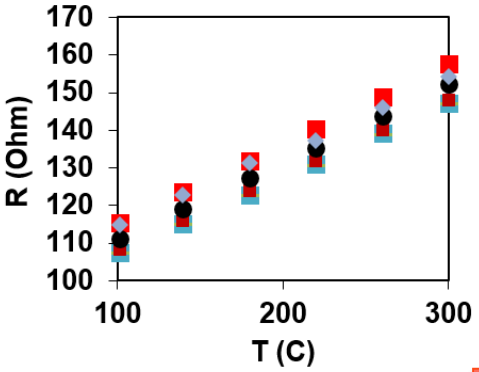
- *Thermo-optic tuning realized using doped Si stripe or* ***W wires***

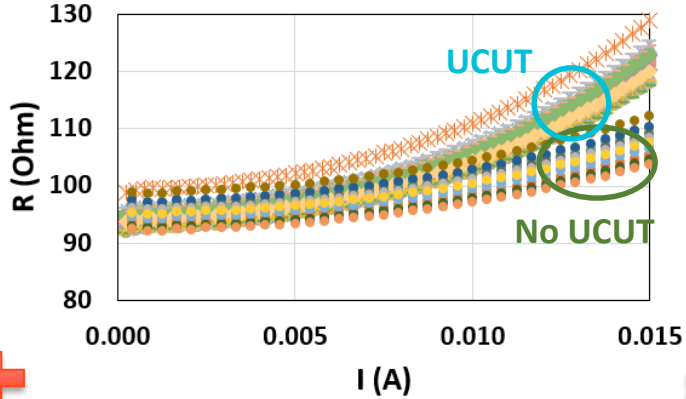
Application – W heaters

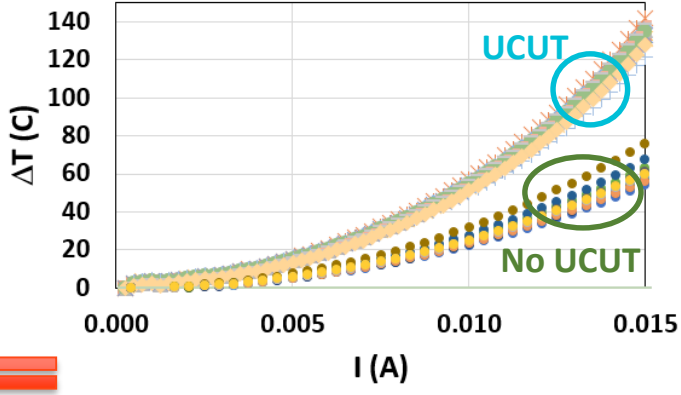
- *W wires with/without UCUT used to put modulators at a constant temperature over time*



- *High electrical power through heater leads to high temperature increase*

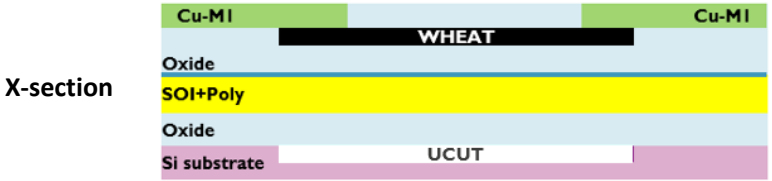




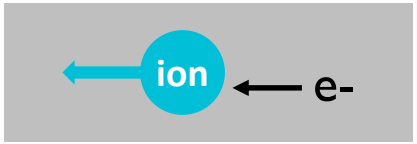


W heaters – Electromigration concern

- *W wires with/without UCUT used to put modulators at a constant temperature over time*

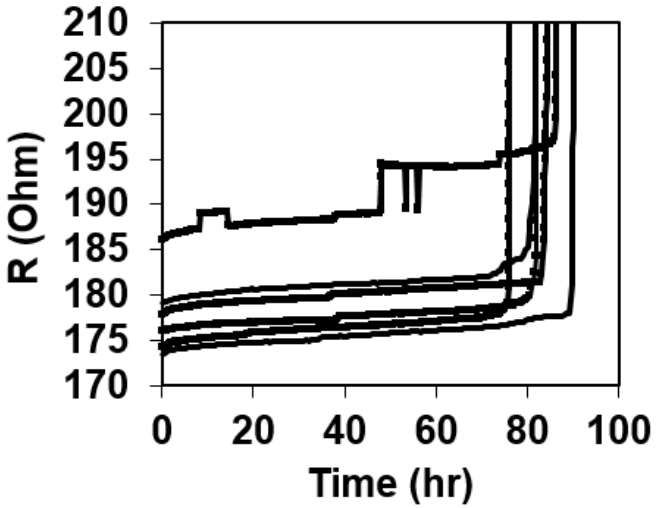


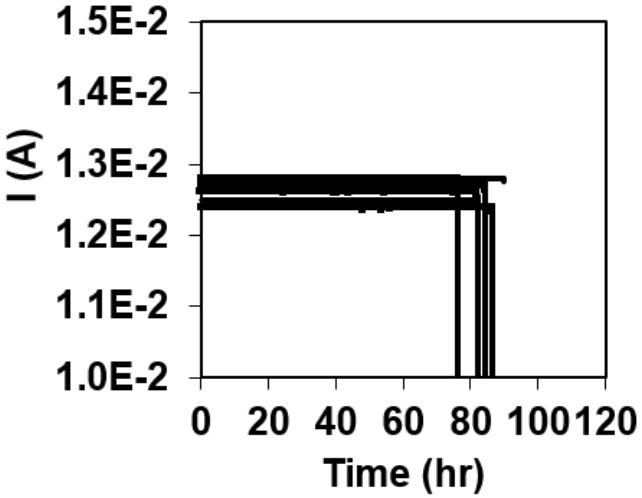
- *Heater requires high currents*
  - Depending on design: several 10s of mA
  - Electromigration is a concern



W heaters – Standard EM test

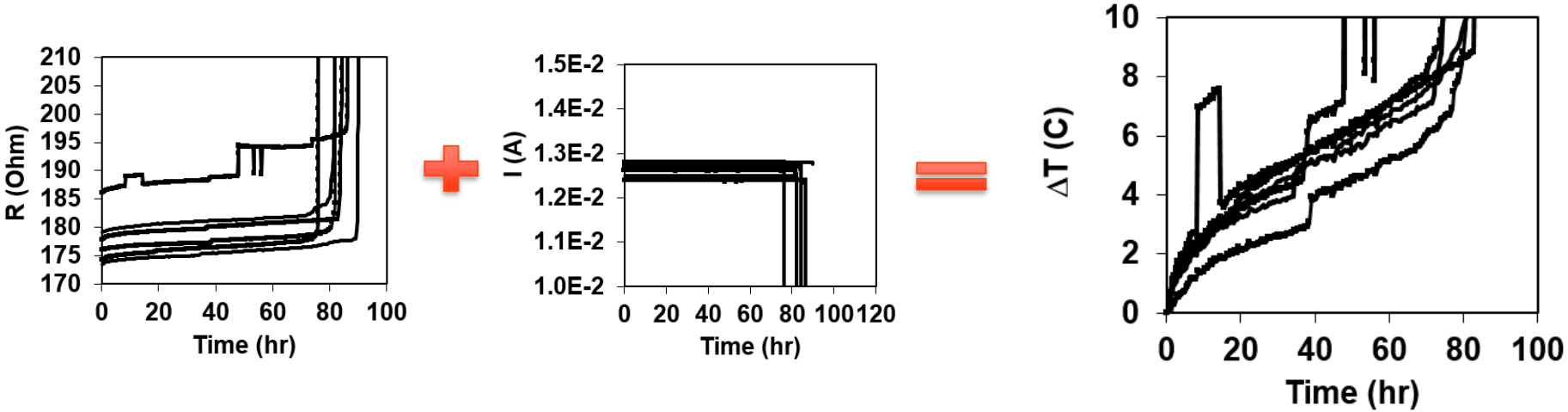
- *EM is a current driven-process*
  - EM testing is mostly done with a constant current
  - Tests happen with high currents and at temperatures in order to get fast failures
- *Typical EM test*
  - 300C ambient
  - I~12.5mA
  - 145C extra heating





Standard EM test on heaters - Concern

- *Temperature increases during EM test with constant current*

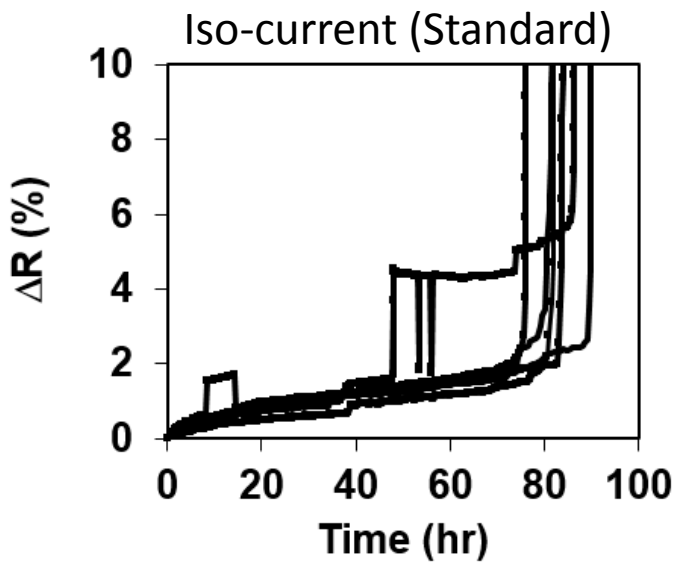


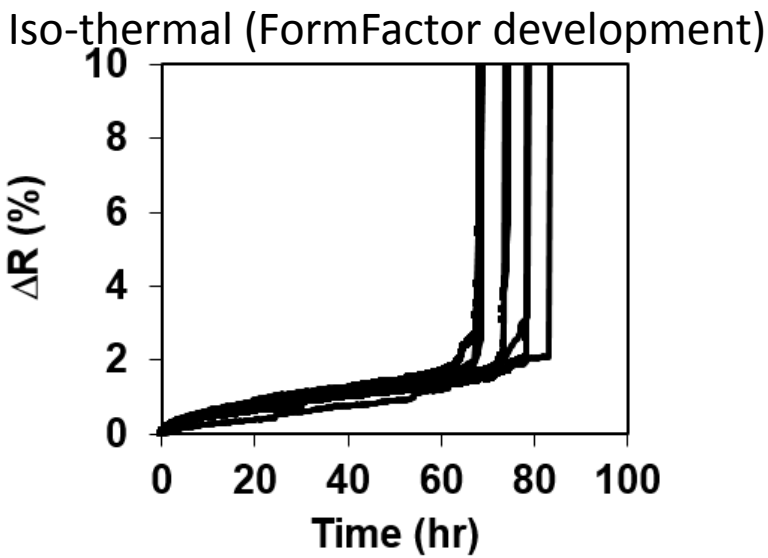
- *During operation temperature is kept constant (NOT CURRENT)*

➔ *Isothermal testing developed at FormFactor and applied to imec's W heaters*

Iso-Current vs Iso-thermal tests

- *Resistance-increase versus time*



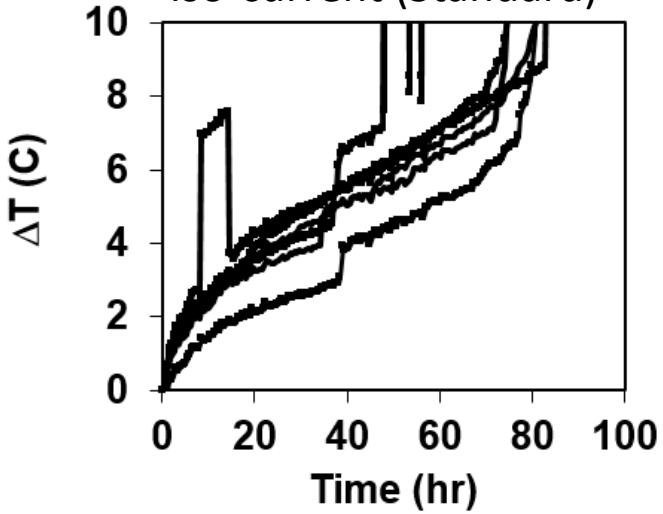


- *Similar curves ➔ same degradation mechanism*

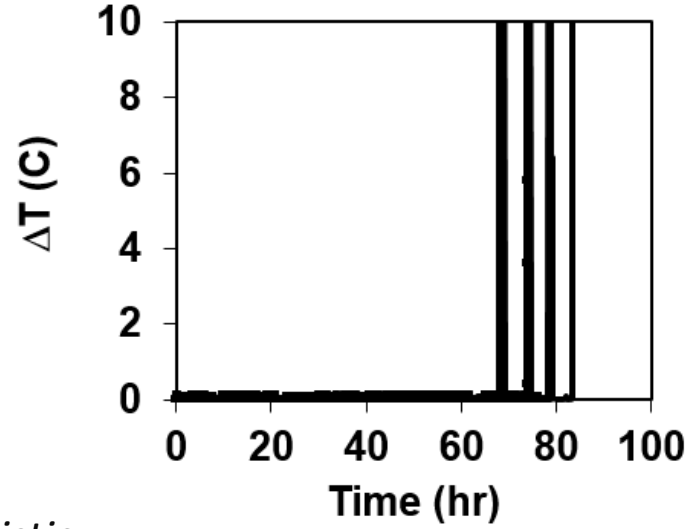
Iso-Current vs Iso-thermal tests

- *Temperature-change versus time*

Iso-current (Standard)



Iso-thermal (FormFactor development)

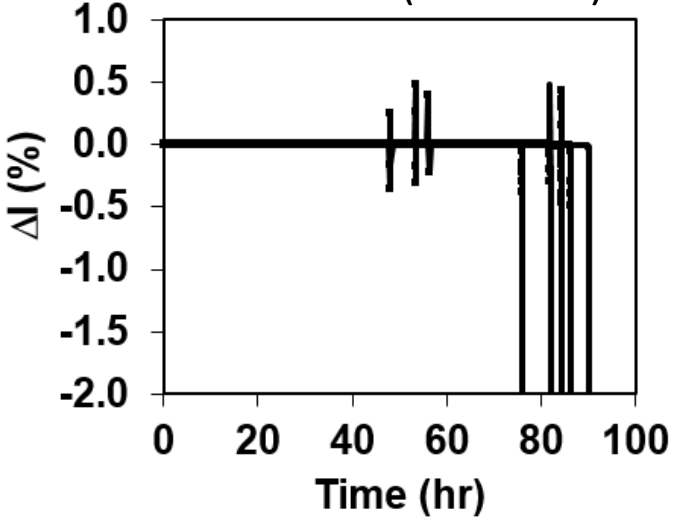


- *Iso-current ➔ Temperature drifts ➔ not realistic*
- *Iso-thermal ➔ Temperature stays constant ➔ more realistic*

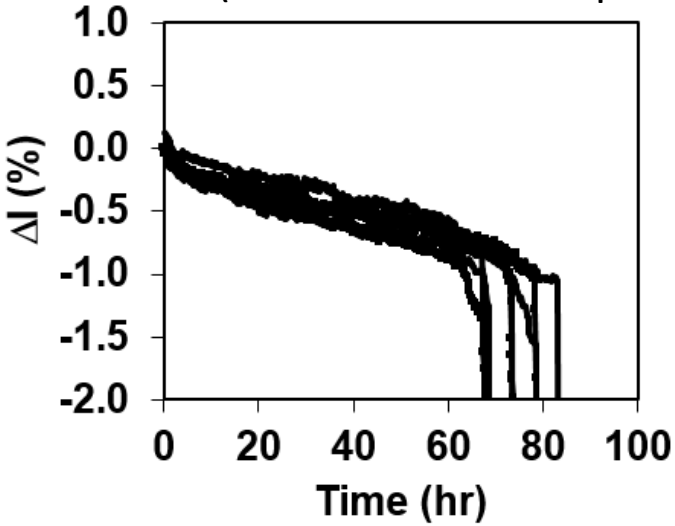
Iso-Current vs Iso-thermal tests

- *Current-change versus time*

Iso-current (Standard)

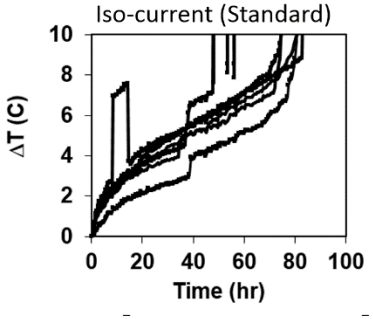


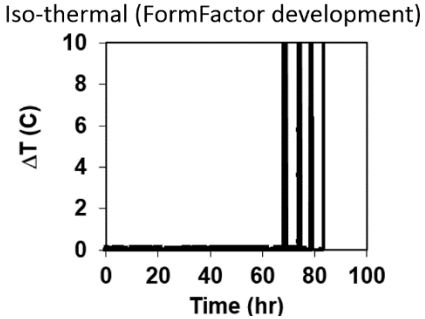
Iso-thermal (FormFactor development)

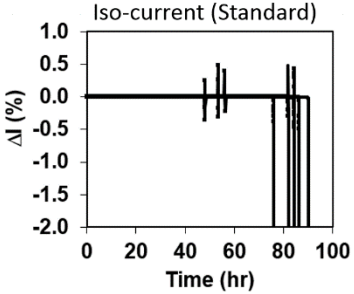


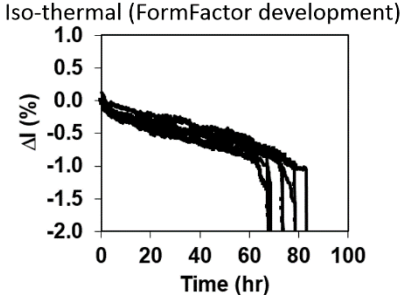
- *Iso-current ➔ Current is pushed through till failure*
- *Iso-thermal ➔ Current lowered during degradation ➔ more realistic*

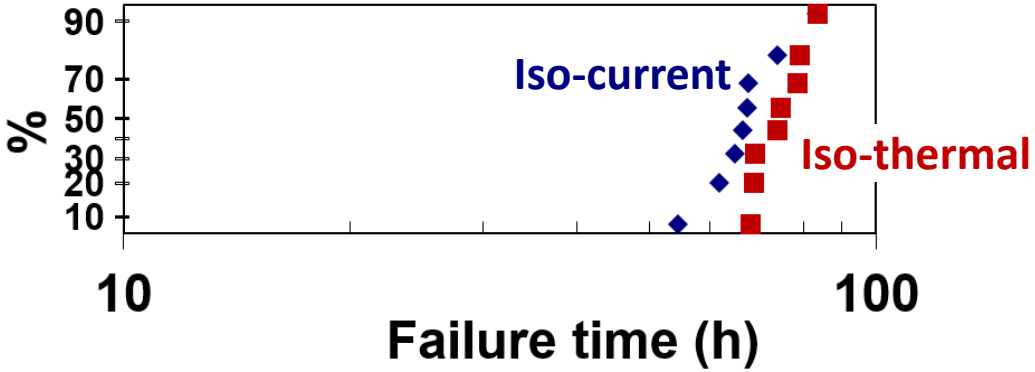
Comparison of failure times







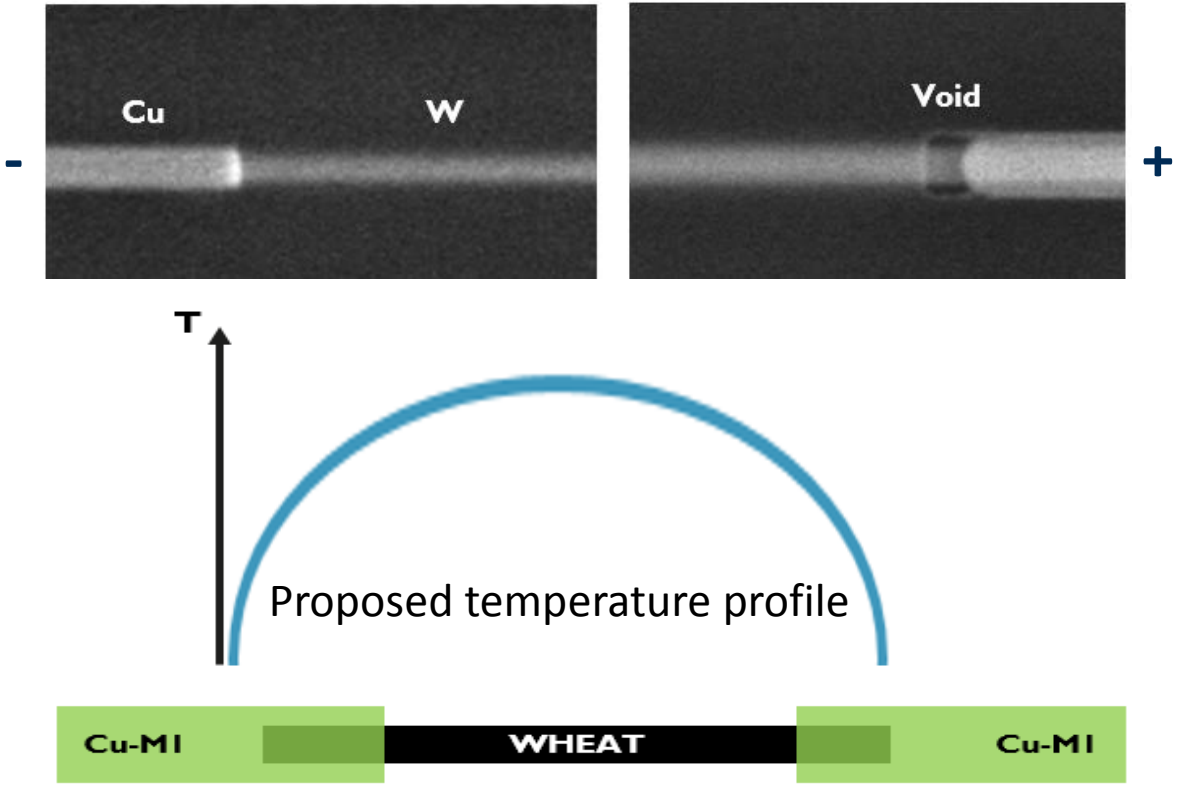




Lower currents and lower temperatures lead to slightly higher failure times for iso-thermal tests

➔ Lifetime benefit, but lower than expected ➔ Failure location on next slide

Failure location



- *Failure location is at copper-injector*
  - W more robust than Cu regarding EM
- *Proposed temperature profile*
  - "Cold" in Cu
- *Only lifetime gain due to smaller currents expected*

Content

- *Introduction Interconnect Test and Reliability group@imec*
- *Overview of our collaborations with FormFactor*
  - Test activities
  - Electromigration activities
    - BEOL interconnects
    - MRAM
    - 3D interconnects
- *Today: Si Photonics interconnects*
- *Conclusions*

Conclusions

- *Long term successful leading egde collaborations between imec and FormFactor test-station and reliability system developers*
  - E-test
    - Adapted CM300 probe station for 300mm tape frames
    - Pyramid RBI low-force probes for probing ultra-thin wafers on tape
    - Advanced probe card + station for probing dense arrays of micro-bumps
    - Velox AlignChip + PreMapWafer to measure Singulated die (stacks) on tape
  - O-test
    - Fully automated optical test system
  - Reliability
    - Focus on BEOL, 3D-interconnects and MRAM
    - This presentation
      - Isothermal electromigration test successfully applied to heaters for Si Photonics applications

➔ **<u>Much more realistic EM-testing for this application!</u>**