SiTime:
Going from 0 to 3 Million Units
in less than 3 Years

Kurt Petersen
Co-Founder
MEMS are EVERYWHERE

- Accelerometers for Air Bag Deployment
- Gyroscopes for Electronic Stability Control
- Pressure Sensors for oil, tires, intake manifold, etc
- FBAR Filter
- Microphone
- Accelerometer for hard drive protection
- Image Stabilization
- DLP Chip
- Ink Jet Printers
- Wafer Probe Cards
- Catheter tip Pressure Sensor
- Hand Held Tire Pressure
mems30
Top 30 MEMS manufacturers in 2006 by revenue

$5.6B total

Source: WTC  www.wtc-consult.de
Notable MEMS Products

- **DLP**
  - Most complex structure; >1M mirrors

- **Ink Jet Nozzles**
  - Largest dollar volume, >$1.5B/yr

- **Accelerometer**
  - Air-bag deployment

- **Gyroscope**
  - Electronic stability control

- **DNA Detection**
  - *All your mail is checked for anthrax*

- **FBAR Filter**
  - Over 500M total shipped

- **Microphone**
  - ~500M to be shipped in 2007

- **High-Q Resonator**
  - Newest on the market (>200K/wk shipping)

- **RF Switches**
  - (?)

- **Direct View Displays**
  - (?)
### New Technology Adoption

<table>
<thead>
<tr>
<th>OLD TECHNOLOGY</th>
<th>NEW TECHNOLOGY</th>
<th>YEARS</th>
<th>WHY IT HAPPENED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analog Cell Phone</td>
<td>Digital Cell Phone</td>
<td>6</td>
<td>Spectrum efficiency</td>
</tr>
<tr>
<td>Film camera</td>
<td>Digital Camera</td>
<td>8</td>
<td>New use environment, PC, Imaging Technology</td>
</tr>
<tr>
<td>CRT</td>
<td>Flat TV</td>
<td>8</td>
<td>Weight, Size</td>
</tr>
<tr>
<td>CCD Image Sensor</td>
<td>CMOS Image Sensors</td>
<td>3</td>
<td>Speed, Cost, CMOS friendliness</td>
</tr>
<tr>
<td>Electret Microphone</td>
<td>MEMS Microphone</td>
<td>4</td>
<td>PCB friendliness, integration</td>
</tr>
<tr>
<td>Magnetic Ball in Tube</td>
<td>MEMS Accelerometer</td>
<td>5</td>
<td>Ease of use, reliability, cost</td>
</tr>
<tr>
<td>Quartz Gyros</td>
<td>MEMS Gyroscope</td>
<td>6</td>
<td>Cost, Production efficiency</td>
</tr>
<tr>
<td>Computer Projectors</td>
<td>Digital Light Projector</td>
<td>5</td>
<td>Performance, weight, digital interface</td>
</tr>
<tr>
<td>Quartz, SAW Filters</td>
<td>MEMS FBAR</td>
<td>4</td>
<td>Performance, size</td>
</tr>
<tr>
<td>Quartz Resonator</td>
<td>MEMS Resonator</td>
<td>?</td>
<td>Ease of use, reliability, supply chain, cost</td>
</tr>
</tbody>
</table>

Transition = years to attain ~50% market share. Mean is ~5 years.
Knowles MEMS Microphone

- Very Rapid Volume Ramp-up
- Only 5 year-old product
- Mostly Cell Phone Applications
Sounds pretty exciting !!

- Need an outstanding founding team
  - preferably with previous start-up success
- Need an outstanding technology/idea
  - preferably with good IP position
- Need an outstanding market opportunity
  - preferably with several $100M market
- Need a LOT of patience
- Need a VERY thick skin
- Need a LOT of luck
I started working on MEMS before "MEMS" existed

- IBM Research
- TDI
- NovaSensor
- Cepheid
- SiTime


- Brett born
- Brett graduated from U Mich
NovaSensor

- **Founders:** Janusz Bryzek, Joe Mallon, Kurt Petersen
- **Investors:** Schlumberger
- **Investments:**
  - Equity - $2.5M
  - R&D - $2.5M
- **Funding:** October 1985; self-funded for ~6 months
- **Sold company in April 1990 to Lucas Industries**
- **Acquired by GE Sensing in 2004**
- **First product, second source pressure sensor chip, shipped 8 months after funding**
NovaSensor gets started
NovaSensor

- **Mission:** be the most advanced MEMS company
- 10 weeks from first PO, to product development, to first product delivery
- Used “borrowed” fabs for first 1½ years
- “Second” source product became first source
  - on-time deliveries
  - advanced process allows MUCH tighter spec distribution
- NovaSensor pioneered Silicon Fusion Bonding and DRIE for MEMS
- Today, NovaSensor has sales >$100M/year
Cepheid

- **Founders:** Tom Gutshall, Kurt Petersen, Bill McMillan, Greg Kovacs, Lee Christel, Allen Northrup
- **Investors:** HNW individuals, CampVentures
- **Investments:**
  - self-funded for 18 months
  - Series A - $3.2M - Mar 1997
  - Series B - $10.5M - Nov 1998
  - Series C - $19.2M - Feb 2000
  - IPO - $32.4M - Jun 2000
  - Various after market - >$100M
- **First product, SmartCycler, shipped 39 months after start**
Cepheid

- **Mission**: to change the way DNA testing is performed using microfluidics and PCR
- ALL US mail is screened for anthrax in Cepheid systems
- Cepheid has now entered the human diagnostics market
  - one of first tests, rapid, easy MRSA
- Today, CPHD has >$1.2B market cap
  - but, not yet profitable
- After the market crash in 2001, market cap dropped to a low of $40M. If you bought stock at that point, you’ve had an ROI of ~55%/year for 6 straight years.
“Providing DNA/RNA test results \textit{when} and \textit{where} they are needed”
1728 mail sorting machines in the US Postal Service. Each performs one Anthrax test/hour.
SiTime

- **Founders:** Kurt Petersen, Markus Lutz, Tom Kenny, Aaron Partridge, Joe Brown, Bernhard Boser,
- **Investors:** NEA, Greylock, CampVentures, Bosch
- **Investments:**
  - License negotiations with Robert Bosch last 16 months
  - Series A - $11.5M - Dec 2004
  - Series B - $12.0M - Mar 2006
  - Series C - $20.0M - May 2007
- License negotiations with Bosch started June 2003
- First product, SiT8002, shipped 33 months after start
SiTime

- **Mission**: introduce the first MEMS-based oscillators to the market
- Currently shipping at >200K/week
- Employees in Japan and China in second year
- One of the advantages of silicon valley; at Series A closing, SiTime owed lawyers $120K for over a year of work
SiTime Founders

Joe  Tom  Aaron  Kurt  Markus
Recognition for SiTime MEMS Resonators

- **Electronic Products**: 2006 Product of the Year
- **FSA**: 2005 Startup to Watch - Fabless Semiconductor Association
- **EuroAsia IC Industry Awards**: 2006 Start-up of the Year Award - EuroAsia Semiconductor Magazine
- **R&D 100 Award**: 2006 R&D 100 Award - 100 most technologically significant products introduced into the marketplace over the past year - R & D Magazine
- **Micro Nano 25 Award**: Micro Nano 25 Award for SiT8002 product - 25 most innovative products of 2006
Yearly Revenues after Founding

![Graph showing yearly revenues over years of operation for NovaSensor, CPHD, and SiTime. The graph demonstrates significant growth in revenue over the years, with SiTime showing the most rapid increase.](image-url)
Quartz Crystal Resonators

- Grew to be fairly large in the US during WWII for military radios
- *Industry collapsed after the war*
- Expanded again during the Korean War
- *Industry collapsed again in the US*
- However, the quartz crystal market continued to expand and grow *in Japan* in the mid-to-late 50’s
- Seiko became the chief time-keeper at the 1964 Tokyo Olympics
- Today, Epson (a Seiko spin-off) is the world’s largest quartz crystal company
- ~2/3 of market is owned by Japanese companies
The Quartz and Timing Marketplace

Quartz Crystals

- 8.5%/year growth
- $3.1B in 2005
  - 10B units
- $4.7B in 2010
  - 18B units

Timing Chips

- 10%/year growth
- $1.4B in 2005
- $2.3B in 2010

Total Market will be ~$7B in 2010.
30% of apps are in portable devices,
where size and power are critical.

This market dwarfs any other MEMS application.
MEMS Resonators

• Under development for over 40 years
• ( same as MEMS Switches ? )
• First demonstration by Westinghouse in 1965
• Devices have never been able to compete with quartz
• ppm accuracy requirement places a severe constraint on the replacement of quartz crystals for timing applications
• Drift over time and stress, as well as temperature hysteresis, are huge problems which were not solved during 40 years of MEMS development - until now
Earliest MEMS Resonator

1965 Harvey Nathanson, Westinghouse
SiTime MEMS Resonator

- Quad Resonator
- Single-point attachment
- High quality vacuum chamber
MEMS First™ Resonators

Phase contrast visible light photo

Exclusive License from Robert Bosch GmbH

Infrared microscope photo

0.6 mm

0.8 mm

300 µm
MEMS First™ Cross Section

Manufacturing Partner:

**Jazz Semiconductor**

MEMS First means that the MEMS is built first, before any circuitry and sealed at 1100°C. Water vapor is eliminated.
Sealing the resonator in an epi reactor

- Gases are only hydrogen (~98%), silicon reactive gases, and chlorine reactive gases at >1000ºC
- This atmosphere is designed to remove any and all contaminating molecules from the surface of silicon
- Once the cavity is sealed, only hydrogen gas is left behind (silicon and chlorine molecules decompose to the surface).
- Later, this H\textsubscript{2} diffuses through the silicon at ~700ºC
- An extremely good vacuum (~1mTorr) is left behind
- Meanwhile, the resonator has been annealed at 1000ºC
Aging 1 year

Aging Histogram (ppm/yr@25C)

Typical Quartz is 3ppm in first year
SiT8002 System Architecture

Kobe - Programmable Oscillator

MEMS Resonator

Oscillator

Frac-N PLL
spread-spectrum capable

CLK
(1~125MHz)

5MHz

Prog. frequency

Digital

Temperature Sensor

A/D

Digital Temperature Compensation

VDD

GND

Bandgap & Bias

NVM

I/O

PROG

TSMC 0.18 μm first tapeout on 9/26/2005
Customer sampling began March, 2006
High Volume Production began Q3 2007

1.4 mm
Frequency Stability over Temperature

100 parts calibrated at room temperature only

-45°C to 85°C

±50ppm
World’s Smallest Programmable Oscillator
MEMS Resonator Design Advantages

Today

MemS inside

Tomorrow

Fewer components
Less board space
Improved reliability
Reduced cost
Complete **timing solution**
The Future of MEMS First Resonators

- Today, we have only scratched the surface of MEMS First technology
- MEMS/CMOS integration was recently demonstrated at our MEMS vendor
- Recent new devices have phase noise of -140dBc
- Recent work by Tom Kenny’s students at Stanford
  a) oxidized silicon beams compensate frequency performance to <100ppm over 0-70°C
  b) a resistively heated beam (constant temperature of 80°C) has shown 0.03ppm from -55 to 80°C
  c) using a) plus b) together is expected to yield 0.003ppm
- Now that the high quality vacuum chamber (MEMS First) is in production, new innovations will hugely expand the application space
MEMS Penetration of Quartz Market

- **~$1.2B**
  - OCXOs, TCXOs, very low jitter, very low phase noise, ≤ 2ppm over temp

- **~$1.2B**
  - Consumer electronics, SMD, medium jitter, <100ppm over temp

- **~$1.2B**
  - Watches, metal-can packages, >100ppm over temp, low-end
Circuit Designers have had no choice!

- Quartz Crystals have been the *de facto* standard for high precision resonators for ~40 years

but:

- MEMS First™ resonators are ~50x smaller by volume
- MEMS First™ resonators are more stable than quartz
- MEMS resonators are more reliable than quartz
- MEMS resonators are fabricated on SILICON
- MEMS resonators are more cost effective than quartz
- SiTime is now shipping over 200K devices/week

*Things are about to change!*
SiTime Team