

Interactive Session on NEMS' Future with Sensors

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Presentation plan

- Assessment of sensors operating in:
 - High temperature environments
 - High radiation environments
- Potential for integrating sensors on a NEMs die
- NEMS as a sensor interface
 - Prototype ADC - specifications analysis
 - Data transfer - wireless power and communication
- This is an interactive session – we are not sensor experts and seek input.

Sensor applications that match our present capability?

- **Review by the following characteristics:**
- Power - Battery-less NEMS power
 - Sensors with a low current drain
- Size - small sensors?
 - Can they be integrated into our packages
 - Or onto our die
- Current NEMS ADC and electronics support:
 - Infrequent measurement
 - Discrete missions
 - Sit and wait

Sensors operating in a high temperature environment

Adding value to sensors at >200°C with NEMS?

- No added value to a sensor in a >200°C environment where:
 - a **cold junction** is required - thermocouple
 - **measurement by wire** to instrumentation in a cool zone is ok
 - (Most sensors....)
- Added value where:
 - **Wireless** operation required – mobile measurement devices
 - **Wires** cause measurement errors – on-sensor interface needed
 - **Bandwidth limitations** – multiplexing sensor arrays, limit alarms for Edge devices
- I'm not a sensor expert so...I asked ChatGPT!
 - **What do you agree with its suggestions?**



What sensors operate at over 200C? (according to ChatGPT)

- 1.High-Temperature Thermocouples:** Thermocouples are commonly used for temperature measurement in high-temperature environments. Some types, like type K or type N thermocouples, can operate at temperatures exceeding 200°C and even up to 1,300°C.
- 2.High-Temperature Resistance Temperature Detectors (RTDs):** RTDs, also known as platinum resistance thermometers (PRTs), can be used at high temperatures. Typically, RTDs with platinum elements are used for temperature measurement in environments exceeding 200°C.
- 3.Pressure Sensors:** Certain types of pressure sensors, such as piezoelectric or capacitive pressure sensors, can be designed to operate at high temperatures. These sensors are used in applications like oil and gas drilling, aerospace, and combustion engines.
- 4.Strain Gauges:** High-temperature strain gauges, which measure mechanical strain, can be used in applications where temperature exceeds 200°C. They are often employed in structural health monitoring and materials testing at elevated temperatures.
- 5.High-Temperature Accelerometers:** Accelerometers designed for high-temperature applications can measure acceleration in extreme environments, including those above 200°C. These sensors are used in industries like aerospace and automotive.
- 6.High-Temperature Gas Sensors:** Some gas sensors are designed to operate in high-temperature environments for applications such as emissions monitoring, combustion control, and industrial processes.
- 7.High-Temperature Humidity Sensors:** Certain high-temperature humidity sensors are used in applications where both temperature and humidity need to be monitored at elevated levels, such as industrial drying processes and exhaust gas analysis.
- 8.High-Temperature Optical Sensors:** Some optical sensors can operate at elevated temperatures, particularly in applications like combustion diagnostics and materials processing.
- 9.High-Temperature pH Sensors:** pH sensors used in applications with high-temperature liquids or solutions, such as in chemical processes, may be designed to withstand temperatures exceeding 200°C.
- 10.High-Temperature Magnetic Sensors:** Some magnetic sensors, including Hall effect sensors, can operate in high-temperature environments and are used in applications like automotive systems and industrial equipment.

Any other ideas?

- ChatGPT is deterministic- it only lists sensors that have been tried
 - what sensor might not have been tried in hostile temperatures?

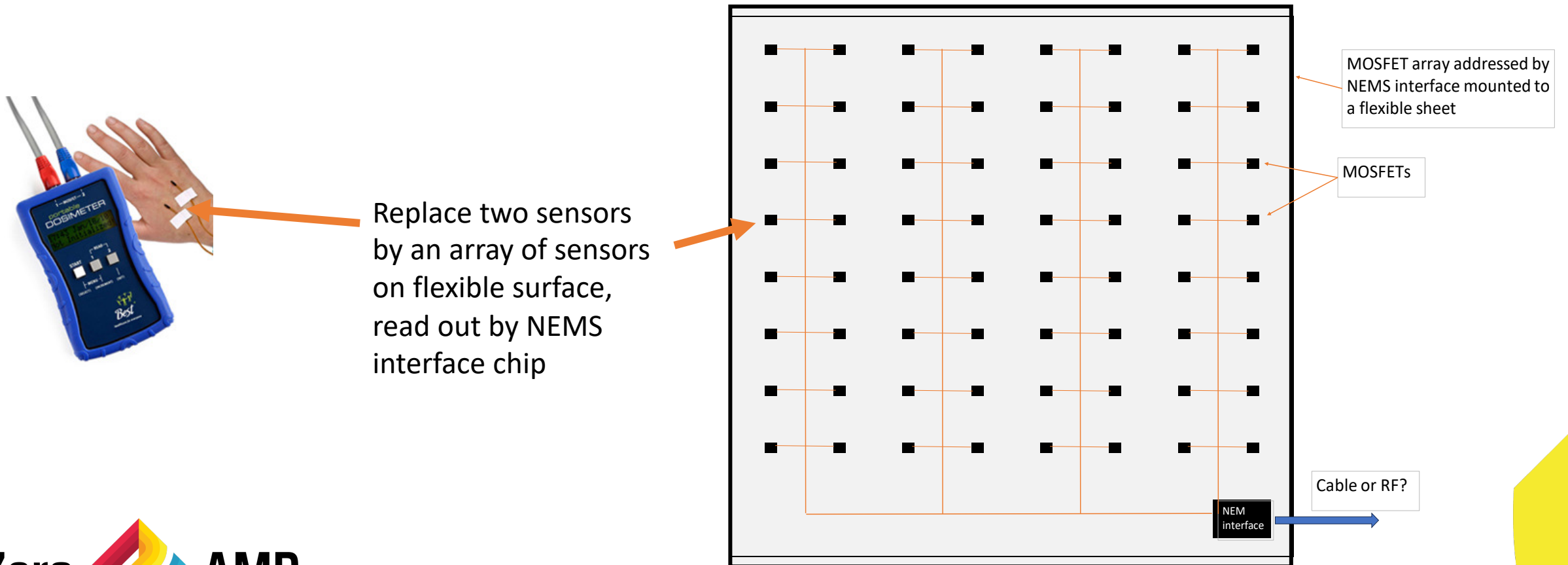
Sensors operating in a high radiation environment

Adding measurement value to sensors at >1 Gray with NEMS?

- No added value to a sensor in a >1 Gray environment where:
 - Ordinary or radiation hard electronics is sufficient
 - It is conveniently measured by via wire to instrumentation a radiation free zone
- Added value where
 - **Long wires** cause measurement errors – interface on sensor
 - **Failure to measure** is inconvenient or dangerous
 - **High radiation** levels cause
 - Uneconomic chip life
 - Inconvenience – frequent maintenance, unreliability
 - Extreme radiation level – CMOS data processing is impossible

Real time radiation level mapping

- Bringing together multiple sensors for radiotherapy, industrial or nuclear industry
 - **Allows a more complete map of radiation**



What sensors operate at over 1 Gray?

- 1. Radiation Dosimeters:** These sensors are designed to measure and monitor radiation exposure for personnel working in nuclear facilities, medical radiology, and other environments where ionizing radiation is present.
- 2. Nuclear Reactor Sensors:** Sensors used in and around nuclear reactors for monitoring reactor conditions, such as temperature, pressure, and radiation levels, must withstand high radiation doses.
- 3. Radiation Hardened Electronics:** In addition to specific sensors, many electronic components, such as integrated circuits, sensors, and communication devices, are designed to be "radiation-hardened" and can operate in radiation-intensive environments.
- 4. Particle Detectors:** Sensors used in high-energy physics experiments and research facilities, such as particle accelerators and colliders, must be capable of operating at extremely high radiation levels.
- 5. Radiation Therapy Sensors:** Sensors used in medical radiation therapy, both for cancer treatment and research, need to withstand significant radiation doses.
- 6. Space and Aerospace Sensors:** Sensors on spacecraft and satellites that travel through or orbit regions of space with high radiation levels must be radiation-hardened to ensure their functionality.
- 7. Nuclear Waste Monitoring Sensors:** Sensors used for monitoring and managing nuclear waste may need to operate in high-radiation environments.
- 8. Industrial Radiography Sensors:** In industrial radiography applications, sensors are used to inspect materials and structures for defects, and they can be exposed to significant radiation doses during this process.
- 9. Neutron and Gamma-Ray Sensors:** Sensors designed for detecting and measuring neutron and gamma-ray radiation in research, industrial, and medical applications must be capable of withstanding high radiation doses.

Any other ideas?

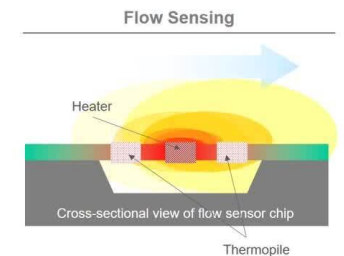
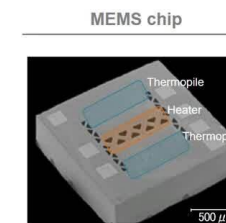
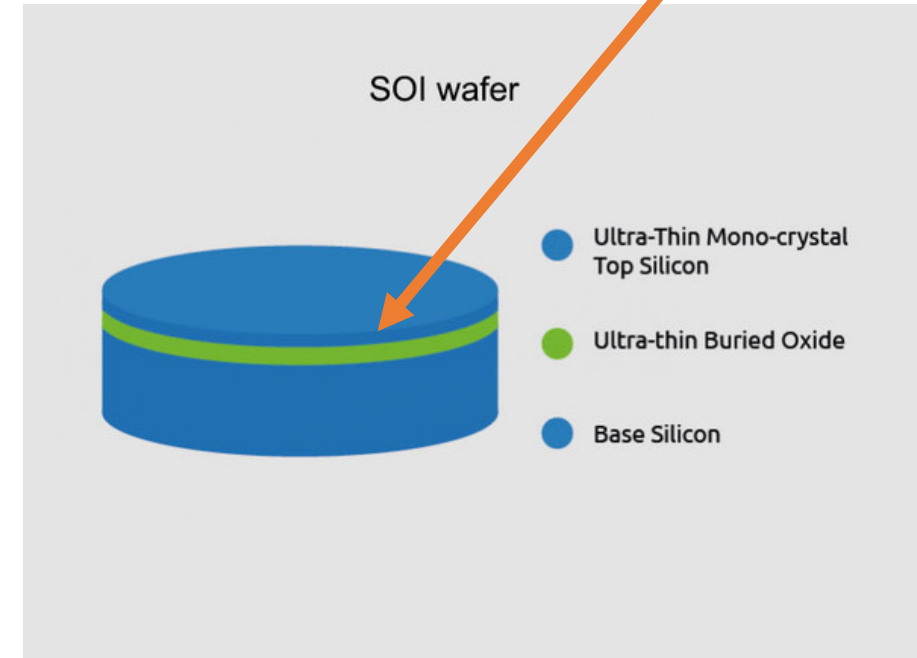
- ChatGPT is deterministic- it only lists sensors that have been tried
 - what sensor might not have been tried in high radiation?

Potential for integrating sensors on a NEMs die

Integrated MEMS sensors on NEMS die

- NEMS uses a Silicon on Insulator wafer
 - Usually too thin for suspended mass sensors
 - ie Accelerometers, vibration, IMUs
- Many pressure sensors are piezo
 - Non Sol substrate
- Some MEMS sensors have diffused structures
 - Eg Thermopiles on air flow sensors
- Thin diaphragm sensors are more feasible
 - Microphones, capacitive pressure sensors but manufacturing flows would need to be similar
- RTD temperature sensor being evaluated in ZeroAMP

150nm- 2um thick top silicon device layer



“What sensors use SoI?” (...and might be integrated?)

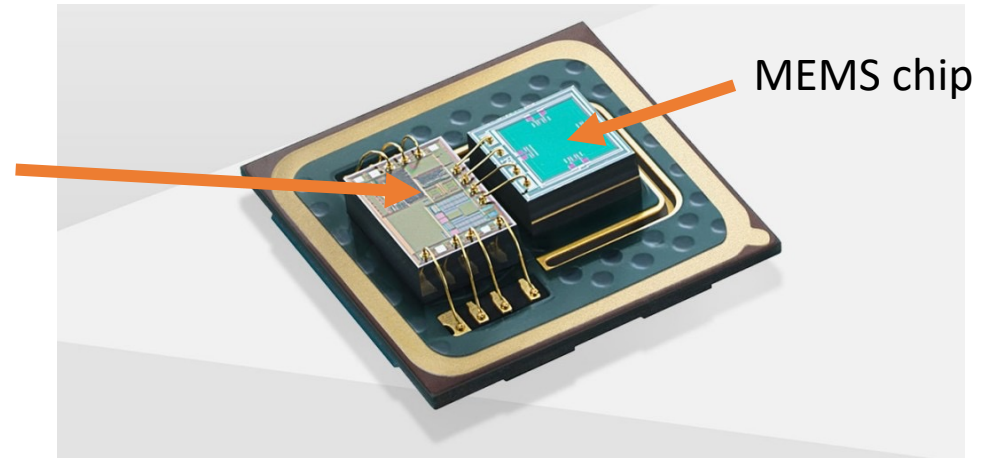
1. **Accelerometers:** SOI wafers are often used to make capacitive or piezoresistive accelerometers. These sensors are used for measuring acceleration in a wide range of applications, from automotive airbags to mobile devices.
2. **Gyroscopes:** MEMS gyroscopes on SOI wafers can be used for measuring angular velocity. They are essential in applications like inertial navigation systems and image stabilization in cameras.
3. **Pressure Sensors:** SOI wafers are used to create capacitive pressure sensors, which can be found in various applications such as automotive systems, industrial equipment, and medical devices.
4. **Microphones:** MEMS microphones are often fabricated on SOI wafers. These are commonly used in consumer electronics, hearing aids, and communication devices.
5. **Inertial Measurement Units (IMUs):** IMUs combine accelerometers and gyroscopes on a single chip, enabling the measurement of both linear and angular motion. SOI wafers are used to manufacture these devices.
6. **Micro-mirrors:** SOI wafers can be employed to fabricate micro-mirrors used in applications like digital projectors, optical switches, and adaptive optics systems.
7. **Resonant Sensors:** SOI wafers are used in the creation of resonant sensors such as resonant pressure sensors, resonant temperature sensors, and resonant accelerometers.
8. **Gas Sensors:** SOI wafers can be utilized in the fabrication of gas sensors that rely on the piezoresistive or capacitive changes in response to the presence of specific gases.
9. **Biosensors:** Some types of biosensors, particularly those used in medical and environmental monitoring, can be fabricated on SOI wafers, enabling integration with electronics for data processing.
10. **RF MEMS:** Radio-frequency MEMS devices, used in communication systems and RF switches, can be manufactured using SOI wafers. These devices often use the insulating layer of SOI for isolation.

Towards NEMS as a sensor interface

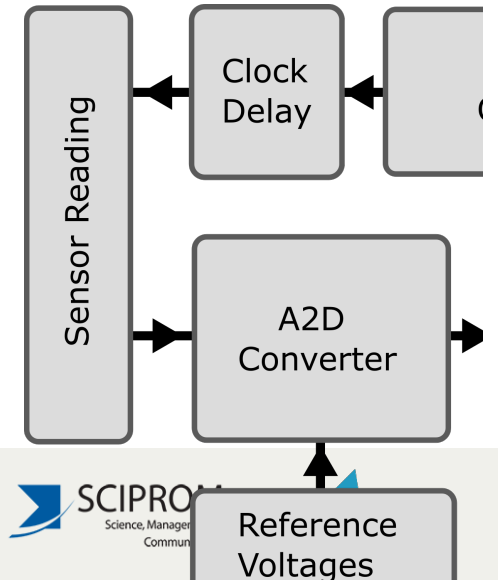
NEMS as a sensor interface

- Replacement of the CMOS instrumentation chip - ultimate NEMS integration

CMOS
instrumentation
chip



- Our Token demonstrator contains a prototype ADC



ADC performance

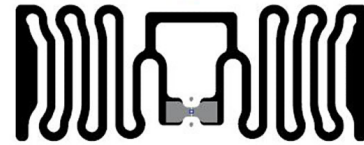
- Example of a high temperature ADC that's available for use (SAR – Successive Approximation) vs expected NEM Switch ADC (Flash architecture)
- NEM Switch figures are yet to be verified and are proposed for purposes of discussion
-is this performance advantage useful?

	Architecture	Resolution	High Temp	Input Range	Supply Voltage	Current Draw	External Clock	Sample Rate	Data Latency
SOI CMOS	SAR	10 bit	225°C	-15 V to +10 V	+5 V	250 µA	500 kHz	25 kS/s	13 cycles (26 µS)
NEM	Flash	Up to 12 bits	300°C	-25 V to +25 V	+5 V	Zero standby current, dynamic current < 100 µA when sampling	None, upper limit of	60 kS/s	1.3 µS

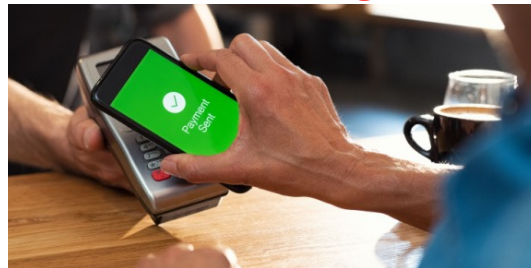
Data transfer - wireless power and communication

Possible NEMS based battery-less wireless communication

- RFID tag
 - No battery
 - Range 0.3m – 3m
 - **Real time RF measurement at temperature**



- Near field communication (NFC)
 - Range 4cms
 - Can charge a NEMS power storage capacitor bank
 - **Avoids long term heat damage to connectors**



Data out - realtime RF wireless temperature measurement

- RF meat thermometer

- Max temp 100C
 - (Protected by the meat)
- Bluetooth
- Diameter 7mm, 200gms



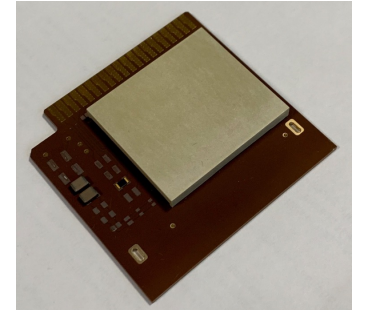
- NEMS wireless temperature measurement concept

- Probe with NEMS reader sitting outside (the meat or anything)
 - On the probe or connected by cable
 - Any probe: needle, magnetic, screwed down
- Max temp 325C
- RFID antenna - in oven or on door glass



NFC and RFID – Ilo asset tracking & condition monitoring

- RF challenged process steps –
 - No or poor antenna eg hot chemical baths
 - NFC charging
 - Then recorded data logging to memory
 - NFC data download
- RFID real time measurement
 - Where an antenna can be within 3m
 - Eg in ovens



NEM Switch Tag

Value of RF communication?

- Sensors at temperature
 - Is $>100^{\circ}\text{C}$ NEMS real time RF measurement useful?
- Sensors in high radiation
 - Is $>1\text{Gray}$ NEMS real time RF measurement useful?

END



CONFIDENTIAL INFORMATION

www.Zero-AMP.eu

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