How MicroSystems and Entrepreneurs are Driving the Internet of Things

Kurt Petersen, PhD
Silicon Valley Band of Angels

Seattle University
## My Background

<table>
<thead>
<tr>
<th>Company</th>
<th>Year</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>IBM Research</td>
<td>1975</td>
<td>Began work on MEMS Technology</td>
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<tr>
<td>TDI</td>
<td>1982</td>
<td>MEMS pressure sensors and R&amp;D</td>
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<tr>
<td>NovaSensor</td>
<td>1985</td>
<td>MEMS sensors; <strong>ACQUIRED</strong> by GE</td>
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<tr>
<td>Cepheid</td>
<td>1996</td>
<td>IPO in 2000; $450M yearly sales. <strong>ACQUIRED</strong> by Danaher in 2016 for $4B</td>
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<tr>
<td>SiTime</td>
<td>2004</td>
<td>Has sold &gt;300M MEMS oscillators; <strong>ACQUIRED</strong> by MegaChips in 2014 for $200M</td>
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<tr>
<td>Profusa</td>
<td>2008</td>
<td>Implantable glucose sensor $22M+ over the years from DARPA and NIH Now closing a Series C at a valuation of $100M</td>
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<tr>
<td>Verreon</td>
<td>2009</td>
<td>MEMS sensors; <strong>ACQUIRED</strong> by Qualcomm</td>
</tr>
<tr>
<td>Band of Angels</td>
<td>2011</td>
<td>Mentoring and investing group for high tech start-up companies</td>
</tr>
</tbody>
</table>
Global Sales for Semiconductor and MEMS

MicroElectroMechanical Systems

Blue: SEMI, Green: MEMS, Red: MEMS/SEMI (right axis)

Billions

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High Volume Consumer MEMS

**Today:**
- Pressure Sensors
- Ink Jet Nozzles
- Accelerometers
- Gyroscopes
- Microphones
- FBAR Filters
- Magnetic Field
- Oscillators

**Tomorrow:**
- Speakers
- Ultrasonic Ranging
- Variable Antenna Tuners
- Variable PA and LNA Filters
- Eye-Tracking Sensors
- Mechanical Switches
- Chemical/Gas Sensors
- Force Sensors
- IR Imagers
- Camera Auto-Focus
- Camera Zoom
- Energy Harvesting
- Optical Interconnects
- Better Inertial Devices
Three ENORMOUS IoT Initiatives

Trillion Sensor Roadmap !!
initiated by Janusz Bryzek

Introducing the Qualcomm Tricorder X PRIZE
A $10 million competition to bring healthcare to the palm of your hand

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Mobile as an Innovation Platform

- Credit Card Reader
- Baby Monitoring Patch
- Ultrasound, the cheap and mobile way
- Blood pressure monitoring cuff
- Glucose Finger-stick Monitor
- Wireless is an ENABLER for MEMS!!
Newest High Volume Product

Small kHZ Timing 300M total units shipped 120M/year in 2017

2.0 x 1.2 mm  1.5 x 0.8 mm

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Variable Capacitor Array

- First MEMS variable capacitor arrays
  - Cavendish Kinetics and WiSpry
- On the market for cell-phones in 2014
  - Still relatively small volumes
  - WiSpry briefly on the market in 2011
First Application: Tunable Antenna
MEMS Ultrasonics by Chirp

• Chip-sized ultrasonic transducer and receiver allowing object detection and gesture recognition in a few square millimeter package with ultra-low power – size of MEMS microphone
• Traction with wearables, drones, robots, VR/AR

• Very exciting new high volume MEMS product
Eye-Tracking by Adhawk

- Scans the eye with NIR light
  - Uses a MEMS scanning mirror
  - Eye cannot detect the light
- Determines where the eye is looking within a few degrees
- Scans FAST: 250 times/sec
- It actually PREDICTS where the eye will be looking
- Huge markets in VR/AR
- Intel invested
  - High volume production in 2019
**polight Auto Focus**

- Polymer is “warped” by a piezoelectric layer
  - causes the transparent polymer to become a convex lens
- (not traditional MEMS, but STMicro is a partner)
- Company founded in 2005
- **Still** not in high volume production
DigitalOptics (Tessera) MEMS Auto Focus

- 2-3x faster
  - Faster settling time
  - Position awareness
- Lower power consumption
  - 1/100th the power of current CMOS and lens
- Semiconductors precision
  - Improved motor and lens control
  - Longer operating life
- Size: 4x4 mm
  - Smaller footprint and travel requirement

Strong technology roadmap
- Zoom, motion sensing, stabilization, image enhancement

Project is now “on hold”
Force Sensing

- A third dimension of **Touch** enables a richer, more intuitive human interface.
- **NextInput** has developed a force sensitive touch technology – ForceTouch®.
- ForceTouch solution consists of three parts
  - MEMS force sensor
  - Algorithms and software
  - Mechanical design to implement the solution

Tactile Force Sensor developed at TDI In 1984

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Coming soon - MEMS Speakers

Other Contenders:

- UNSOUND from Fraunhofer
- TIKI AUDIO from Japan and San Jose

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“Soft” Sensors; Vapors, Humidity

- Recent introductions of first mass-produced “chemical” sensors suitable for mobile devices (3x3 mm)
  - Water vapor, VOCs, CO, CH$_4$, CO$_2$

- **Goal**: networked cell-phones collecting pollution information also, additional information for contextual awareness

- **Problem**: these devices tend to drift over time

- These devices are precursors to more complex chemical sensing

- Growing need for gas sensors in automated HVAC systems – CO$_2$ for occupancy detection, e.g. Nest
Next Generation Gas Sensing

- Suspended MEMS hotplates
- Cantilever arrays with heaters

- Accurately identify gases
- Quantify @ PPM/PPB levels
- Low power, small size – IoT ready

Array of transducers
- Dozens of measurements
- Multi-variate analytics

Gas Sensing Applications
- Indoor Air Quality
- Environmental Air Quality
- Industrial Process Control
- Life Safety
- Leak Detection
- Health Diagnostics

from:
NevadaNano

Chip = 3x3 mm

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Next Generation Gas Sensing

Suspended MEMS heater element
Encapsulated in a wafer-sealed vacuum cavity
Emitting infrared radiation
Creating a Non-Dispersive IR sensor (NDIR)

from:
eLichens
a LETI Company

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Ubiquitous IR Imagers

• The most expensive part of an IR imager is the lens
  – Expensive germanium or chalcogenides
  – Diamond-turned
  – Molded at high temperature
• Current FLIR cell-phone imager sells for $200.
• But, there are huge un-met needs, particularly in self-driving autos, occupancy detection, and industrial monitoring for an inexpensive imager
• The bolometer chip, FPA, is also a suspended MEMS-based device
Next Gen IR Lenses Using DRIE

- Gradient Index (GRIN) lenses can be made by DRIE on standard, flat silicon wafers
- Developed by my start-up company, INVIS
- Extensive modelling validated by fabricated/tested chips
- Funding:
  - NSF Phase 1 and Phase 2
  - Founders investments
- Patents filed
- Partnering with strategic corporations

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Big IoT Problem: POWER

- EXTREMELY low power circuits will continue to be developed
- BUT, this has diminishing returns for many sensor circuits
- Energy harvesting will continue to be developed
  - Light, Vibration, Heat, RF Energy, INTEGRATED COMBINATIONS OF THESE
- micro-Gen uses piezoelectrics for vibration/motion harvesting
- Allowing stand-alone lifetimes of IoT for 10 years or more
Mechanical Electrical Switches

- I built the first MEMS mechanical switches over 40 years ago
- Companies have been trying to commercialize such devices since then - no one has been successful
- Low lifetimes have been the primary problem
- Recently, there has been some success stories
- GE has spun off a start-up company after >10 years of R&D
  - Menlo Microsystems
  - Switches installed in GE instruments
- IMT in Santa Barbara has sampled high performance devices
- We are close to commercialization!
Totally Disposable Diagnostics

Metrika
Developed a **fully disposable** hbA1C test in 2000. Sold to Bayer.

- **Xip Dx** is bringing this type of test to a new level
- Uses a single silicon IC optical sensing chip
- First test is for troponin, a heart attack indicator

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eXo – Next Gen Ultrasonic Imaging

MISSION
Democratize medical imaging

$250-500k
(POST-PAYMENT)
4D ULTRASOUND
FOR SONOGRAPHERS

$999
POINT & SHOOT IMAGER
STETHOSCOPE FOR THE
21ST CENTURY

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Artificial Retina Implants

Also, Second Sight, Inc.
Microfluidics

- HUGE trend in microbiology is toward single cell analysis
- Realized by micro-droplet manipulation
- **10X Genomics**
- **Mission Bio, Raindance**
- “Droplet Digital PCR”
- Consumables are glass-based or plastic
- 10s of thousands of droplets per second
Start-up Companies Discussed Here

• SiTime
• Audio Pixels, U Sound, Tiki Audio
• InvenSense
• poLight, Digital Optics
• Menlo MicroSystems
• Cavendish Kinetics, Wispry
• Microgen
• Nevada Nano
• Mission Bio
• Chirp
• NextInput
• AdHawk
• Metrika, XipDx
• Second Sight, Optobionics
• Exo
• eLichens
• 10X Genomics
• INVIS
• Raindance

The Newest Generation of MEMS are ALL from Start-ups !!!
World-wide Start-up Culture

• Today Entrepreneurs are DRIVING innovations in IoT
• We are far from saturating new MEMS innovations
• In Silicon Valley, there are THOUSANDS of start-ups
  – VERY many of these are hardware, bio-tech, med-tech, IoT
• HEAVY start-up support by US government agencies
  – DARPA, NSF, NIH: entrepreneurship classes, money, networking
• This is a world-wide phenomenon
  – Spain, Israel, France, UK, Singapore, Taiwan, China
• Even the largest VCs are now finding ways to invest in early-stage start-ups – they never did this previously

➢ It is an exciting time to be a MEMS entrepreneur
Thank You