MEMS & Sensors packaging: Wafer-Level-Packaging Technology and market trends

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Fields of expertise:

Yole Développement’s 30 analysts operate in the following areas:

- MEMS & Sensors
- Displays
- Compound Semi – LED & OLEDs
- Imaging
- Photonics
- MedTech
- Manufacturing
- Advanced Packaging
- Power Electronics
- Batteries / Energy Management
A group of companies

- **Yole Development**
  - Market, technology and strategy consulting
  - [www.yole.fr](http://www.yole.fr)

- **Yole Finance**
  - M&A operations
  - Due diligences
  - [www.yolefinance.com](http://www.yolefinance.com)

- **Blumorpho**
  - Innovation and business maker
  - [www.bmorpho.com](http://www.bmorpho.com)

- **System Plus Consulting**
  - Manufacturing costs analysis
  - Teardown and reverse engineering
  - Cost simulation tools
  - [www.systemplus.fr](http://www.systemplus.fr)

- **KnowMade**
  - IP analysis
  - Patent assessment
  - [www.knowmade.fr](http://www.knowmade.fr)
Outline of the presentation

- Market trends & MEMS sensors
- Focus on Packaging technologies for MEMS devices
- Conclusion
The 5 senses and many more: MEMS, sensors
The 5 senses and many more: Mems, sensors & actuators

- Sight
- RF communication
- Smell
- Focus
- Taste
- Speech
- Pressure
- Touch

- Body balance
- Audio
- Fluids
MEMS & sensors Roadmap

From More than Moore towards Beyond Law
Overview of the MEMS sensors & actuators

**SENSORS**
- **Movement**
  - Accelerometers
  - Gyroscopes
  - Magnetometers
  - MUs (6 to 9 DOF)
- **Pressure**
- **Sound (microphone)**
- **Environment**
  - Gas
  - Humidity
  - Particles
  - Temperature
  - Micro bolometers
  - PIR & thermopiles
  - Ambient light sensor
  - Vision
  - Optical benches
- **Optical sensors**
  - PIR & thermopiles
  - Temperature
  - Micro bolometers
  - Ambient light sensor
  - Vision
  - Optical benches

**ACTUATORS**
- **Optical MEMS**
  - Auto-Focus
  - Micro mirrors
  - Optical benches
- **Microfluidics**
  - Ink jet delivery
  - Drug delivery
  - Biochips
- **RF**
  - Switch
  - Filter
  - Resonator
- **Micro structures**
  - Micro tips
  - Probes
  - Watches components

Possible integration with environment combos
Possible integration with opto combos

**Examples**
- InvenSens MPU9250
- STM pressure sensor
- Infineon microphone
- Bosch BME680
- FLIR Lepton One
- Debiotech micro pump
- Texas Instruments DLP
- poLight AF
- Avago FBAR Filter
- SiTime oscillator
- Spiromax Patek Philippe

Audio Pixels MEMS based speaker
MEMS & sensors transitioning towards 3 main Hubs...

**INERTIAL**
- Accelerometer
- Gyroscope
- Magnetometer
- IMU

**ENVIRONMENTAL**
- Gas/Particle
- Pressure
- Temp/Humidity
- Microphone

**OPTICAL**
- Visible
- Proximity/ambient
- 3D vision
- Multi-spectral

Closed Package Hub

Open Cavity Hub

Optical Hub
MEMS & sensors: The inertial hub

Complete integration has been achieved at sensor level

Strong miniaturization race

Still some developments on power consumption, advanced packaging

Major developments at Software level to achieve sensor fusion

→ Accurate data acquisition
→ Precise tracking within the environment

Inertial Bill Of Materials
~$1
MEMS & sensors: The optical hub

An ever growing market

Imaging is highly valued

Imaging

Bill Of Materials

$10

The imaging industry stopped the low cost/high integration model by increasing the pixel size and thus the die size
MEMS & sensors: The environmental hub

Interesting way for the MEMS industry to gain value:

- More integration at environmental level
- Pressure + Microphone
- Add Particles & Gas detection (market pull)

Environmental Bill Of Materials
- TODAY: ~$0.70
- TOMORROW: ~$1.50
MEMS market by application

- Consumer is still the main driver

MEMS $M forecast per application
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MEMS average selling price

Is the market able to absorb such a price decrease?

2000 – 2020 MEMS ASP decrease
Source Yole Développement

CAGR -6%

CAGR -13%

Accelerometer only $0.14!

Microphone only $0.19!

Under $1 since 2013...
New MEMS challenges

- Yesterday, the main MEMS challenges were size decrease, which in turn led to price decrease then volume growth.
- Today, trends are different. They are: importance of user case (start with the definition of an application), fusion different sensors with software and power decrease (which paradoxically is linked to an chip size increase because of the ASIC).
Smarter or smaller? Two different paths in integration

- While some companies focus on developing smaller & smaller packaged dies, others prefer to go into another direction integrating more functions in the package.
- Winners are those that can merge both approaches: more functions in a reduced package!

Examples of MEMS companies with a « sensors integration » road (e.g., mCube with iGyro, Spectral Engines with integrated spectrometer, Bosch with environmental combo sensors, AMS with optical combos, InvenSense with IMUs ....)
MEMS Evolution

MEMS die is put in a ceramic or metal package

→ Reduced form factor
→ Cost reduction
→ Improved performance

PAST

Wafer –Level Packaging
• Wafer Level capping combined with Vertical interconnection
• Wafer to wafer bonding
• WLCSP

TODAY
WLP for microbolometers

<table>
<thead>
<tr>
<th>Before</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional microbolometers</td>
</tr>
<tr>
<td>• Ceramic or metal package</td>
</tr>
<tr>
<td>• The air is pumped out before the package is sealed with a silicon or germanium window</td>
</tr>
<tr>
<td>• Slow</td>
</tr>
<tr>
<td>• Costly $\rightarrow$ metal packaging</td>
</tr>
</tbody>
</table>

WLP technologies

<table>
<thead>
<tr>
<th>WLP microbolometers</th>
</tr>
</thead>
<tbody>
<tr>
<td>• more chips can be packaged on the wafer $\rightarrow$ cost reduced</td>
</tr>
<tr>
<td>• Vacuum sealing with a silicon window in parallel at the wafer level $\rightarrow$ improve throughput and yield</td>
</tr>
<tr>
<td>• Sensor size reduced</td>
</tr>
<tr>
<td>• Cost reduced</td>
</tr>
<tr>
<td>• Vacuum or temperature resistance improved</td>
</tr>
</tbody>
</table>
3-Axis Accelerometer Package size comparison – TSV Inside!

Surface: $S_{ST} = 4\text{mm}^2$
Package thickness: $T_{ST} = 1\text{mm}$
LGA package

Surface: $S_{mCube} = 4\text{mm}^2$
Package thickness: $T_{mCube} = 0.9\text{mm}$
LGA package

Surface: $S_{Bosch} = 1.8\text{mm}^2$
Package thickness: $T_{Bosch} = 0.8\text{mm}$
WLCSP

Surface: $S_{mCube} = 4\text{mm}^2$
Package thickness: $T_{mCube} = 0.9\text{mm}$
LGA package

Surface: $S_{mCube} = 2.56\text{mm}^2$
Package thickness: $T_{mCube} = 0.94\text{mm}$
LGA package

Surface: $S_{mCube} = 1.21\text{mm}^2$
Package thickness: $T_{mCube} = 0.74\text{mm}$
WLCSP

70% reduction in package size enabled by 3D TSV and WLP

Driven by IoT, WLP will be one of the next key trends for MEMS and Sensors devices!
Other MEMS & sensors using TSV & WLP!

- Oscillator (2010)
- IMU 6-Axis Accelerometer (2015)
- Finger Print Sensor (2015)

TSV etch with DRIE (Silex Microsystems process)
- Polysilicon substrate
  - TSV diameter 6µm
  - TSV Depth 100µm

LGA package type
- TSV etch with DRIE
  - TSV diameter 6µm
  - TSV depth 150µm
  - TSV diameter 6µm

And much more to come!

TSV - VIA LAST approach is being used.
- TSV diameter 80µm
- TSV depth 200µm
- Tungsten lining is deposited with PVD.

TSV - VIA Middle approach is being used.
- TSV diameter 10µm
- TSV depth 85µm
- Similar AR as Silicon interposer (2,5D)
- Cu bottom-up filling is used like in TSV memory manufacturing
Conclusions
Conclusions and future perspectives

• MEMS & sensors are facing a strong demand driven by the consumer and cost pressure

• Wafer Level Packaging significantly reduces the sensor size and has an impact on the cost and performance

• New MEMS architectures are more and more required to achieve higher features and functionalities in smaller footprint

• Therefore, WLP and TSV are the key packaging technologies enabling to achieve innovative functions, higher performances as well as cost effective integration
Thank you for your attention!

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