Emerging MEMS & Sensor Technologies to Watch: 2018

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AMFITZGERALD
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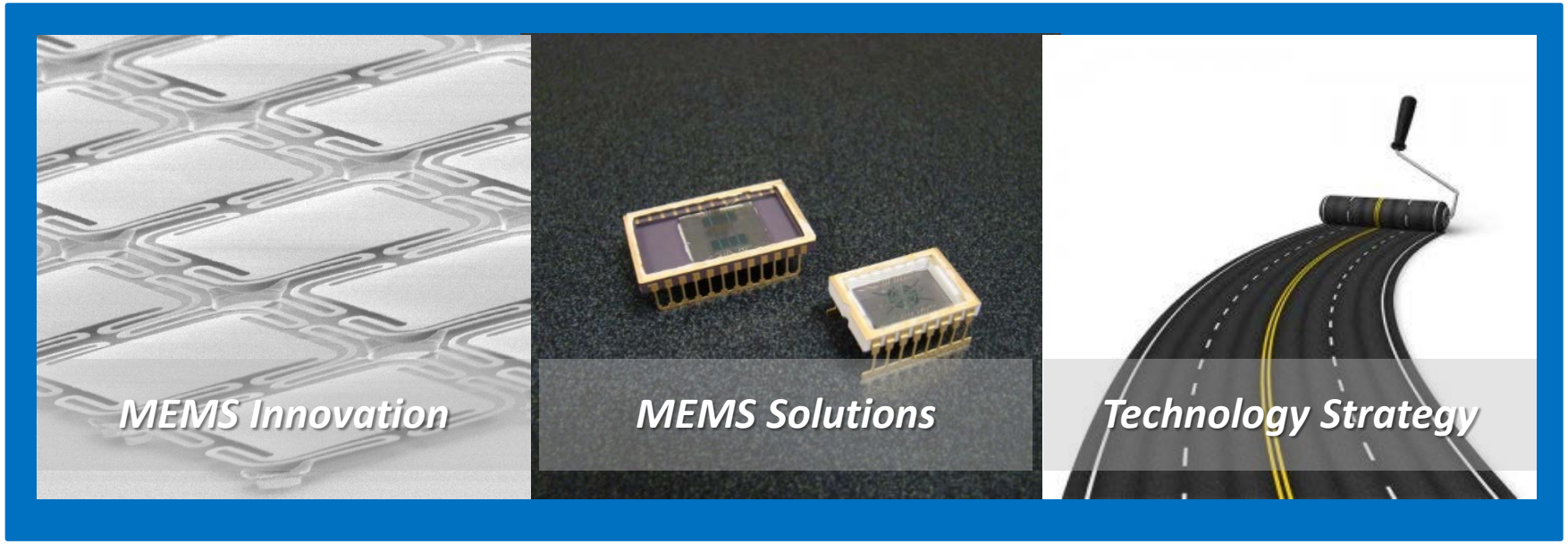
Outline

- About AMFitzgerald
- What “emerging” means in this presentation
- Emerging MEMS & sensor technologies
- Implications for the industry
- Summary

AMFitzgerald: Innovations and solutions for performance products

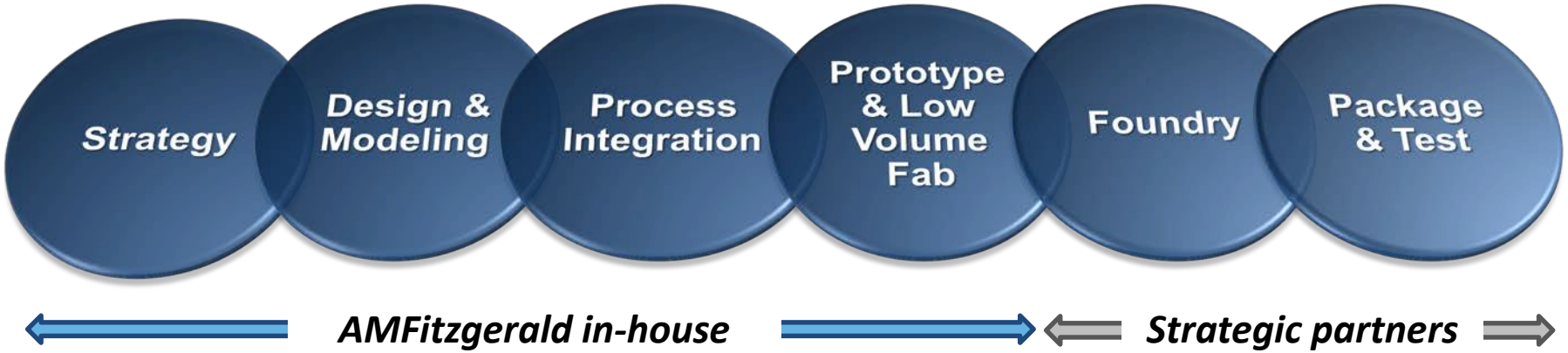


Creation of novel micro devices and IP

Paths to volume manufacturing and market

Business insights from micro technology experts

Development services from concept to production



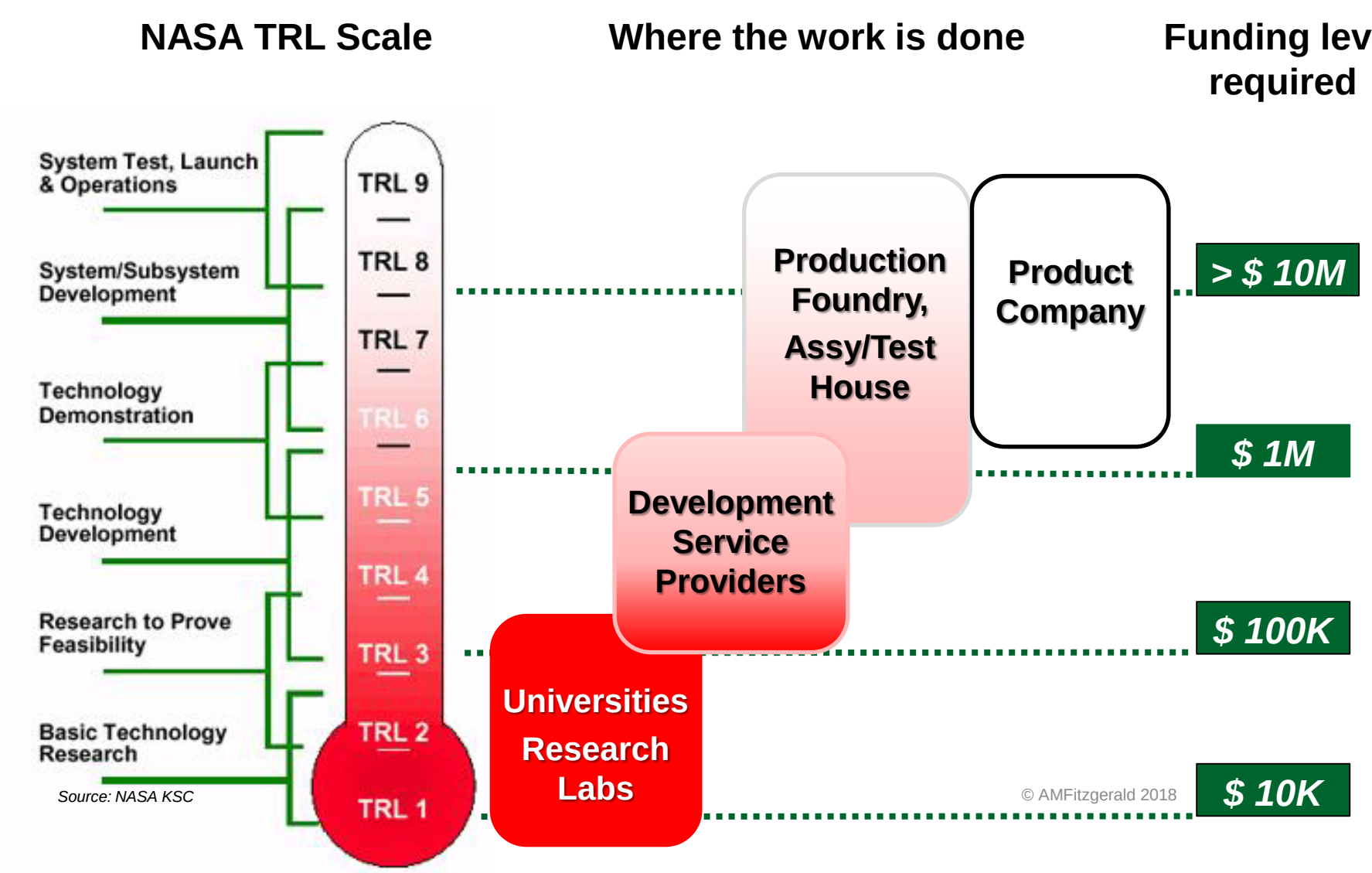
- **Custom MEMS development for commercial production**
- **Rapid prototyping on state-of-the-art tools**
- **Supply chain creation and management**
- **Focus on high-performance, specialty applications**

Headquarters in Burlingame, CA

Fab operations at 1,500 m^2 UCB Marvell Nanolab

What “emerging” means in this presentation

MEMS technology readiness levels (TRL)



“Emerging technologies” definition for this presentation

- **Pre-commercial: TRL 1 - 4**
  - **University/research lab**
  - **Proof-of-concept devices**
- **Best market application(s) unknown**
- **5-10 years and $10-100M yet needed for full commercialization**

- **Why do we care about academic R&D?**

Where the next products will come from!

Academic R&D to Market: Chirp Microsystems

- **Highlighted in AMFitzgerald 2012 "Emerging Technologies" report:**

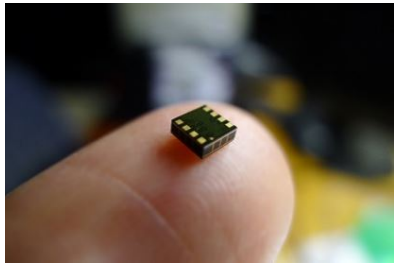
Proximity sensors

Researchers at UC Berkeley and Davis have created a new type of MEMS ultrasound sensor for proximity detection.[6] Much of the prior research on MEMS ultrasound had been on sensors optimized for medical diagnostic imaging, i.e. in an aqueous medium. The Berkeley/Davis team has instead developed an aluminum nitride ultrasound sensor optimized for transmission in air, which can be used as a proximity sensor, just as a bat uses ultrasonic cries to find and catch its prey. This technology could make the leap to the commercial market as a sensor that enables gesture recognition in mobile phones, gaming systems and other user interfaces.

BSAC

- **Chirp Microsystems incorporated in 2013 to commercialize ultrasonic gesture-recognition technology**
- **Sold to TDK in 2018**

Chirp



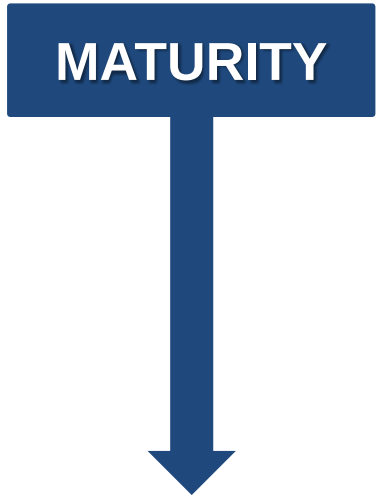
Research methods

- **Review of recent research and academic conferences**
  - **Hilton Head Workshop, June 2018**
- **Filter for:**
  - **Commercial viability**
  - **Offers solutions to known/anticipated problems**
  - **Technology game-changer**
- **Representative examples provided**
  - **Citations at end of presentation**

Emerging MEMS & sensor technologies

Emerging technologies to watch

- **Event-driven sensors**
- **Piezoelectric resonators**
- **Intra-body devices**
- **Screen- and 3D-printed sensors**
- **Biodegradable batteries**



Event-driven sensors: motion, thermal

INNOVATION

- Open circuit until event closes switch
- Very clever use of coupled physics

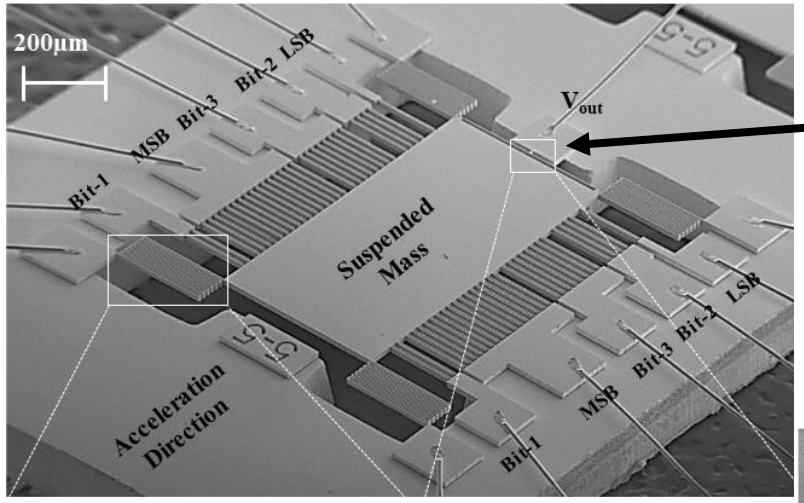
APPLICATION

- Internet of Things
- Security sentinel
- Large arrays of sensors

MATURITY

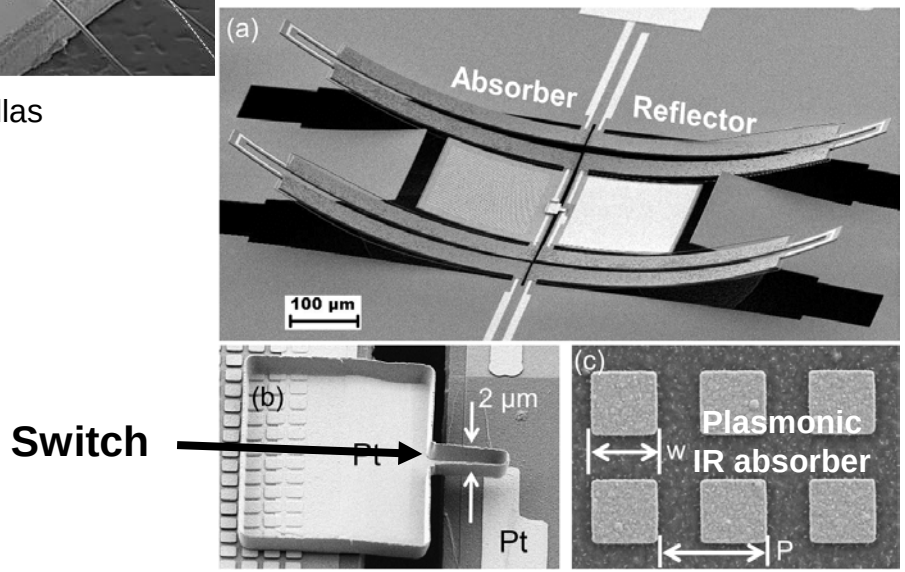
- TRL 4
- New embodiment of existing MEMS process technologies

5-bit accelerometer switch having zero standby power



Source: University of Texas at Dallas

IR signature detector with near-zero standby power



Source: Northeastern University

Piezoelectric resonators

INNOVATION

PZT acoustic resonator integrated in CMOS
Small footprint
No post-processing or packaging

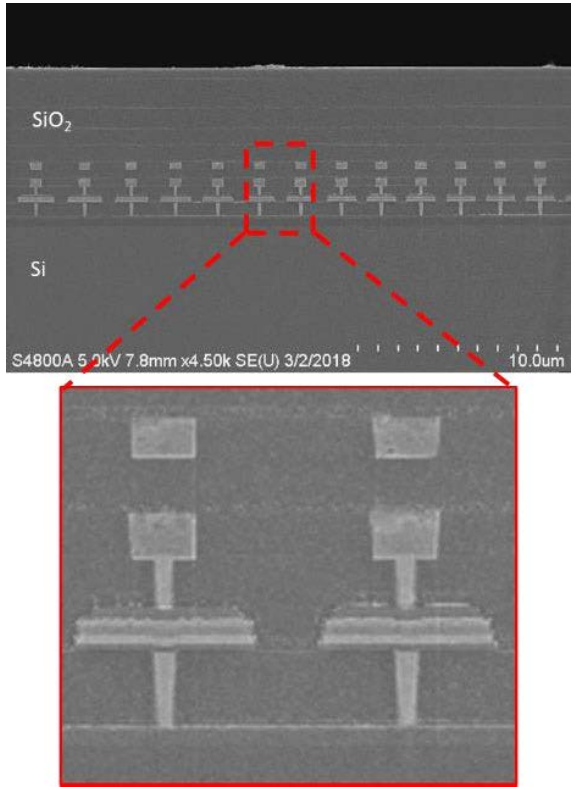
APPLICATION

RF filters for 5G
Millimeter wave imaging
Personal radars

MATURITY

TRL 4
New embodiment of existing process technologies

Acoustic wave-guided CMOS resonator with PZT FeCAPs



Source: Purdue University and Texas Instruments

Intra-body communications

INNOVATION

0.6 Mbit/s data rate via ultrasound
Aluminum nitride PMUTs
Arrays enable beam forming

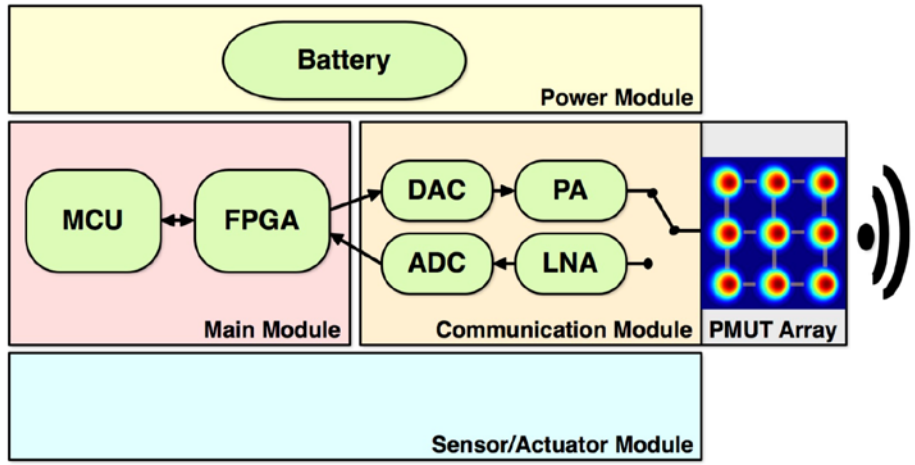
APPLICATION

Imaging telemetry
Health monitoring
Wearable sensors

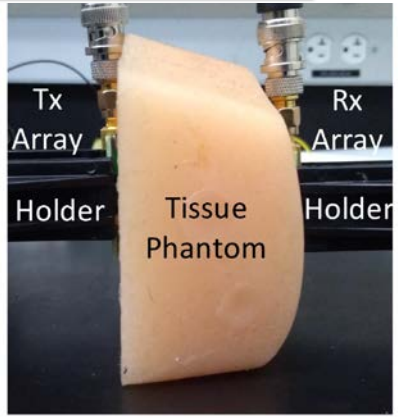
MATURITY

TRL 3
Further testing needed

Ultrasonic intra-body transceiver based on PMUTs



Source: Northeastern University



Screen- and 3D-printed sensors

INNOVATION

Screen-printed potentiometric sensor with 3D printed porous housing
Biodegradable coating allows time-based sampling
Low cost

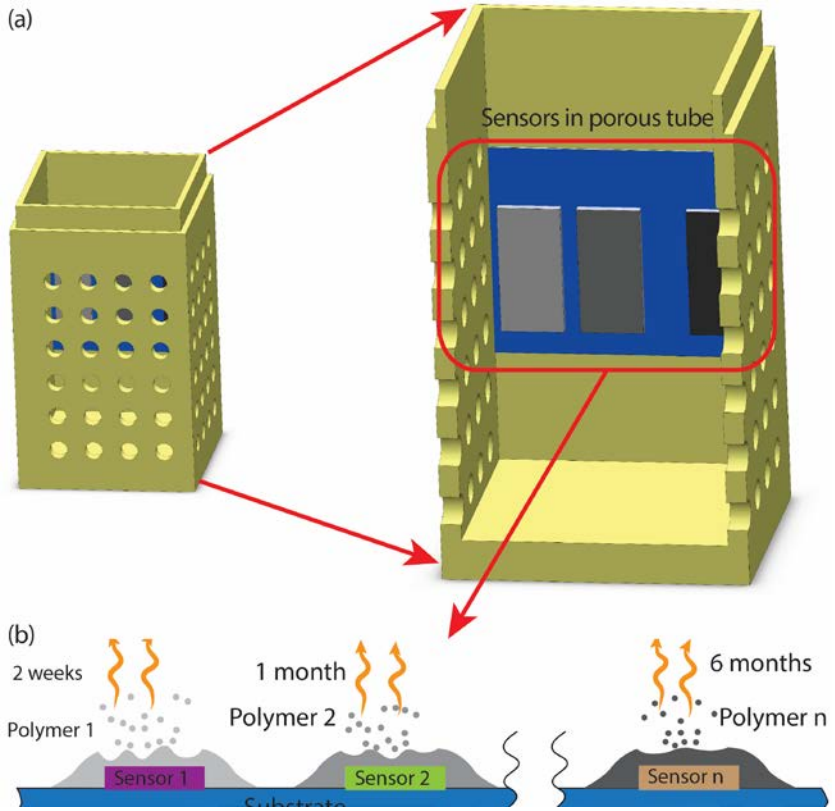
APPLICATION

Precision agriculture
Environmental monitoring
Large arrays of sensors

MATURITY

TRL 2
No volume manufacturing infrastructure

Nitrate soil sensor



Source: Purdue University

Biodegradable batteries

INNOVATION

Paper-based battery delivers 0.5 uW
Bacterial metabolism as electron source
Dissolves in water

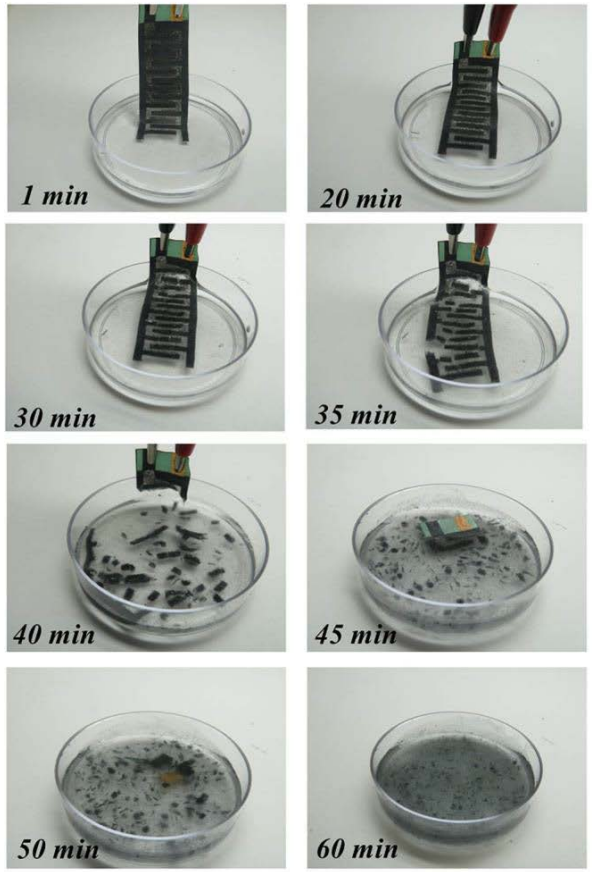
APPLICATION

Temporary medical implants
Environmental/agricultural sensors
Disposable consumer electronics

MATURITY

TRL 1
Early stage proof of concept

Paper-based battery dissolves in 60 min



Source:
SUNY
Binghamton

Implications for the industry

Emerging technologies mapped to markets

Market	*Emerging technologies*
Consumer	• **Piezoelectric resonators and sensors**
IoT, Drones	• **Event-driven sensors**
Food/Agriculture	• **Biodegradable sensors**
Medical	• **Intra-body communication and power**
Wearables	• **Textile- and paper-based sensors and batteries**

Technology forecast: the upcoming decades?

2020s Improved thin film piezoelectrics

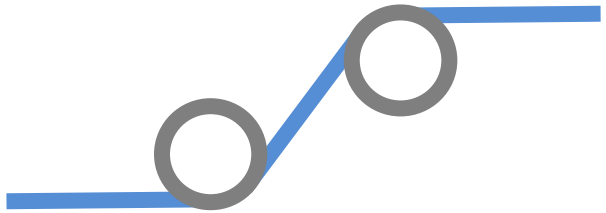
Event-driven sensors

Higher precision, lower power mics, motion sensors

Particle and mass detectors

RF filters and components

2030s New paper and plastic technologies



Biodegradable sensors

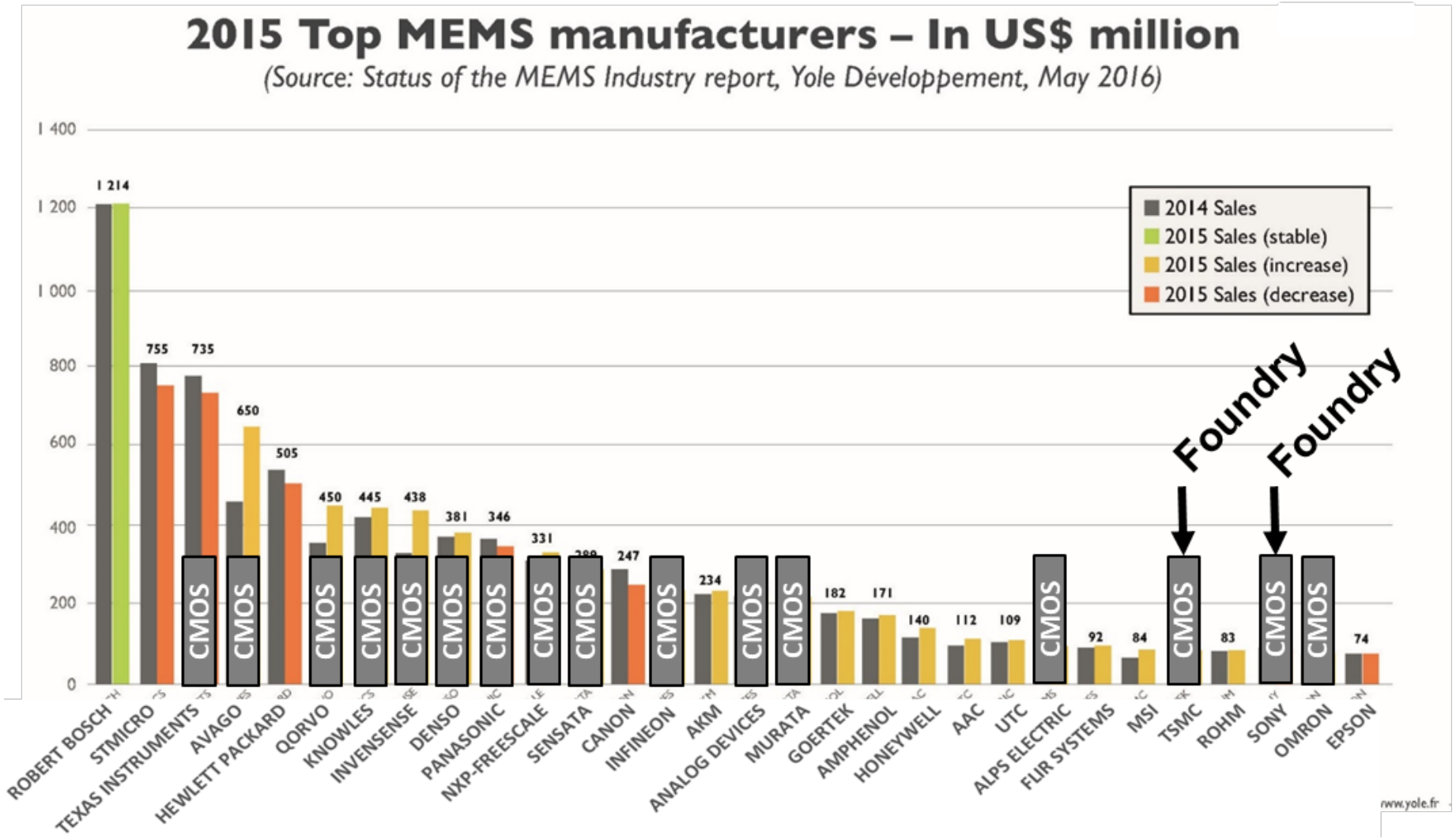
Point of care diagnostics

Disposable packaging sensors

Smart clothing, wearables

Large format sensor arrays: vehicle “wraps,” wall coverings, rooftops, etc.

CMOS manufacturing infrastructure not fully ready for piezoelectrics



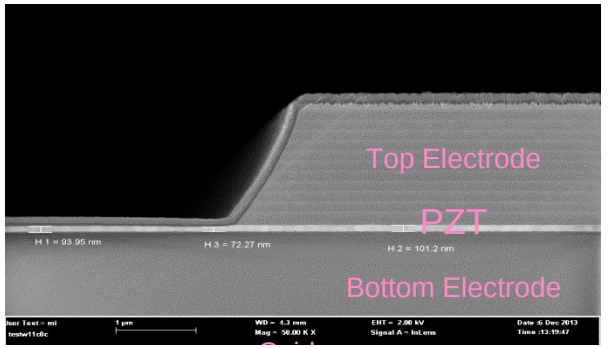
16 out of 30 using CMOS fabs

Fabless MEMS must still be CMOS compatible at front end in order to access high volume fabs

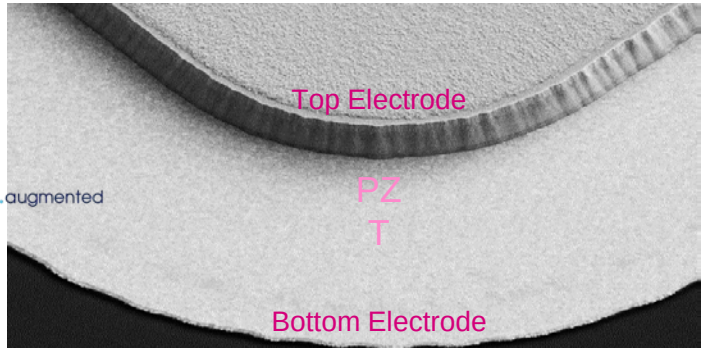
200mm MEMS-specific foundries with piezoelectrics

- **Aluminum nitride (CMOS safe):**
  - **GlobalFoundries**
  - **X-FAB**
- **Thin film PZT (not CMOS friendly):**
  - **STMicroelectronics**
  - **Silex Microsystems**

STMicro “Petra” PZT solgel process



Sloped sidewalls for good passivation step coverage



PZT and the metallic electrodes patterned by dry-etch

Summary

- **Important trends in R&D:**
  - **Piezoelectric sensors and actuators**
  - **Ultra low-power, event-driven and/or battery-free operation**
  - **3D printed, paper-based sensors and batteries**

- **Call to action: Resolve mismatch between emerging technologies and existing manufacturing infrastructure**
  - **High volume foundries should consider adding piezoelectric materials**
  - **How to scale paper and plastic technologies?**

Appendix

References

Event-driven sensors

Rajaram, V. et.al., “MICROELECTROMECHANICAL DETECTOR OF INFRARED SPECTRAL SIGNATURES WITH NEAR-ZERO STANDBY POWER CONSUMPTION,” Transducers 2017, Taiwan

Abbasalipour, A., et. al., “A 5-Bit Digitally Operated MEMS Accelerometer,” Solid-State Sensors, Actuators, and Microsystems Workshop 2018, Hilton Head

Reger, R.W., et. al., “Two-Channel Wakeup System Employing Aluminum Nitride Based MEMS Resonant Accelerometers for Near-Zero Power Applications,” Solid-State Sensors, Actuators, and Microsystems Workshop 2018, Hilton Head

Piezoelectric resonators

He, Y., Bahr, B. and Weinstein, D., “A Ferroelectric Capacitor (FECAP) Based Unreleased Resonator,” Solid-State Sensors, Actuators, and Microsystems Workshop 2018, Hilton Head

Intra-body communications and power

Herrera, B., et. al., “PMUT-Based High Data Rate Ultrasonic Wireless Communication Link for Intra-Body Networks,” Solid-State Sensors, Actuators, and Microsystems Workshop 2018, Hilton Head

Garraud, N., et. al., “Microfabricated Electrodynamic Wireless Power Receiver for Bio-Implants and Wearables,” Solid-State Sensors, Actuators, and Microsystems Workshop 2018, Hilton Head

3D printed sensors

Jiang, H., et. al., “A BIODEGRADABLE SENSOR HOUSED IN 3D PRINTED POROUS TUBE FOR IN-SITU SOIL NITRATE DETECTION,” Solid-State Sensors, Actuators, and Microsystems Workshop 2018, Hilton Head

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Biodegradable and fabric batteries

Mohammadifar, M. and Choi, S., “TRANSIENT BIOBATTERIES: MICROFLUIDIC CONTROL FOR PROGRAMMABLE DISSOLUTION,” Solid-State Sensors, Actuators, and Microsystems Workshop 2018, Hilton Head

Gao, Y., Liu, L., and Choi, S., “A Yarn-Based Bacteria-Powered Battery for Smart Textiles,” Solid-State Sensors, Actuators, and Microsystems Workshop 2018, Hilton Head

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