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28nm Embedded RRAM for Consumer and Industrial Products: Enabling, Design, and Reliability

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Introduction

RRAM = Resistive Random Access Memory

Why a new non-volatile memory technology?

- for newer semiconductor technologies, embedded **Flash does not shrink well**, and
- **increased cost of Flash integration** into advanced manufacturing processes

Why emerging memory in general?

- typically **much lower wafer cost** compared to corresponding embedded Flash
- **no impact on base technology** enables reuse of existing circuits

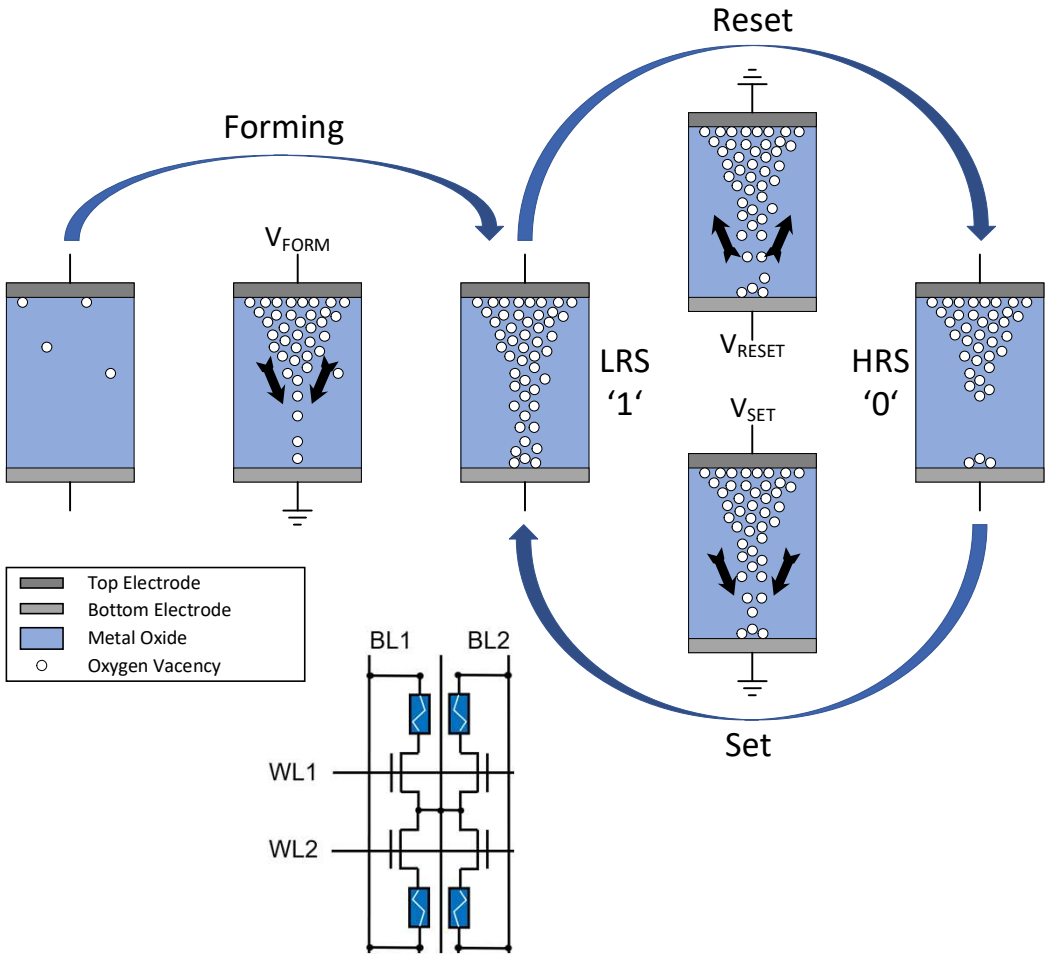
What are the advantages of RRAM?

- **lowest cost** of all emerging memories available at foundries
- **it behaves like a (slow) RAM with retention** and independent bit toggling → easy for SW

What are the challenges for RRAM?

- potential issues with **reliability**:
  - **data retention at high T**
  - **endurance**
- Flash know-how only partly reusable

RRAM – Physical Principle



RRAM is based on a reversible soft breakdown:

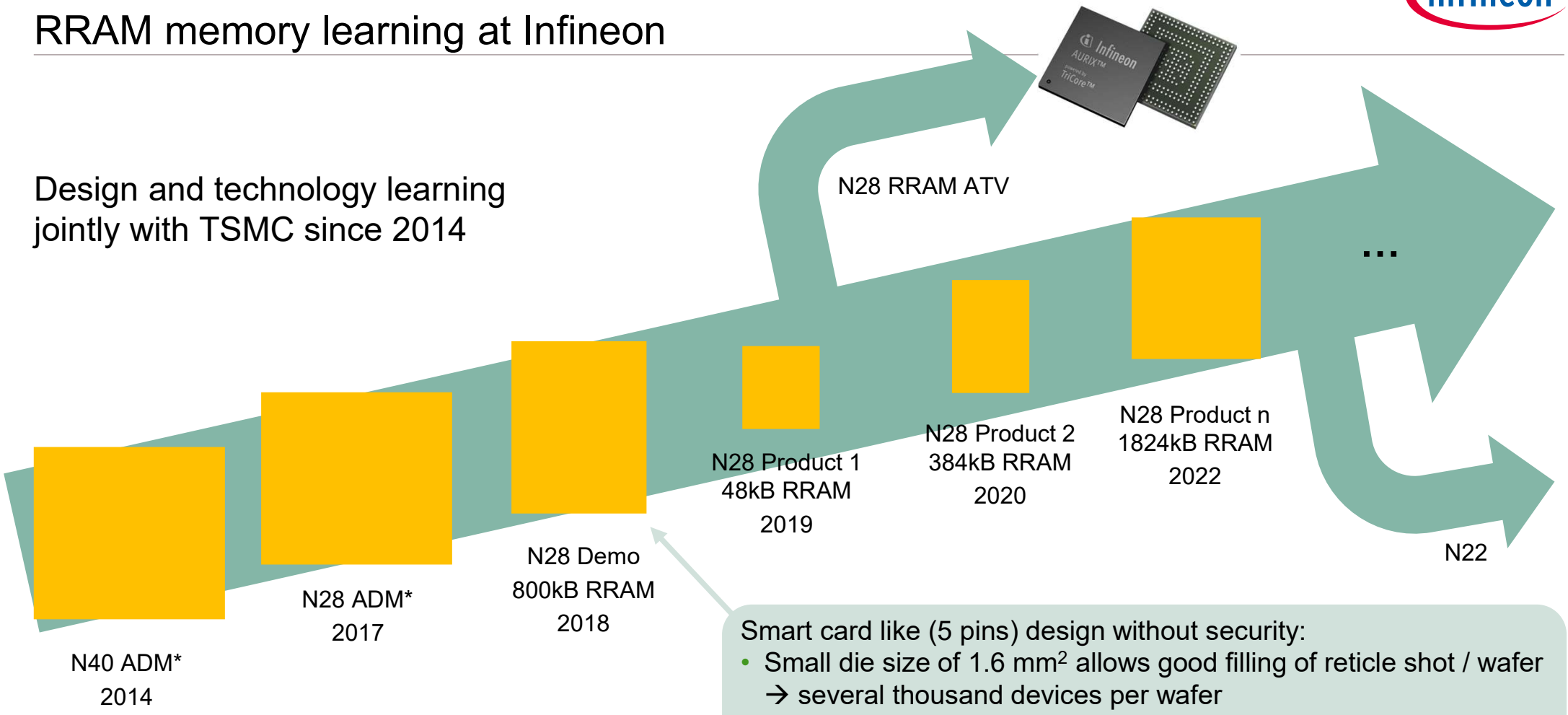
- **Forming** operation creates conductive filament of Oxygen Vacancies
- **Reset** operation breaks the filament, resulting in a High Resistance State (HRS)
- **Set** operation recreates the filament, resulting in a Low Resistance State (LRS)

- RRAM cells located in backend of line between two metal layers, in place of vias
  - Very small number of extra mask layers
  - No extra temperature budget in frontend of line → no influence on base technology

- Memory elements: Combination of RRAM cells plus select transistors in 1T1R configurations, finally forming a memory field

RRAM memory learning at Infineon

Design and technology learning jointly with TSMC since 2014

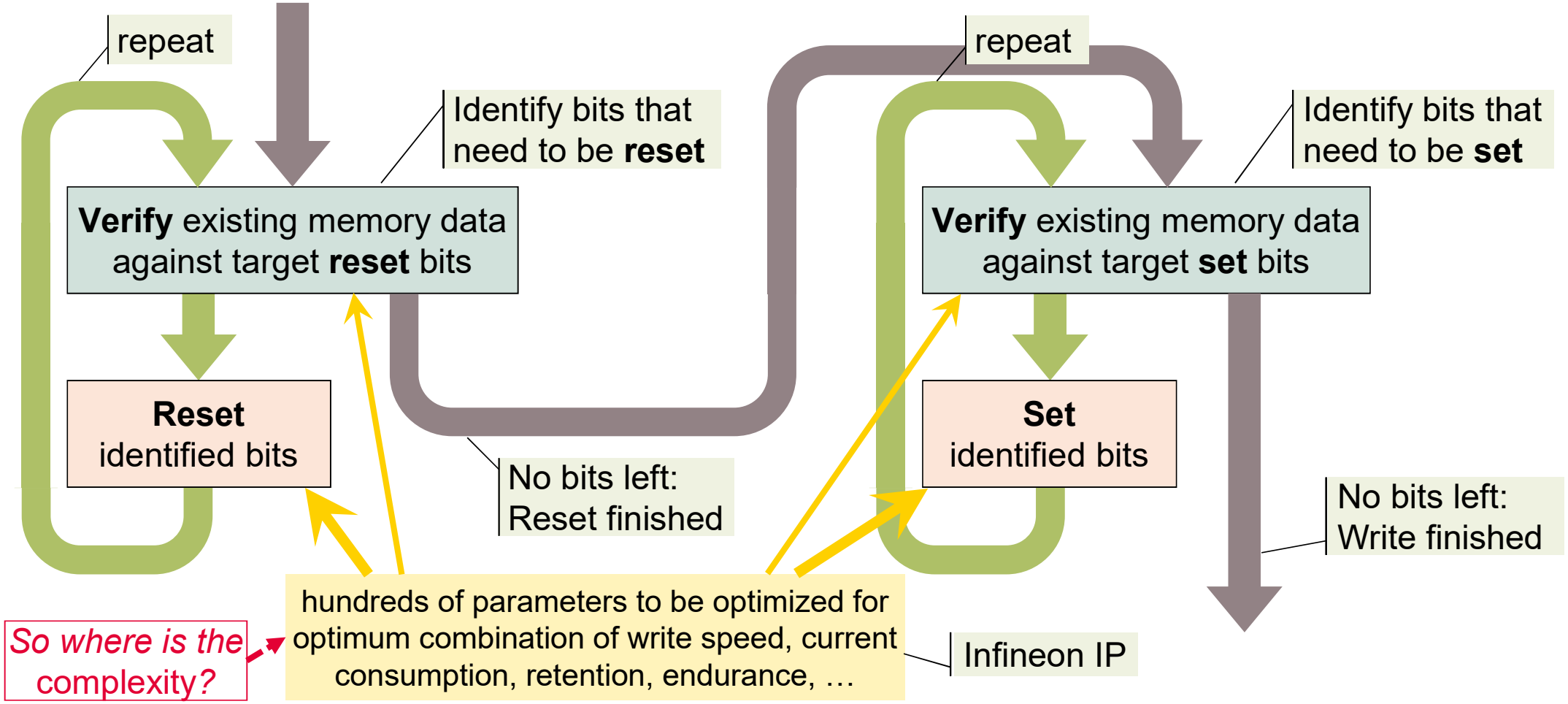


*ADM = Array Diagnostic Memory

Smart card like (5 pins) design without security:

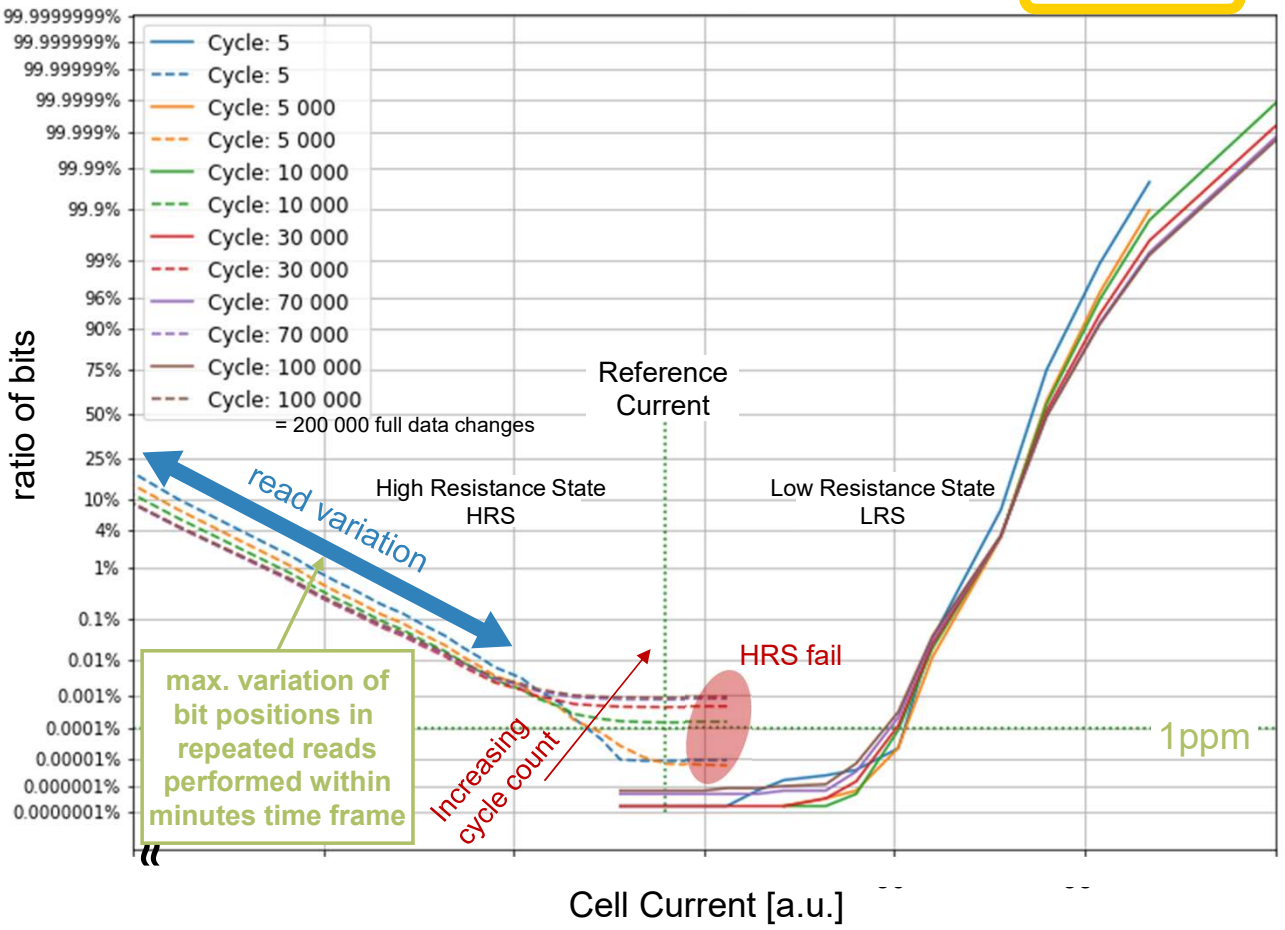
- Small die size of 1.6 mm^2 allows good filling of reticle shot / wafer
  → several thousand devices per wafer
  - billions of bits per wafer
  - high parallel testing

RRAM – Complex Iterative Write Algorithm in Hardware – Even for a Purely Digital Operation



RRAM 28nm – Endurance (Cycling) / Cell Current Distributions

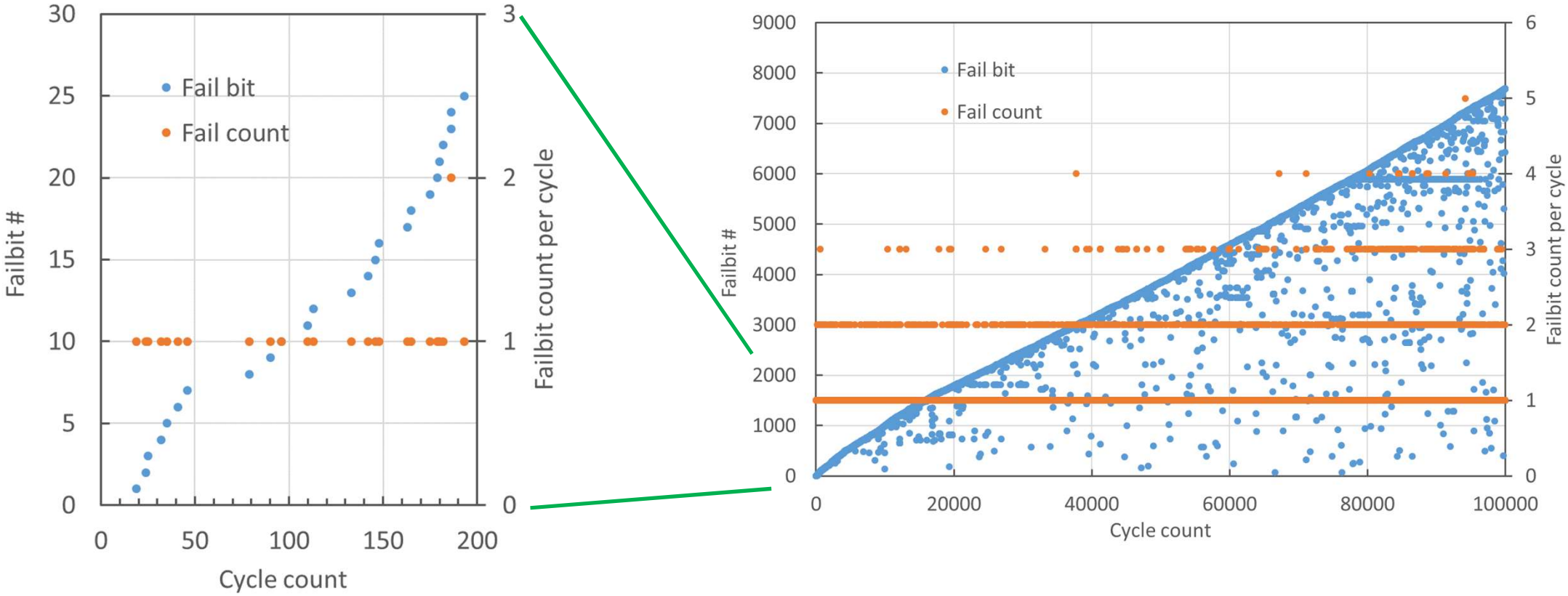
Product Wafer Level Endurance: ~1250 DUTs → **2.2E9 bits**



- Reliable control of read-current distribution achieved
- Large read-window after initial write for use as **digital** memory
- Constant read-window during cycling to 100 000 ckb-ickb cycles
  - HRS fail bits increasing with cycling:
    “Stuck at LRS”
    (erratic / stubborn)

- Side note:
  - distributions are stable,
    but single bit behavior is not!

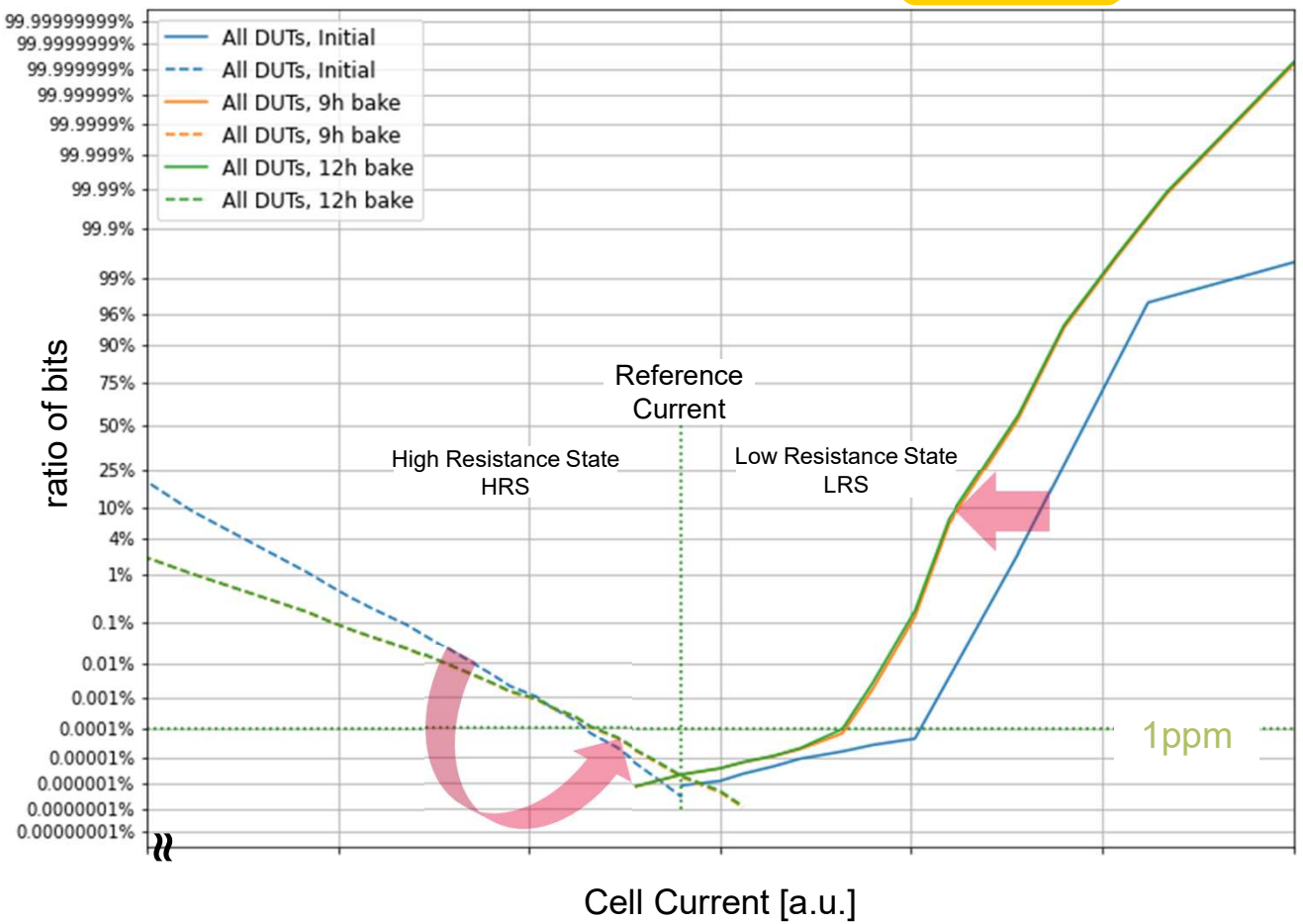
RRAM 28nm – Endurance (Cycling) / Erratic Bit Occurrence



› Almost 3% of cycled bits at least once show erratic behavior during 100 000 cycles endurance test
→ Need suitable error correcting code (ECC) to cover erratic and stubborn bits

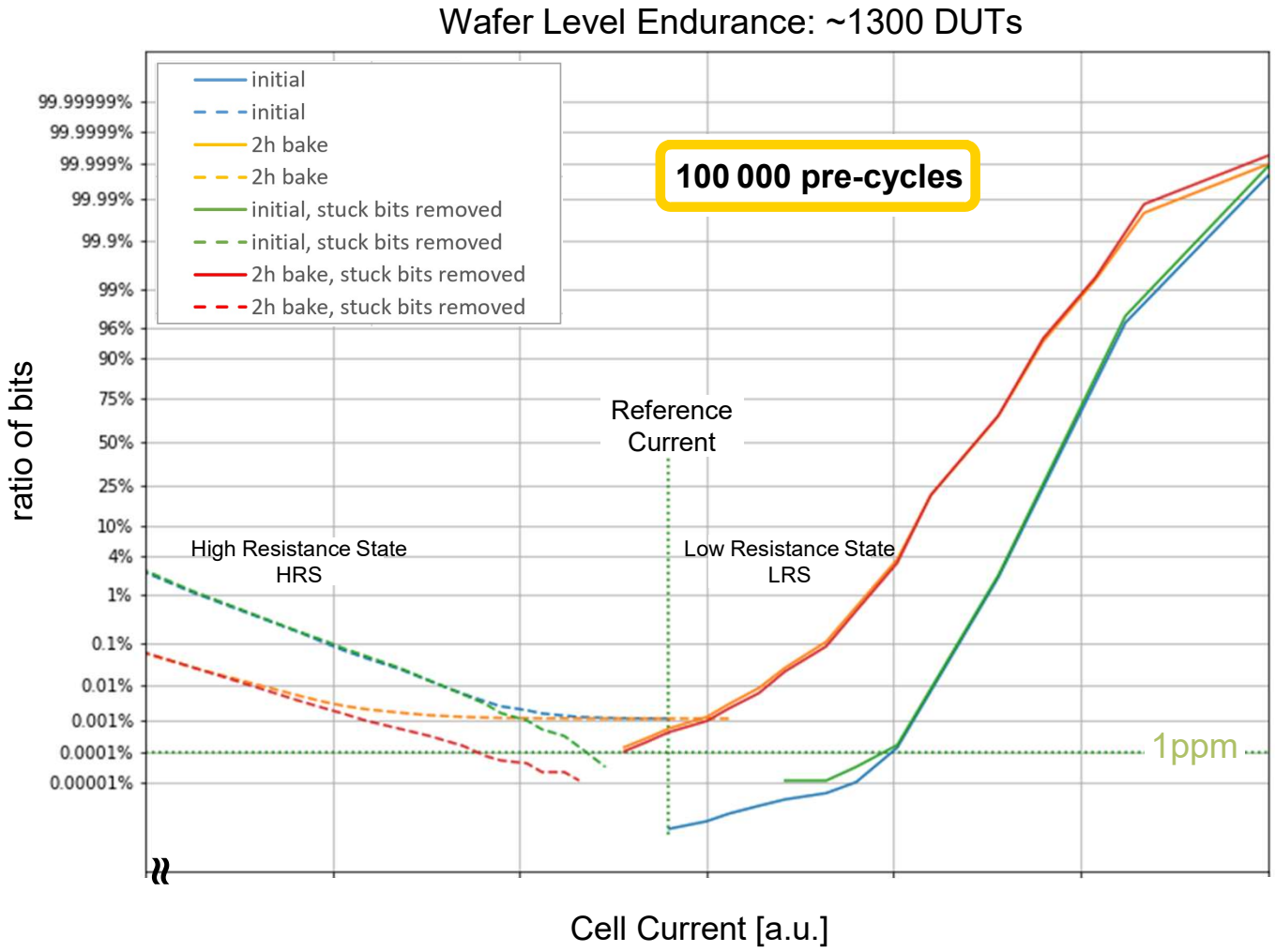
RRAM 28nm – Full Wafer Data Retention @ T=175°C

Product Wafer Level Bake: 5 wafers → **~3E11 bits**



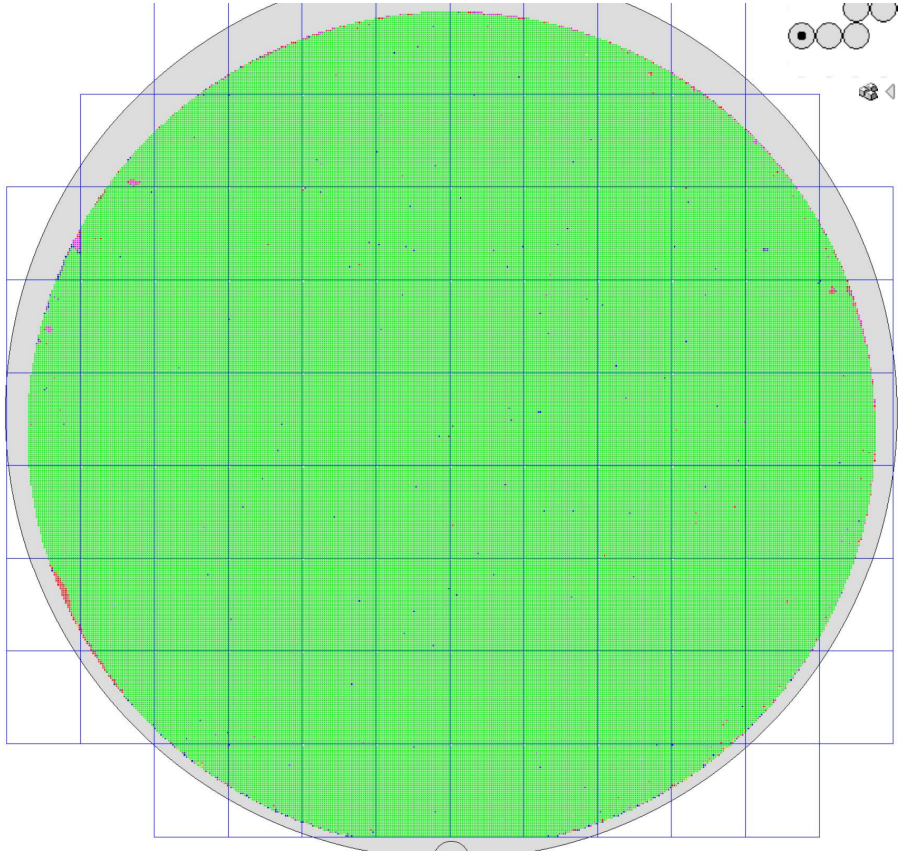
- E_a = 1.65 eV extracted from measurements, but standard Arrhenius model not fully fitting for RRAM → New retention model developed
- High E_a → 9 h @175°C bake equals ~25 years @85°C
- Tilt of HRS- and parallel shift of LRS-distribution during bake
- Additional stress to consider:
  - Soldering (260°C)
  - Chip assembly flow

RRAM 28nm – Retention After Cycling (RAC)



- Good read window after cycling and retention bake (RAC)
- E_a changes with cycling, bake of 2 h @175°C equals ~4 years @85°C
- Side notes:
  - Also CAR (Cycling after Retention) must be checked!
  - All results depend on the used programming algorithm!

RRAM 28nm – Yield of Product Wafer



› 12” Wafer-map of 28nm product with 48kB embedded RRAM, overall product yield > 99 %

Summary

- Infineon together with the silicon foundry partner TSMC developed a 28nm embedded RRAM for consumer and industrial applications. First RRAM-based products in 22nm are available, too.
- The reliability data is looking very good, not only on single DUT data but also on high statistics from many wafers and lots.
- No new additional failure modes were found for RRAM, only retention and erratic (stuck) bits have to be considered.
- The development of the programming algorithm is the key for good reliability (cycling, retention, …), competitive performance and electrical parameters of the embedded RRAM module.
- **The Infineon 28nm and 22nm RRAM products can be manufactured with high yield and safe fulfillment of the reliability targets.**
- Note: Infineon decided to use RRAM also in future high-end automotive microcontrollers.

Summary

- Infineon together with the silicon foundry partner TSMC developed a 28nm embedded RRAM for consumer and industrial applications. First RRAM-based products in 22nm are available, too.
- The reliability data is based on high statistics from many wafers and
- No new additional stuck) bits have to be considered.
- The development ng, retention, …), competitive perfor e.
- **The Infineon 28n h yield and safe fulfillment of the bility targets.**
- Note: Infineon decided to use RRAM also in future high-end automotive microcontrollers.

At least for us

RRAM is the new embedded Flash

Links

- Papers:
  - C. Peters, F. Adler, K. Hofmann and J. Otterstedt,
    "Reliability of 28nm embedded RRAM for consumer and industrial products,“
    2022 IEEE International Memory Workshop (IMW), Dresden, Germany, 2022, pp. 1-3,
    doi: 10.1109/IMW52921.2022.9779300.
  - N. Kopperberg et al.,
    "Endurance of 2 Mbit Based BEOL Integrated ReRAM,“
    in *IEEE Access*, vol. 10, pp. 122696-122705, 2022,
    doi: 10.1109/ACCESS.2022.3223657.
  - Alessandro Grossi et. al.,
    “28nm Data Memory with Embedded RRAM Technology in Automotive Microcontrollers,”
    2023 IEEE International Memory Workshop (IMW), Monterey, US, 2023, pp. 1-4,
    doi: 10.1109/IMW56887.2023.10145951
  - S. Wiefels et al.,
    “Reliability Aspects of 28 nm BEOL integrated ReRAM,”
    in *physica status solidi (a) applications and materials science*,
    doi: 10.1002/pssa.202300401.
  - …
- Press release:
  “Infineon and TSMC to introduce RRAM technology for automotive AURIX™ TC4x product family“,
  https://www.infineon.com/cms/en/about-infineon/press/market-news/2022/INFATV202211-031.html

Acknowledgment

› Many thanks are going to all the supporting colleagues from Infineon and TSMC.

Thank you for your attention!

Questions?

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