ZeroAMP: High Temperature Electronics

Presenter: Piers Tremlett

Date: 29th Oct 2023

IEEE Sensors Workshop

Zero AMP ULTRA LOW-POWER COMPUTING WITH SURVIVAL SKILLS

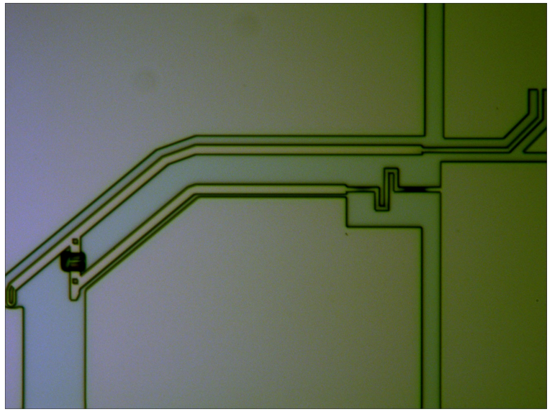
Talk plan

- Why use NEM Switches?
- Application examples …our demonstrators
  - including a temperature measurement application
- Packaging development – for high temperatures
- My afternoon talk "NEMS Future with Sensing"
  - on future potential applications with a focus on sensing

Introduction to ZeroAMP

NEM Switches- sense, compute and communicate in extreme environments!

- Horizon Europe project sponsored by the EU
- Purpose of ZeroAMP is to develop NEM Switch technology
  - From TRL1 to TRL3
  - From single switches into functional multiple switch architecture
  - To establish a manufacturing process for these functional circuits
- Partners can be seen in the lower banner



A ZeroAMP 4T NEM Switch

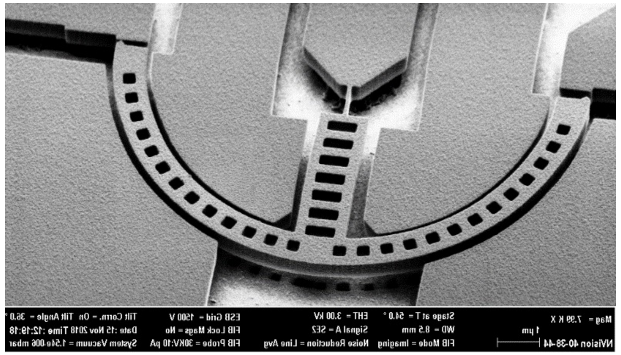
iEdge – the follow-on project from ZeroAMP

- NEMS switch development is supported by two Horizon Europe projects
  - ZeroAMP to TRL3, finishes soon - June 2024
  - iEdge to TRL6, finishes Jun 2026, 3½ year duration

- Total funding of €7M,€3.6M for iEdge and €3.5M for ZeroAMP

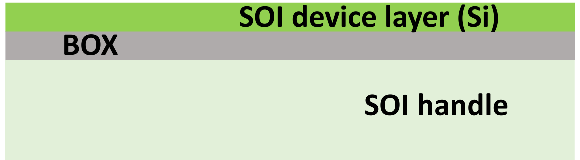
NEM switch manufacturing process

- ZeroAMP
  - establishes the process
- i-EDGE
  - establishes the supply chain

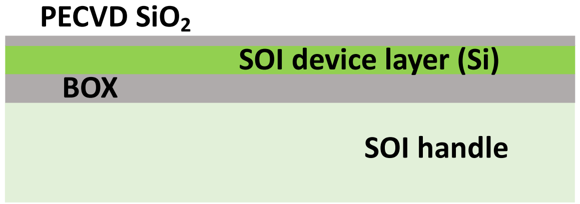


A ZeroAMP 7T NEM Switch

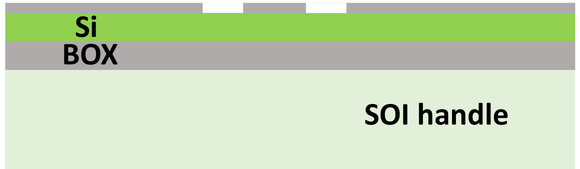
(1) SOI die



(2) PECVD SiO_2 hard mask



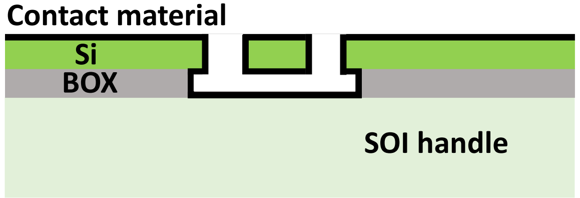
(3) Pattern and etch hard mask using RIE



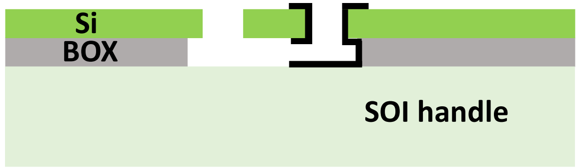
(4) Etch Si device layer using ICP

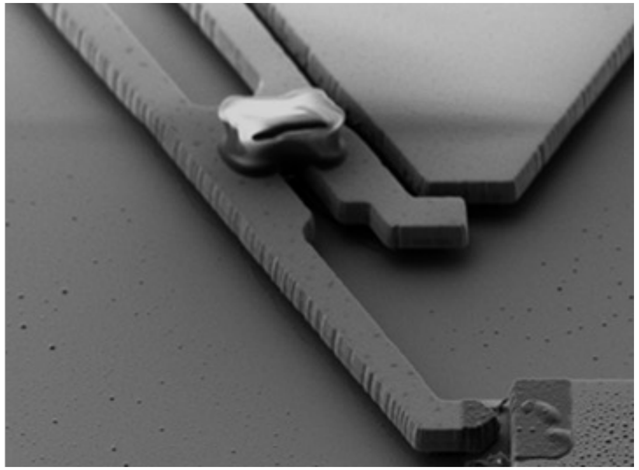
(5) Partially etch BOX using HF etch to release tip, but not fully suspend device

(6) Deposit contact material (PECVD, Sputtering, evaporation etc)



(7) Strip contact material everywhere except at tip, fully suspend device





A ZeroAMP 4T NEM Switch

iEdge objectives

- From TRL3 to TRL6
  - High speeds, yields and greater integration
- From Lab to Fab
  - A supply chain
- From concept to a technology ready for a business
  - Applications
  - Business Interest Group - potential customers

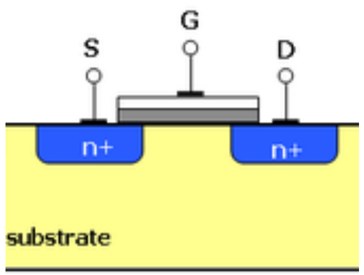
Why use NEM Switches?

The backdrop to our demonstrators and future applications

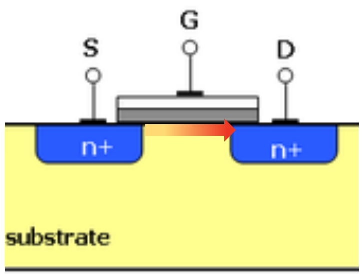
Zero AMP ULTRA LOW-POWER COMPUTING WITH SURVIVAL SKILLS

CMOS operating at temperature

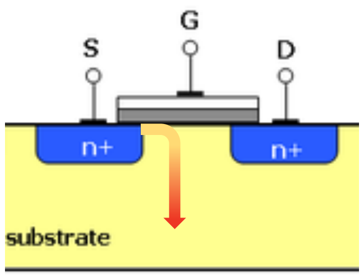
- CMOS FETs leak >150°C



Gate off – no current flow
(at room temperature



Gate on – current flows
(at room temperature)

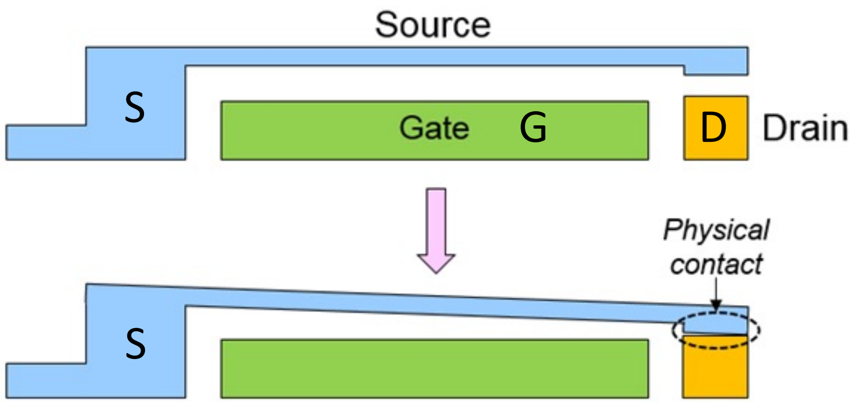


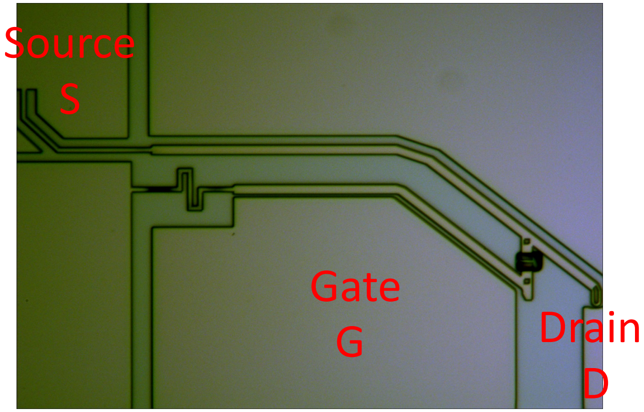
Leakage to die bulk
at >150C

- NEMS no leakage

G

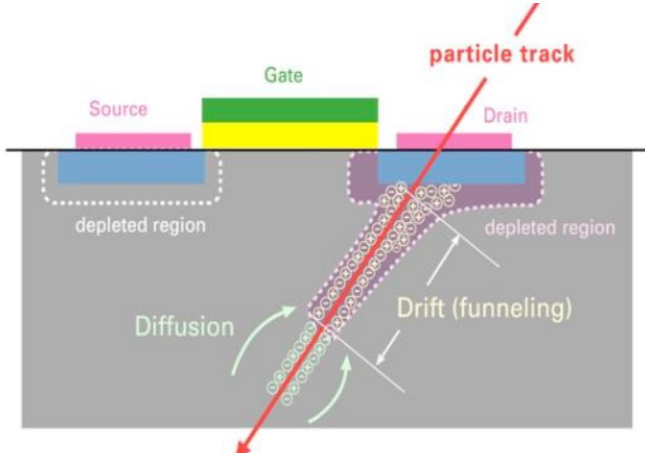
I





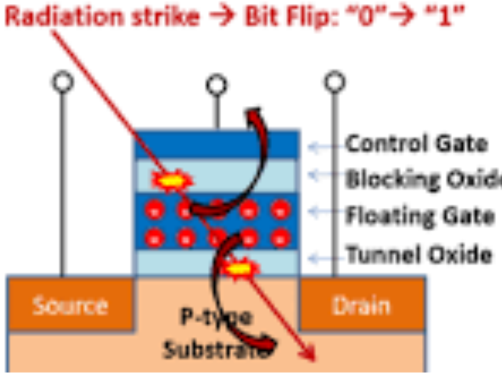
A ZeroAMP 4T NEM Switch

CMOS FETs in radiation

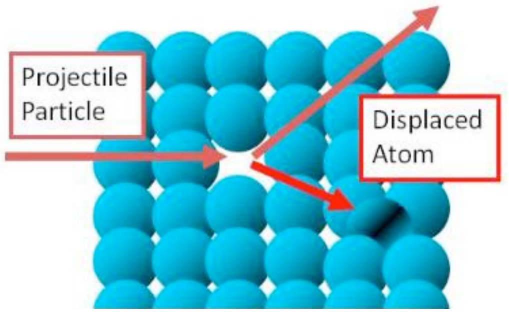


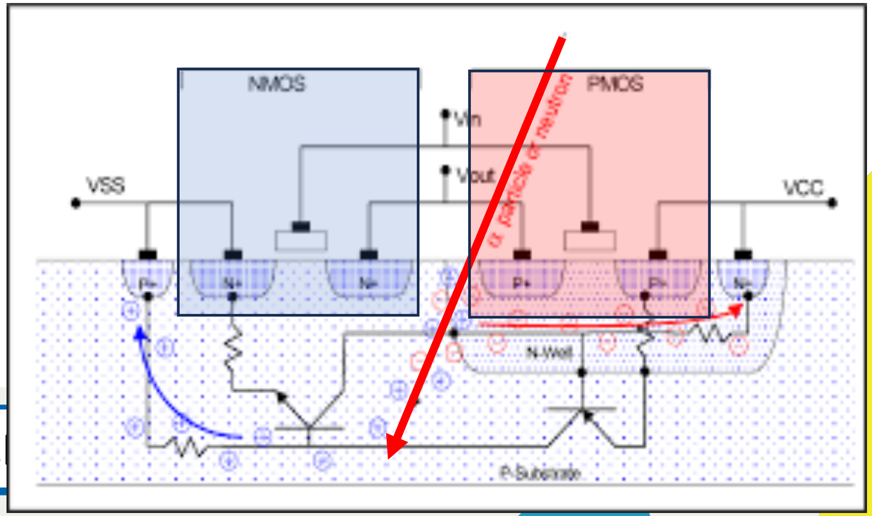
- CMOS is instantly affected by sudden upset event from energetic particles
  - Most times, a reset or reboot restores the system (lower energy particles)
  - Sometimes, a FET is permanently damaged (higher energy)

Memory cell value flip



- CMOS is gradually degraded by all radiation
  - This calibrated by a Total Ion Dose





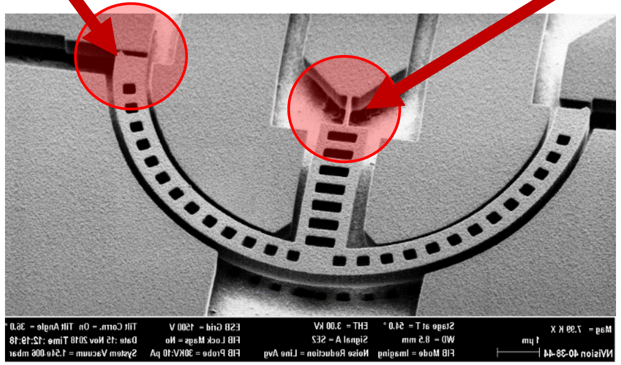
Zero AMP

CONFIDENTIAL INFORMATION

MICROCHIP xfab AMO University of BRISTOL

Power usage – 7T switch sleep current = 0A

- Atomic level forces are higher at the relay tip than the spring force at the hinge

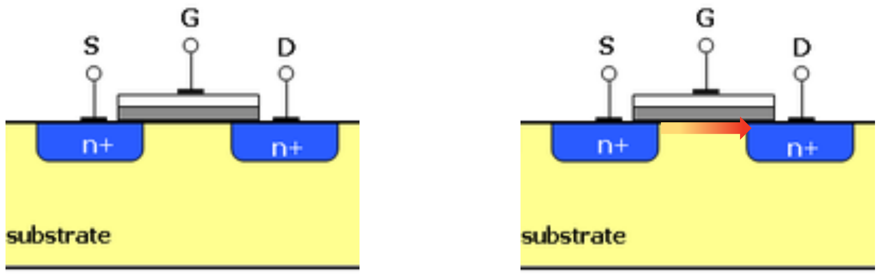


A ZeroAMP 7T NEM Switch

- <u>Zero standby current even at high temperature</u>

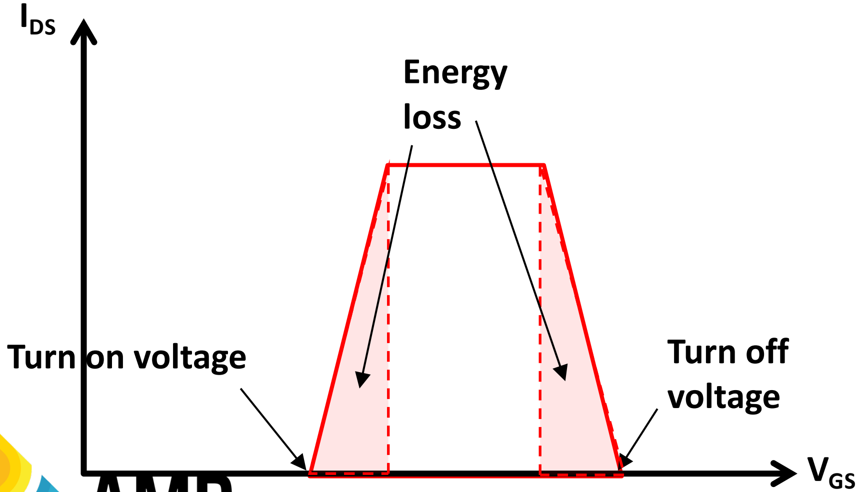
Lower power due to abrupt switching

- CMOS consumes energy whilst switching

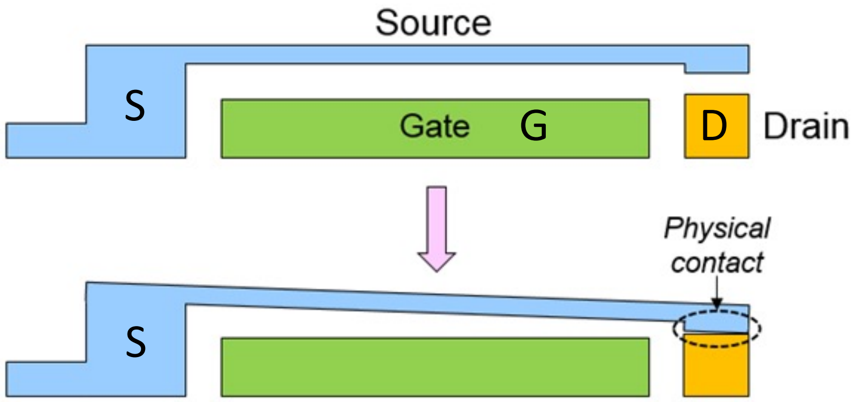


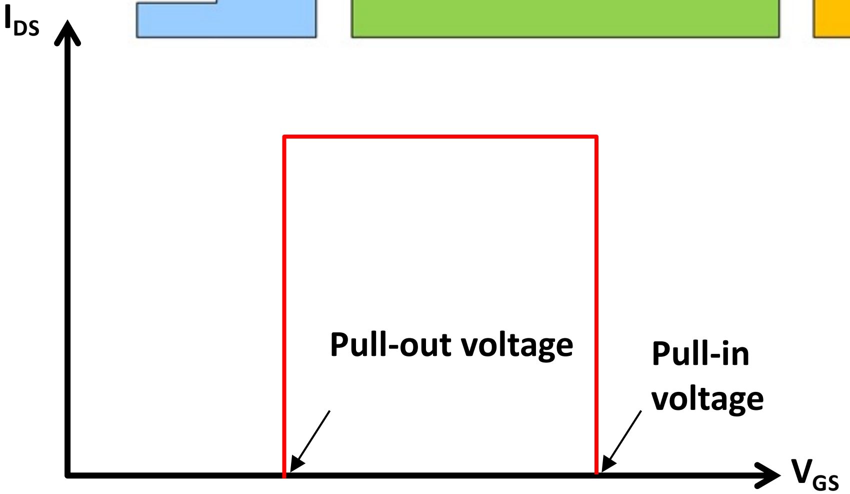
Gate off – no current flow (at room temperature

Gate on – current flows (at room temperature)



NEMS 50% less current, even at high temp's



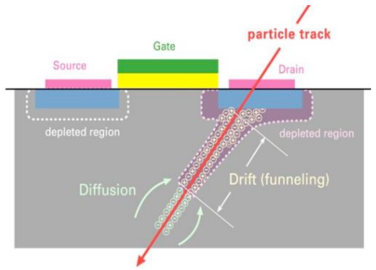


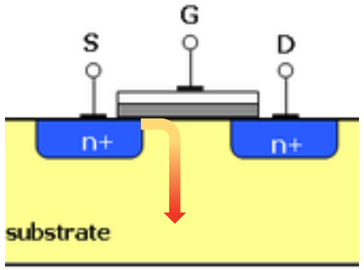
Why use NEM switch technology?

- High temperature tolerance
  - Functions at up to 325C
- Very radiation tolerant
  - >1 Mrad (10Gy)

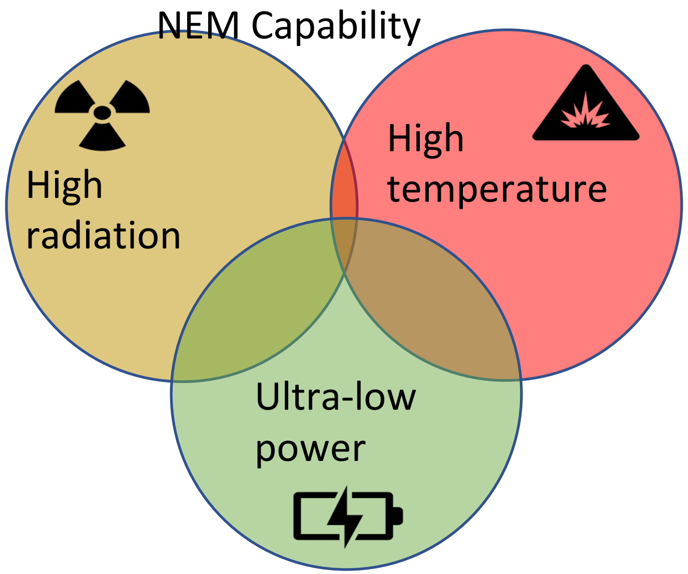
- <u>**Even in high temperature and high radiation**</u>
  - Zero standby current
  - Ultra low power…50% of CMOS

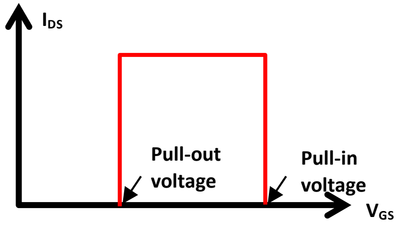
- *“Enabling sensing and data in impossible environments”*





CMOS bulk leakage

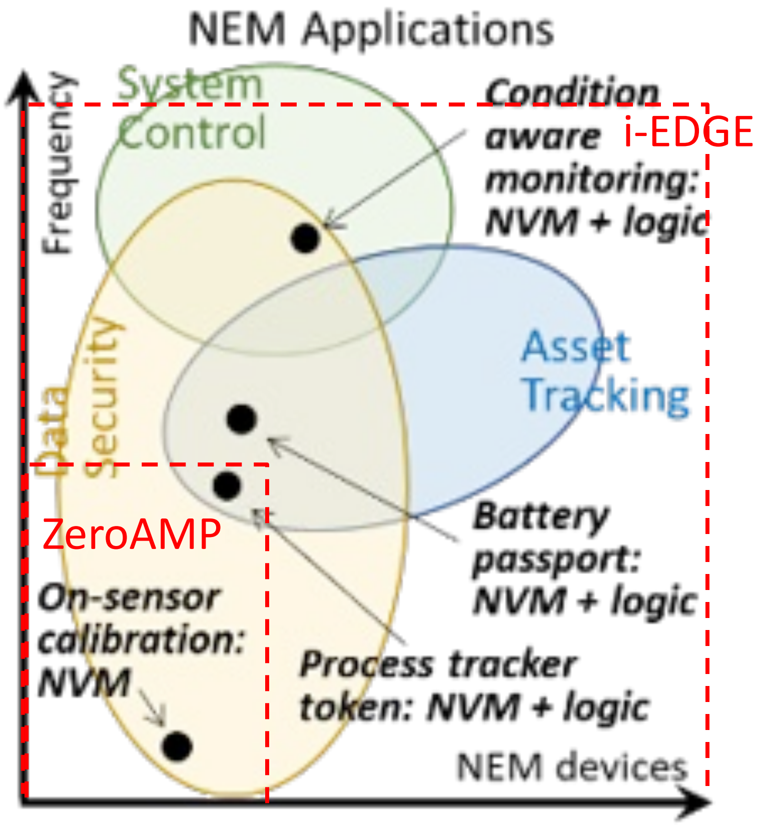




Things to consider with NEMS

- At TRL2/3, we are at Kilby and Noyce stage of IC development
  - Very low oscillator frequencies, life of 10^8 cycles
  - Low level of integration
  - We aim for own our “Moore’s law effect”

- Increased applications capability
  - from ZeroAMP to i-EDGE
  - *….from now to eternity….!?*



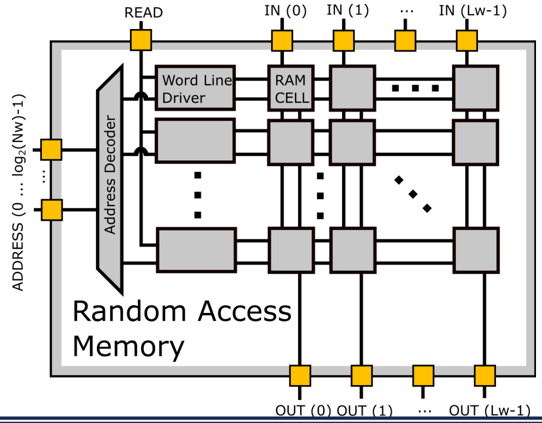
Further advantages of NEMS – to be shown in our three demonstrators

- Architecture simplification
  - Memory read and write power lines
  - FPGA switch box

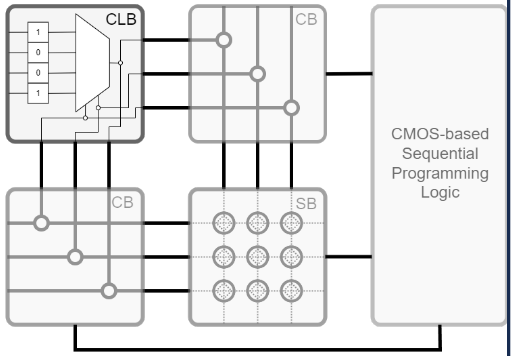
- Non von Neumann architecture
  - NEMS Memory and Logic on the same chip
  - Towards simple AI?

- No batteries between 150 - 300°C
  - They are unsafe – danger of fire and explosion
  - We can use unusal weaker power source

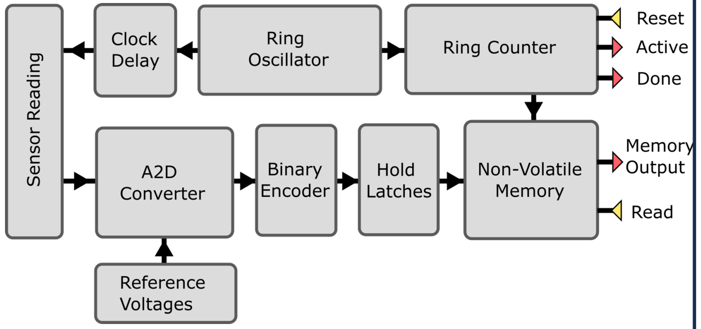
Non- Volatile Memory (NVM)



Field Programmable Gate Array (FPGA)

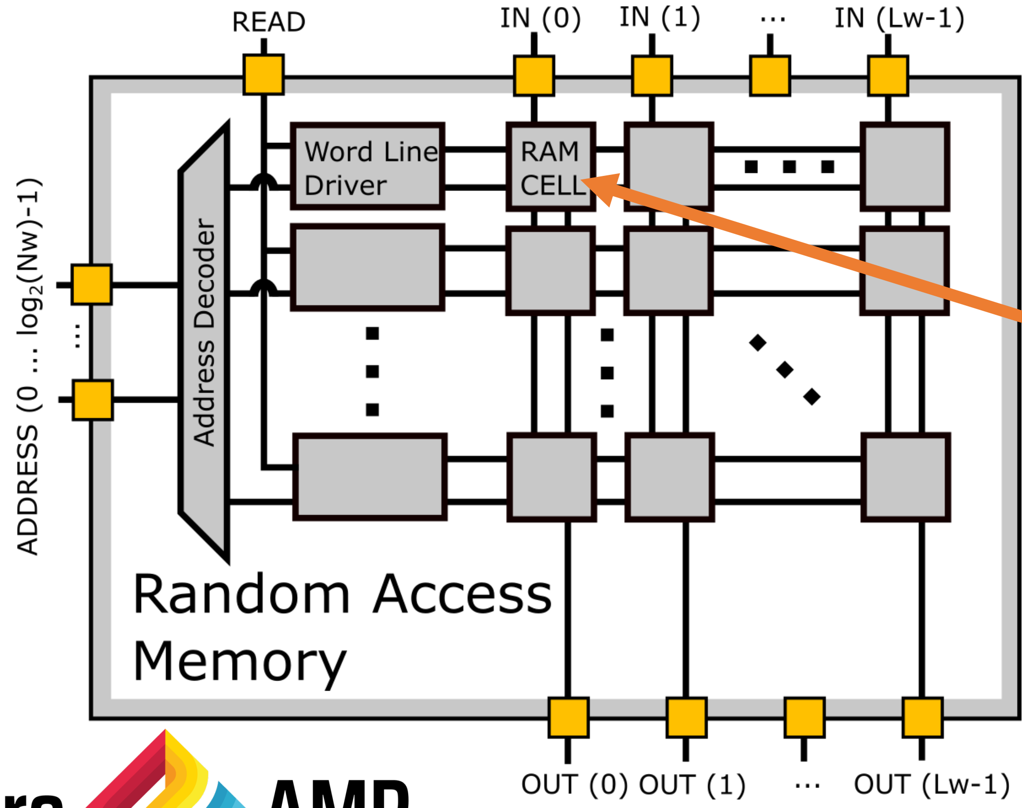


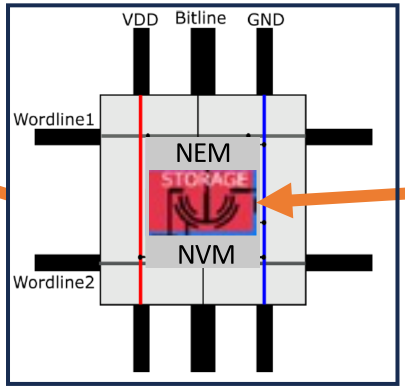
Temperature measurement device

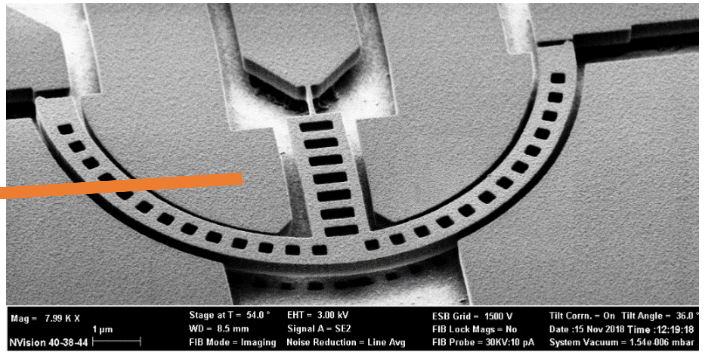


NVM

- Zero standby current – sticky 7T switches from van der Waal's forces
- Read and write at the same voltage – simpler architecture



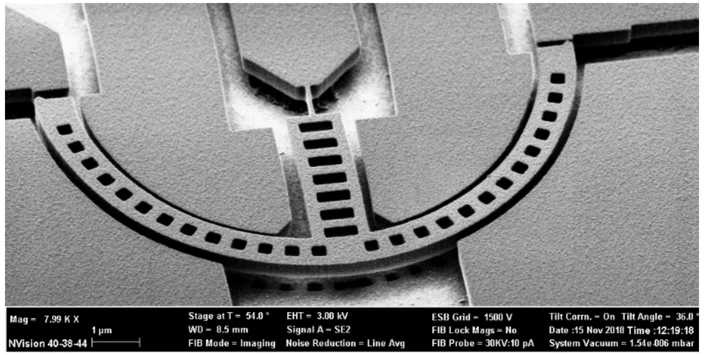




A ZeroAMP 7T NEM Switch

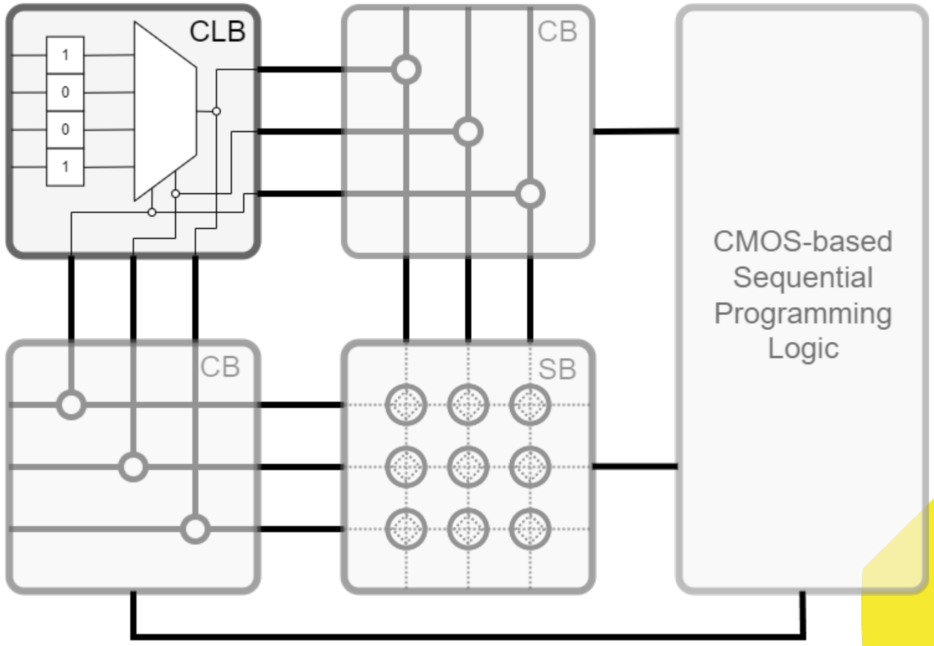
FPGA demonstrator

- Demonstrator is a single FPGA cell
  - CMOS block is for programming only (at room temperature)
  - NEMS segment can operate independently at >250°C



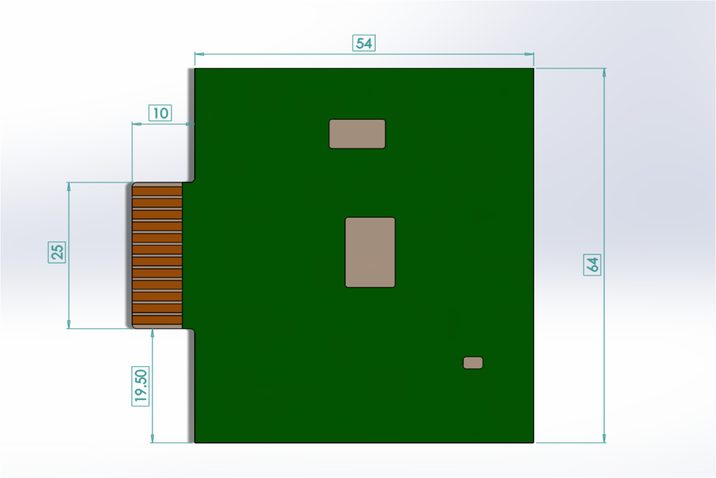
A ZeroAMP 7T NEM Switch

- For the switch box (SB), 7T switch:
  - Adds routing flexibility
  - Simplifies architecture



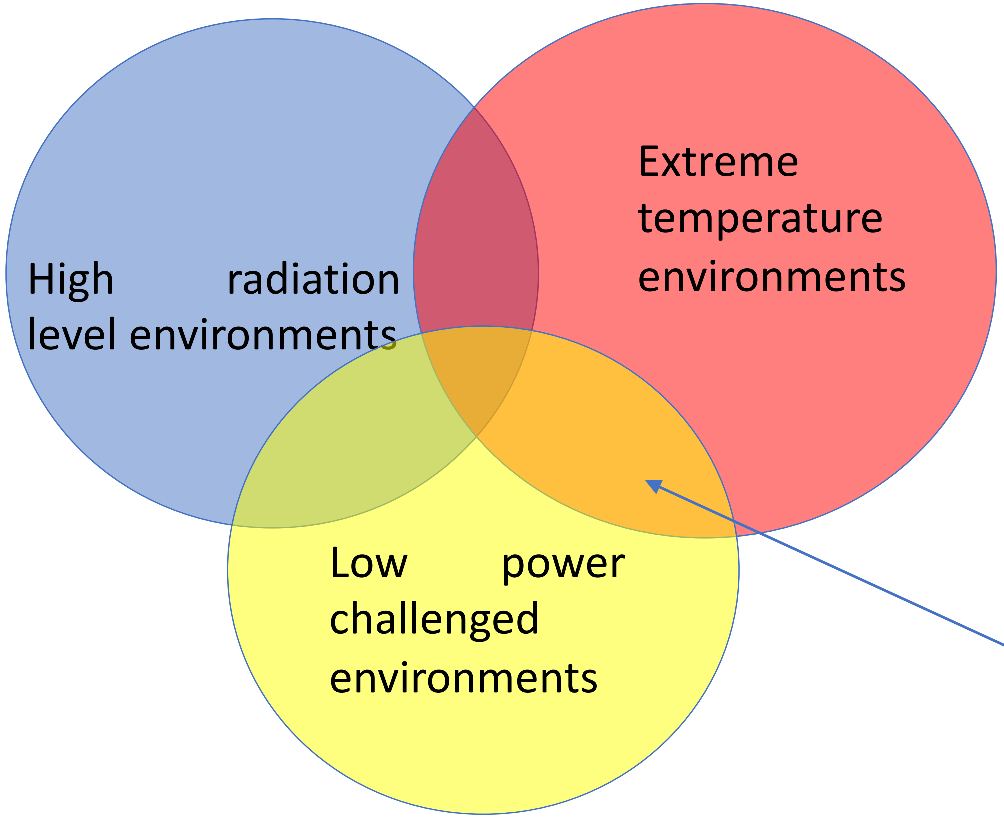
- Non von Neumann architecture
  - NEMS Memory and Logic on the chip
  - Towards simple AI?

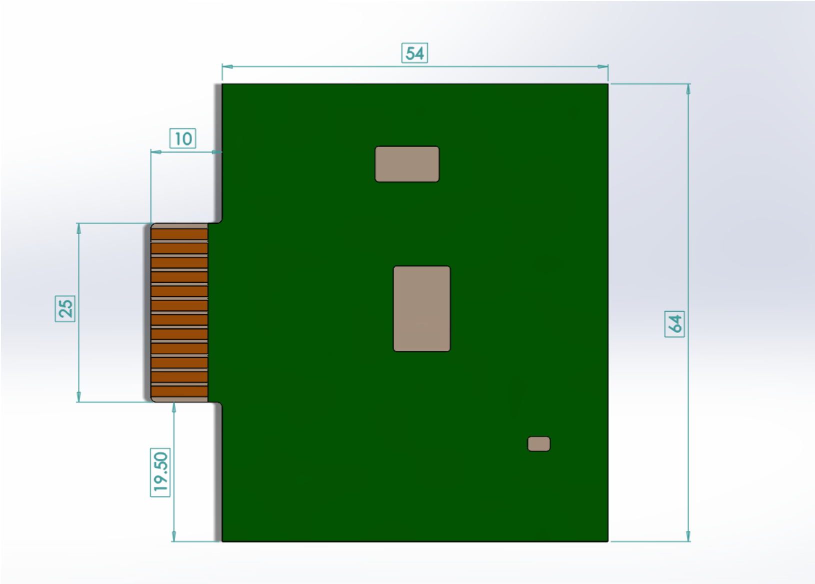
Example demonstrator - industrial temperature recording "Token"



Temperature recording “Token”

Product or applications environment

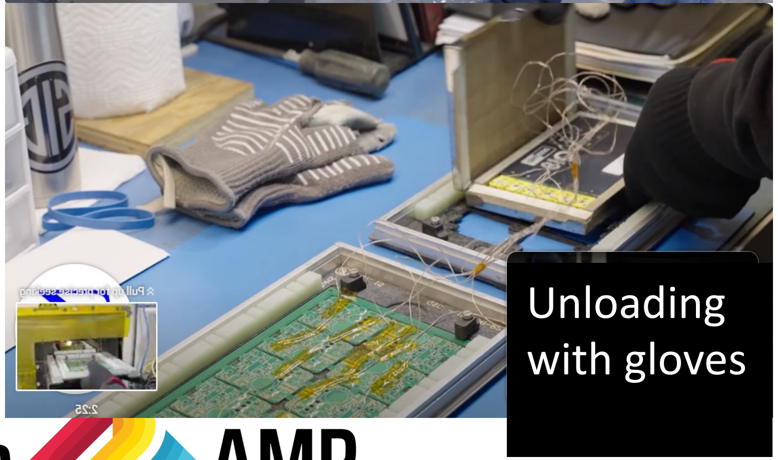


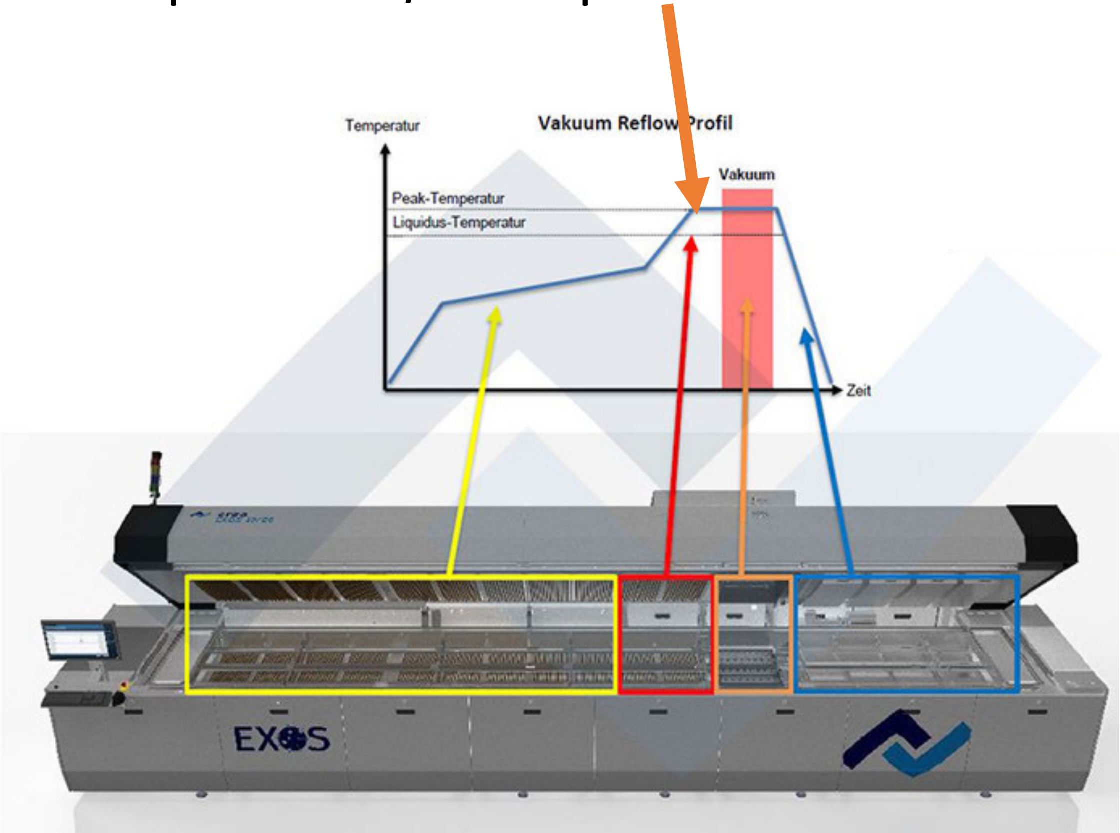


Token uses the overlap of these two characteristics of NEMS devices

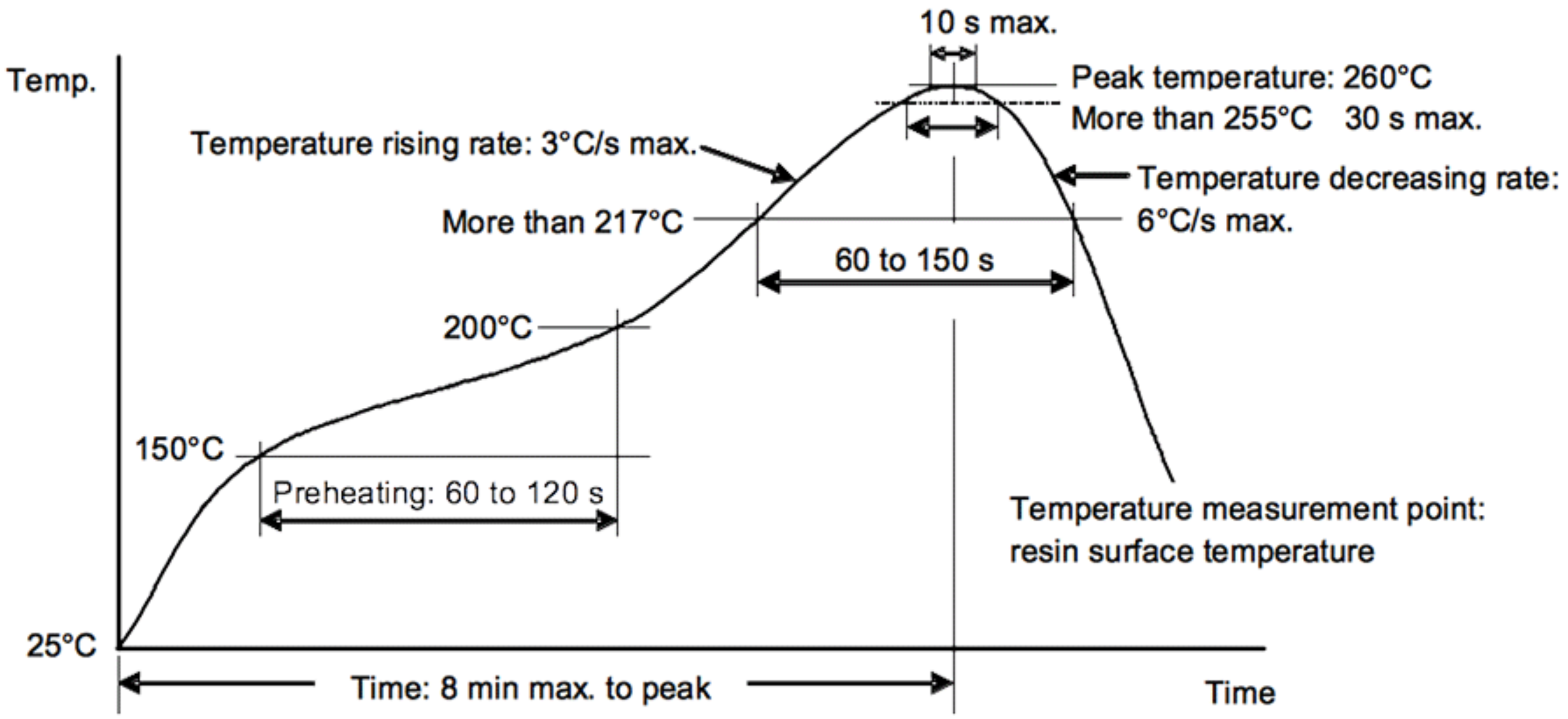
Current temperature profile measurement of belt ovens

- A shielded measurement device and sample is transported through the oven on its belt.
- The device is read on exit to produce a temperature / time profile.



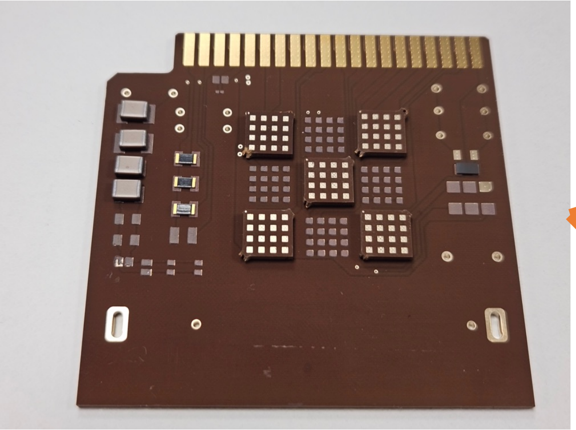


Reflow profile shape and peak temperature are important

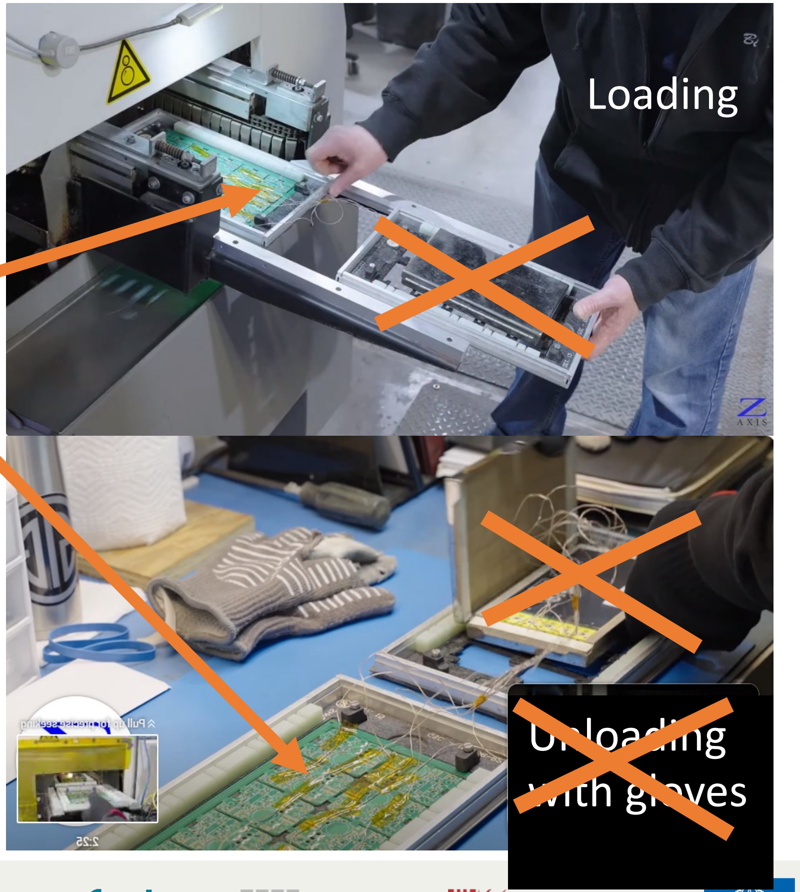


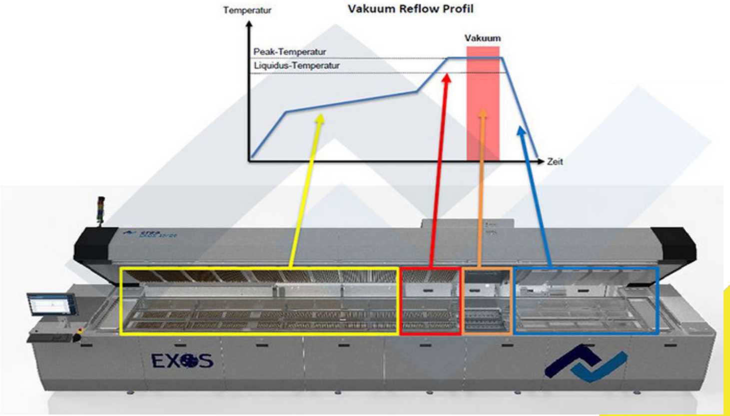
Temperature profile measurement of belt ovens with NEMS

- Now no need for a high mass thermal shield
- NEMS measurement devices can be mounted on a PCB and emerge cold
  - no gloves, leads etc… allowing frequent measurement and better process control



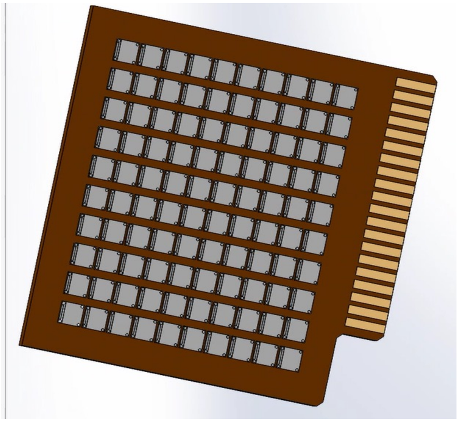
Use a high temp NEMS replica board or mount a smaller NEMS board



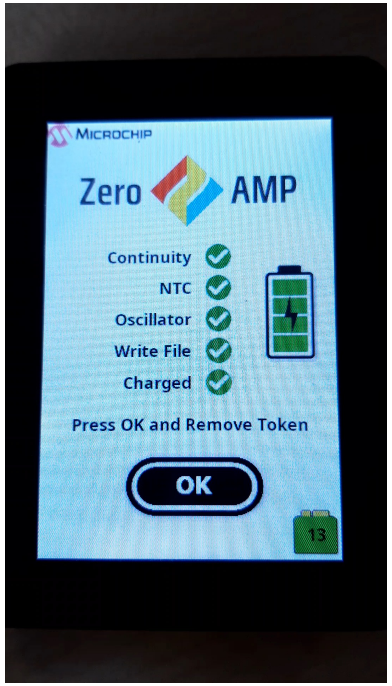


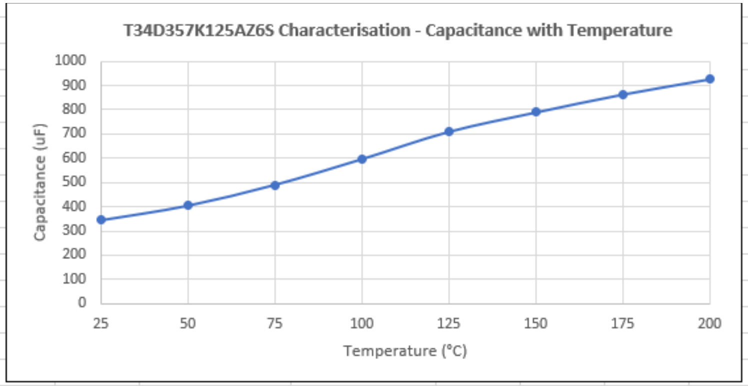
Token power… and its mother station

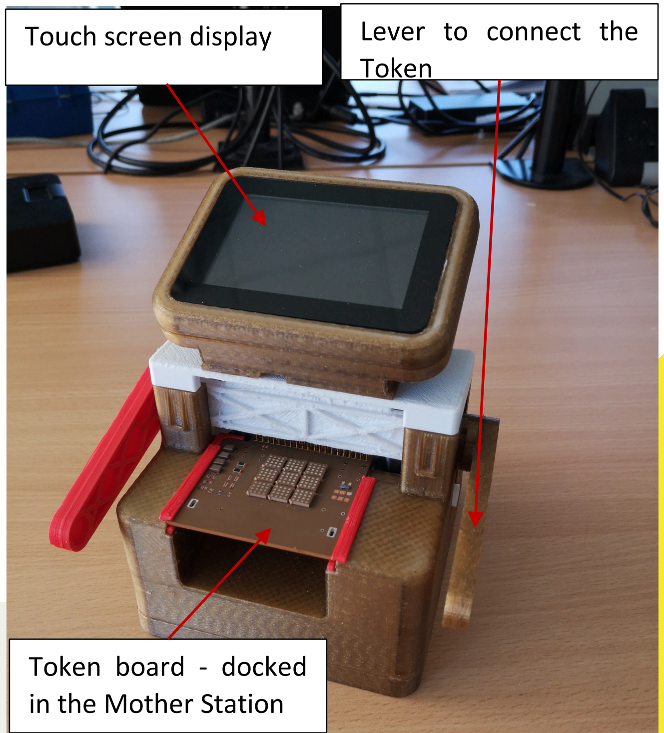
- Batteries are dangerous >150°C
- Token is powered by a capacitor bank (on underside)
- NEMS is low power – even at 250°C!
  - No transistor leakage
- Mother station reads NEMS memory after oven profile trip and recharges capacitors



Back side of Token showing Capacitor Power Bank







Zero AMP

CONFIDENTIAL INFORMATION

MICROCHIP xfab AMO University of BRISTOL KTH csem

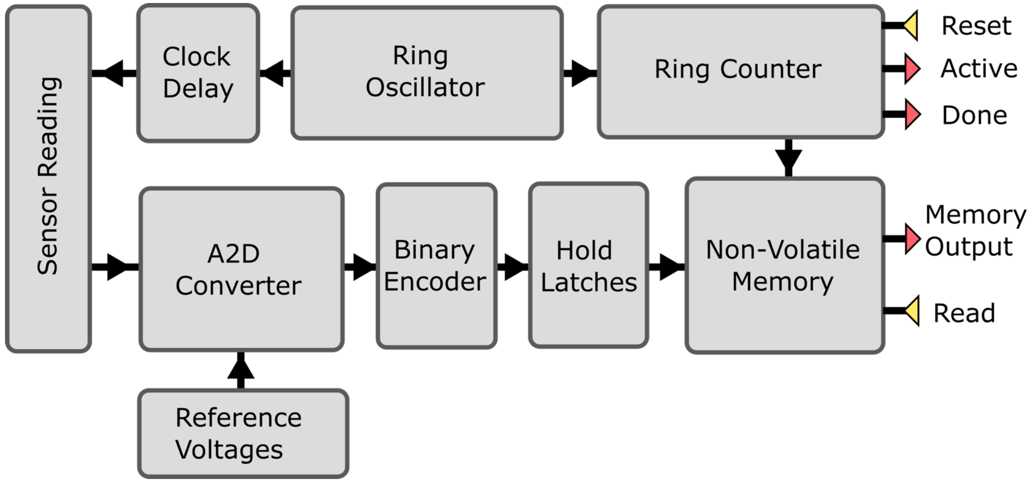
3) Rugged manufacturing flow asset tracking

- Many manufacturing flows contain a critical high temp step
  - eg a solder reflow, hot chemical baths, glue cures, drying

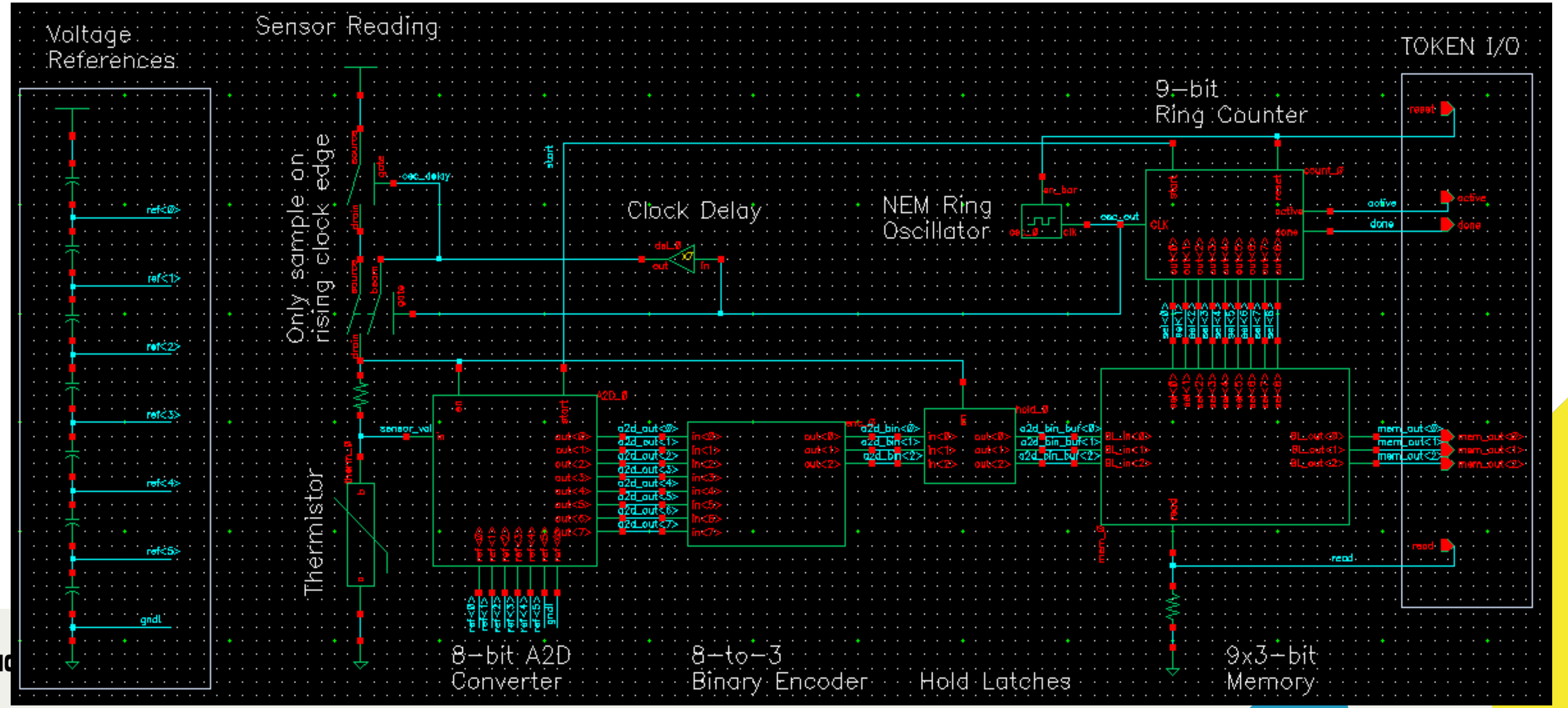
- Rugged RFID tag specifications
  - Operational -40°C to +85°C, *Survival -40°C to +250°C*
  - RFID

- NEM Switch tag specification
  - Operational -40 °C to 250 °C plastic case, 325 °C ceramic case
  - RFID + optional chargeable power supply
  - On board sensors – shock, humidity, temperature
  - Tracking with process monitoring

Token functional block diagram



- One sensor voltage reading per 1 – 3 secs
- Thermistor sample time ~15µsecs

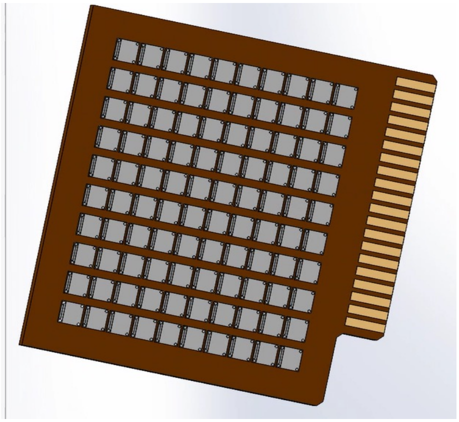


Zero AMP

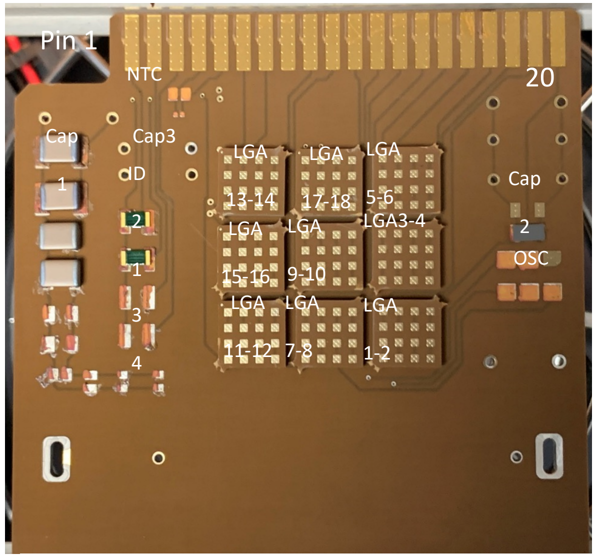
CONFIDENTIAL INFORMATION

Token packaging concept

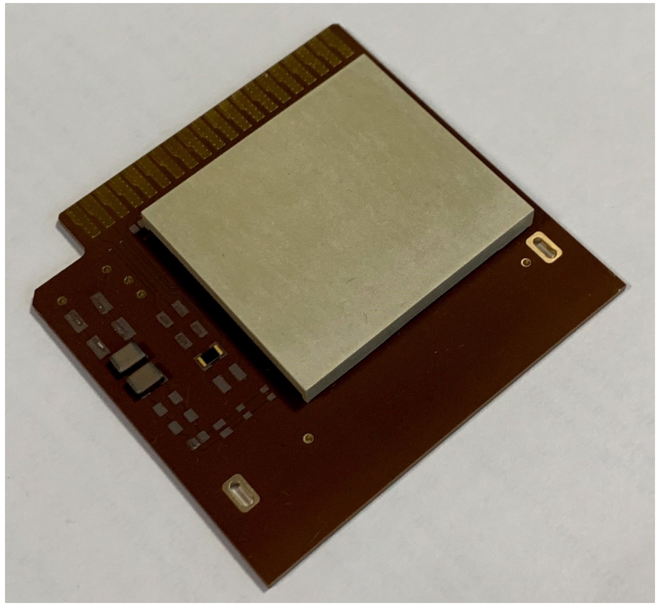
- PCB mounted with:
  - Ceramic SMT capacitors and resistors
  - Wire bonded NEMS die



Back side of Token showing Capacitor Power Bank

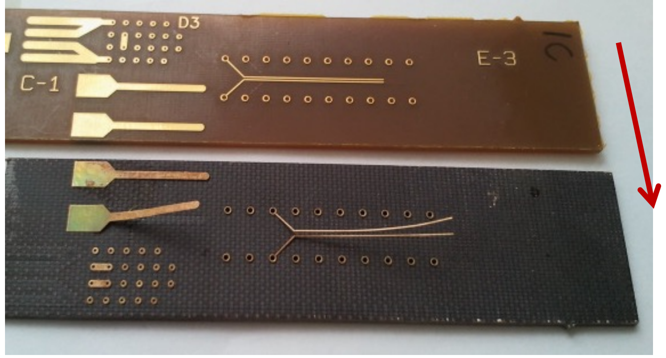


Top side view of the Test Token

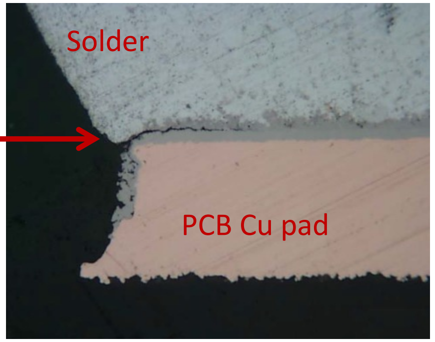


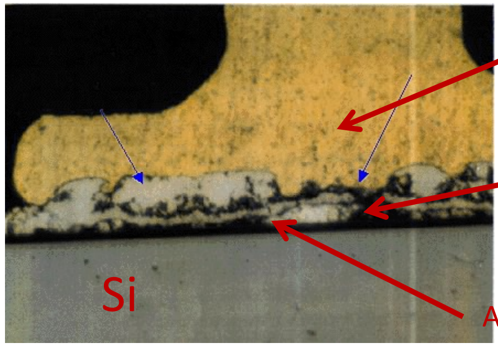
High temperature failure mechanisms

- High temperatures above 175°C are an electronic packaging challenge!
- Degradation due to air

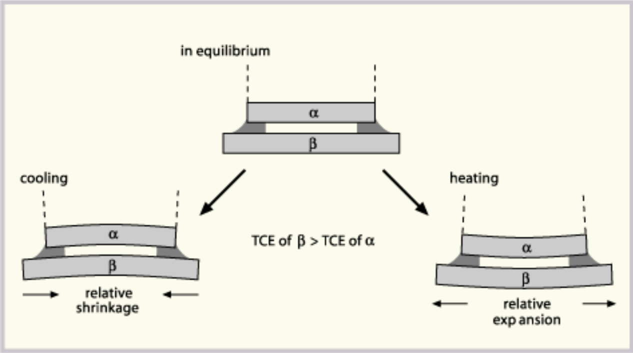


- Diffusion





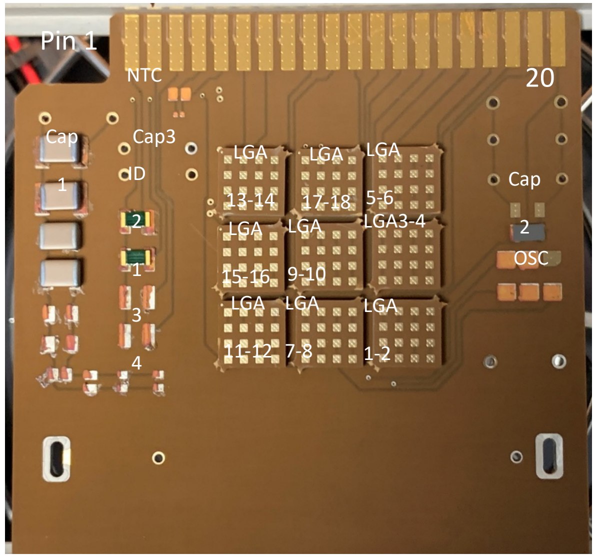
- Thermal expansion



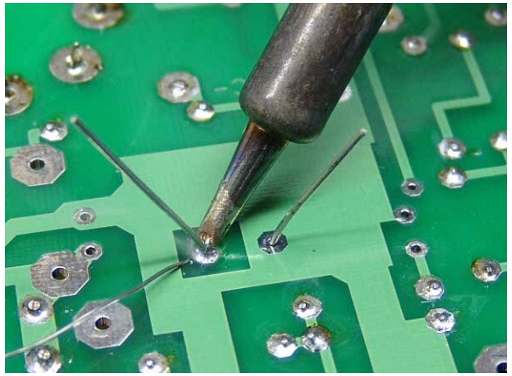
PCB packaging for profile peak temperature of 250°C?

- Microchip source a selected a high temperature PCB material
  - Tested for 1500 thermal cycles -20 to 250°C
  - Survived 1500hours at 250°C

- PCB to component joints
  - normal lead free Tin solder melts at ~220°C
  - High Lead solder melts at 280°C
    - But 320°C reflow peak temperature damages our PCB
  - Evaluating a Cu/Sn Transient Phase Liquid Sinter
    - Reflow at 260°C
    - Resulting melting point is >400°C

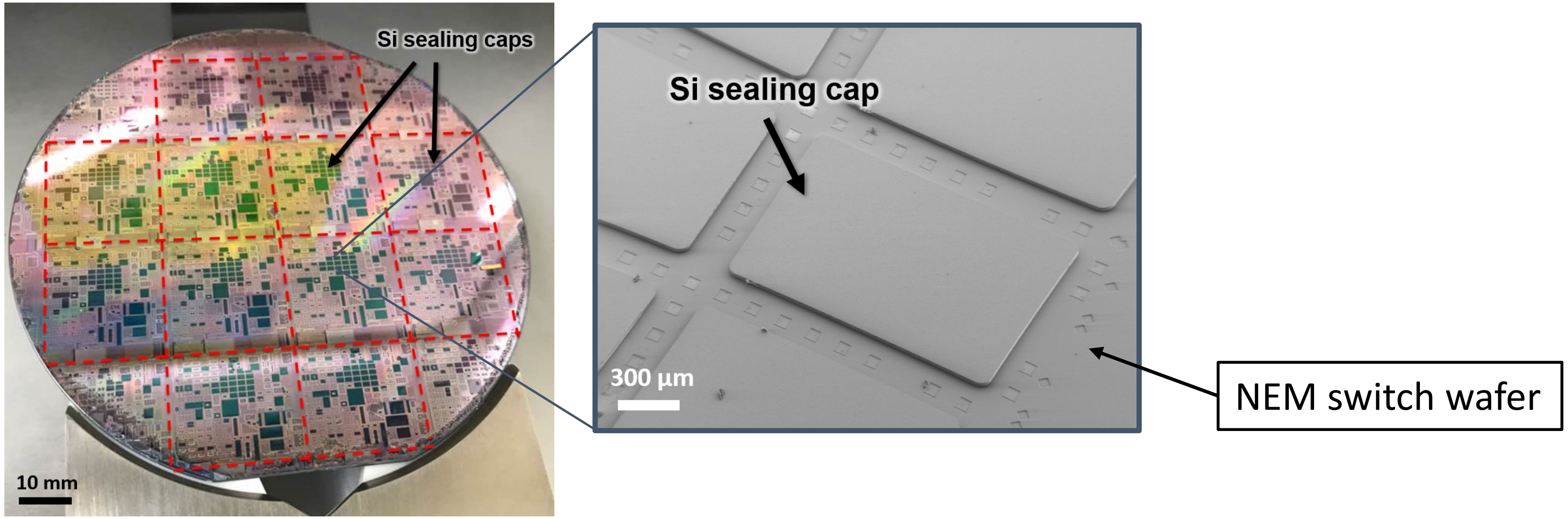


High temperature PCB

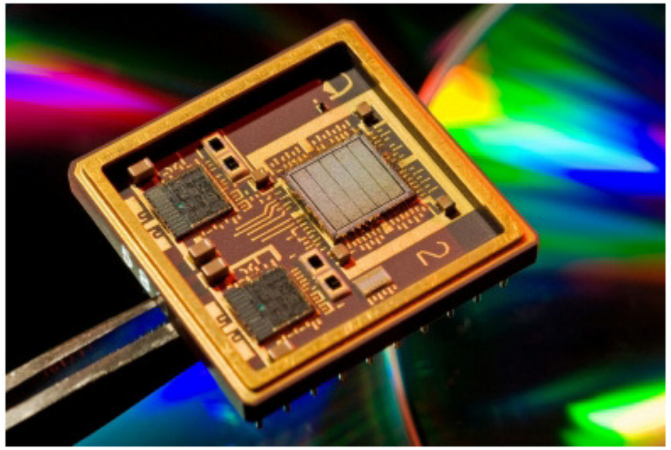


Wafer scale packaging to hermetic seal NEM switches

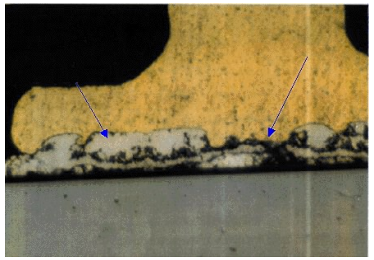
- Lids created on one wafer and bonded on opposite NEM Switch wafer
- Allows control of NEM Switches operating atmosphere

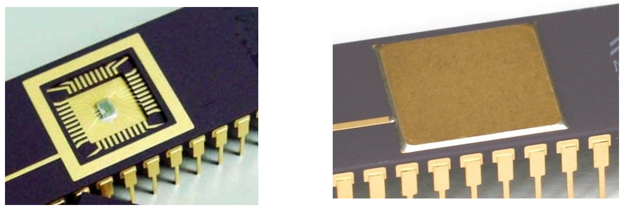


Packaging for up to 325°C



- Development work on a ceramic hermetic package
  - Die bond
    - Alternatives to epoxy: eg AuSi, silver glass
  - Wire bond
    - Avoiding bond interface diffusion problem
      - Au or Al
  - Lid sealing
    - Au Ge solder, seam sealing
  - Aiming for an NFC or RF charge/ comms package

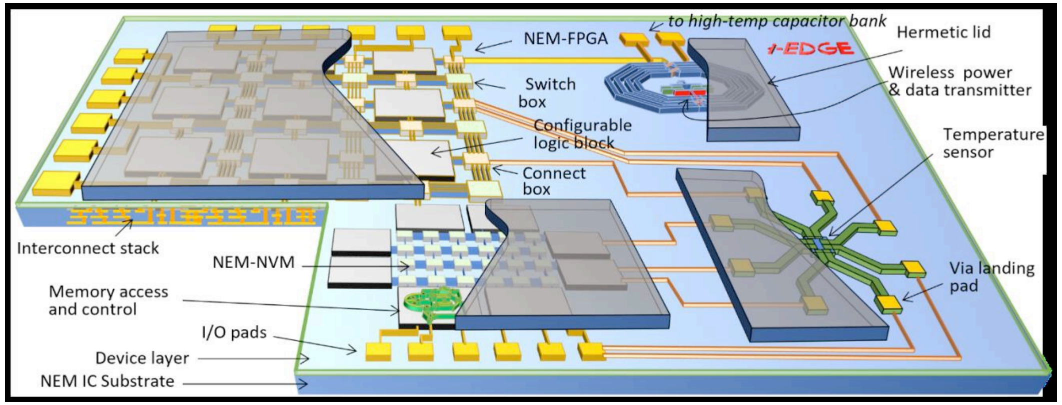




package with die, then lidded

iEdge IoT sensor platform concept

- Power and communication
  - RF: RFID or Near Field
- Memory
- Compute power
- Sensors
  - Internal temperature sensor
  - External sensor port



- Packaging temperature withstand
  - 250 °C polymer package
  - 325 °C hermetic ceramic package
- Radiation – 10Gy

09:00 – 09:15 Welcome & Introduction => JB

09:15 – 10:00 NEM Switch and Sensor Integration Platform for IoT Applications => DP

10:00 – 10:30 Coffee Break

10:30 – 11:15 ZeroAMP: High Temperature Electronics => PT

11:15 – 12:00 Live Demo of Software Tools for NEM Circuit Design and Sensor Integration => Elliott

12:00 – 13:30 Lunch break

13:30 – 13:45 ZeroAMP's integration approach => JB

13:45 – 14:30 Interactive Session on NEMS Future with Integrated sensing => PT

14:30 – 15:00 Coffee Break

1530 – 1630 Interactive Session Continued

END

CONFIDENTIAL INFORMATION

www.Zero-AMP.eu

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 871740 (ZeroAMP).