Emerging MEMS & Sensor Technologies to Watch: 2018

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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

MEMS Innovation

- Creation of novel micro devices and IP

MEMS Solutions

- Paths to volume manufacturing and market

Technology Strategy

- 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

AMFitzgerald in-house

Strategic partners

Headquarters in Burlingame, CA

Fab operations at 1,500 m² UCB Marvell Nanolab
What “emerging” means in this presentation
MEMS technology readiness levels (TRL)

NASA TRL Scale

- TRL 1
- TRL 2
- TRL 3
- TRL 4
- TRL 5
- TRL 6
- TRL 7
- TRL 8
- TRL 9

Where the work is done

- Universities Research Labs
- Development Service Providers
- Production Foundry, Assy/Test House

Funding level required

- > $10M
- $1M
- $100K
- $10K

Source: NASA KSC

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“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. 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.

- Chirp Microsystems incorporated in 2013 to commercialize ultrasonic gesture-recognition technology

- Sold to TDK in 2018
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

Switch

IR signature detector with near-zero standby power

Source: University of Texas at Dallas

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
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

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

<table>
<thead>
<tr>
<th>Market</th>
<th>Emerging technologies</th>
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<tbody>
<tr>
<td><strong>Consumer</strong></td>
<td>• Piezoelectric resonators and sensors</td>
</tr>
<tr>
<td><strong>IoT, Drones</strong></td>
<td>• Event-driven sensors</td>
</tr>
<tr>
<td><strong>Food/Agriculture</strong></td>
<td>• Biodegradable sensors</td>
</tr>
<tr>
<td><strong>Medical</strong></td>
<td>• Intra-body communication and power</td>
</tr>
<tr>
<td><strong>Wearables</strong></td>
<td>• Textile- and paper-based sensors and batteries</td>
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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

2015 Top MEMS manufacturers – In US$ million
(Source: Status of the MEMS Industry report, Yole Développement, May 2016)

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
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


Piezoelectric resonators


Intra-body communications and power


3D printed sensors

Biodegradable and fabric batteries

