MEMS & SENSORS PACKAGING

EVOLUTION

Presented by

Christophe Zinck
ASE Group
September 26th, 2013
Outline

1. Brief presentation of ASE Group
2. Overview of MEMS packaging
3. ASE MEMS packaging background and examples
4. Evolution to wafer level packaging (WLP)
5. ASE MEMS WLP toolbox
6. Conclusion
ASE Group: Business Units

Chairmen
Jason Chang
Richard Chang

ASE ATM
Tien Wu
COO

USI
Sam Liu
CEO

Real Estate

2012 revenues:
ASE ATM: $4.4B
USI: $2.1B
ASE group’s Role in the Manufacturing Value Chain

Unique for an OSAT!

- Material
- Assembly
- Wafer Bumping / Probing
- Final Test
- Module, Board Assembly & Test (DMS)
- Foundry
- Engineering Test
- Integrated Circuit Design

Services Offered by ASE Group

© ASE All rights reserved 2013
Business Models

ASE supports a range of business models:

*Consignment*
Customer consigns most components to ASE

*Buy & Sell*
USI buys all components and owns the module

**System Value**
- Lower
- Higher

**Supply chain management complexity (for customer)**
- Higher
- Lower

**ASE Group System liability**
- System design, test, software, ...
- Lower
- Higher
MEMS market: the big picture

Growing segments:

Mobile is booming:
- more functionalities
- high volume
- lower cost
- smaller size

Automotive:
- safety and driver assistance functions are well established
- large deployment from high end to standards cars
- new needs: car infotainment/car management
- need volume & quality

Medical:
- new big opportunity
- new challenges for packaging: bio-compatibility, size, self powered devices, etc...

MEMS assembly and test: 1.1B$ in 2012 \(\rightarrow\) 1.7B$ by 2016

In 2012, the backend assembly & test outsource rate is \(~35\%\)
\(\rightarrow\) Emerging fabless design house + outsource by IDM

MEMS & sensor packaging market is highly fragmented

© ASE All rights reserved 2013
MEMS are everywhere

**Automotive:**
MEMS & Sensors have drastically improved Automotive safety but not only...

**Safety (active or passive):**
- Collision avoidance
- Accident prevention
- Severity reduction

**Infotainment, environment:** environmental control (atmosphere, temperature, light, etc..), navigation, etc..

The intelligent vehicle is almost there!

**Medical:**
MEMS & Sensors are going to help us to stay healthy and improve treatments quality:
Need for autonomous / communicating Sensors / MEMS

**Mobile / Tablet:**
MEMS are everywhere in mobile: motion, environmental, light & display management
Many devices are burgeoning: gas, radiation, etc...

**Next big move?**
MEMS SiP modules to enable active communication between worlds...

**Human machine Interface**
MEMS / sensors SiP with BT, WiFi, WLAN, μbattery, energy Harvesting...

**Communicating Systems**

**Medical:**
MEMS & Sensors are going to help us to stay healthy and improve treatments quality:
Need for autonomous / communicating Sensors / MEMS

**Mobile / Tablet:**
MEMS are everywhere in mobile: motion, environmental, light & display management
Many devices are burgeoning: gas, radiation, etc...

**Automotive:**
MEMS & Sensors have drastically improved Automotive safety but not only...

**Safety (active or passive):**
- Collision avoidance
- Accident prevention
- Severity reduction

**Infotainment, environment:** environmental control (atmosphere, temperature, light, etc..), navigation, etc..

The intelligent vehicle is almost there!

**Medical:**
MEMS & Sensors are going to help us to stay healthy and improve treatments quality:
Need for autonomous / communicating Sensors / MEMS

**Mobile / Tablet:**
MEMS are everywhere in mobile: motion, environmental, light & display management
Many devices are burgeoning: gas, radiation, etc...

**Next big move?**
MEMS SiP modules to enable active communication between worlds...

**Human machine Interface**
MEMS / sensors SiP with BT, WiFi, WLAN, μbattery, energy Harvesting...

**Communicating Systems**

**Medical:**
MEMS & Sensors are going to help us to stay healthy and improve treatments quality:
Need for autonomous / communicating Sensors / MEMS

**Mobile / Tablet:**
MEMS are everywhere in mobile: motion, environmental, light & display management
Many devices are burgeoning: gas, radiation, etc...

**Next big move?**
MEMS SiP modules to enable active communication between worlds...

**Human machine Interface**
MEMS / sensors SiP with BT, WiFi, WLAN, μbattery, energy Harvesting...

**Communicating Systems**

**Medical:**
MEMS & Sensors are going to help us to stay healthy and improve treatments quality:
Need for autonomous / communicating Sensors / MEMS

**Mobile / Tablet:**
MEMS are everywhere in mobile: motion, environmental, light & display management
Many devices are burgeoning: gas, radiation, etc...

**Next big move?**
MEMS SiP modules to enable active communication between worlds...

**Human machine Interface**
MEMS / sensors SiP with BT, WiFi, WLAN, μbattery, energy Harvesting...

**Communicating Systems**
MEMS & Sensors applications

Applications are very diverse. Is standardization possible?

- Packaging needs to fulfill end-application requirements such as mechanical protection, electrical interconnection, thermal management, hermeticity, etc... ➔ Standardization is difficult from the perspective of application

- Leverage existing platforms (materials, process, equipment) to reduce cost & improve time to market. ➔ Standardization through packaging tool-box

Sensing applications

Voice / Sound
- Silicon microphones
- Gyroscopes
- Accelerometers
- Magnetometers
- Fusion sensor combos & IMUs

Motion / position
- Pressure-sensors
- TPMS modules

Pressure monitoring
- Micro-mirrors

Projecting / receiving Light
- Oscillators / Resonators
- RF-MEMS switches
- FBAR / BAW filters
- SAW filters

RF related functions
- Ink-jet MEMS modules
- Microfluidic & Bio-chips

Managing fluids
- Micro-Displays, MEMS

Emerging MEMS...
- Auto-focus actuators
- Humidity sensors

© ASE All rights reserved 2013
MEMS packaging requirements

**High performance** – key functional requirements (hermeticity, vacuum, etc...)

1 MEMS = 1 device = process = 1 package still apply

- Military, Aeronautic
- Medical
- Industrial
- High-end customer
- Home automation
- Automotive

**Market segments:**
- cost and performance

**Low cost** - Large volume enabling, dual sourcing

High need for Standardization and extend to medium performance devices

- Gaming
- Consumer

**Higher performance**

- Dedicated / customized BOM
- Complex and custom architecture - complex stacking, multiple dice
- Specific 1st level capping depending on functionality

**Price, size, low consumption pressure**

- New low cost solution for cavity/holed package (film assist, new lid)

**Functional requirement, high quality / reliability**

- Wafer level package – 3D integration

**Lower cost**

- Open substrate platforms
- BOM standardization - new solution for stress decoupling

- Leadframe
- COL (Chip On Lead)
- Laminate
- Gel Coat

© ASE All rights reserved 2013
Packaging Technology: Key to Success in MEMS

- MEMS proliferation: delicate balance between performance & cost
- New products through novel MEMS design, fab technology and innovative packaging
- Package–device interaction: Packaging is more important for MEMS than non-MEMS
  - Impact on performance
  - Impact on product cost
- Use common semiconductor packages with some level of customization for:
  - Stress decoupling
  - First level of packaging (direct contact with acting elements)
  - Assembly interconnect
ASE MEMS packaging overview

- Established Production experience:
  - **Since 1993**: Pre molded open cavity packages (cavity SO, cavity LGA, custom LF) for Pressure sensor, Humidity/Temp Sensor, Gyro sensor...
  - **Since 1996**: Overmolded packages (QFN, LGA, BGA, SOIC, SiP) for Motion sensor (Accelerometer, Gyro, Magnetometer), FBAR, Optical Sensor, Humidity/Temp sensor, Oscillator
  - **Since 2009**: LGA + Lid for pressure sensor, Microphone, Humidity Sensor, Gas detection sensor, High frequency devices
  - **Since 2010**: Chip to Wafer WLCSP for Oscillator, Accelerometer, Magnetometer, RF tuner...
  - **Since 2012**: cavity molded package Suitable for Humidity/Temp sensor, Gas detection sensor, Proximity sensor, Optical sensor ...

Several sites working on MEMS & sensors packaging (ASEKR, ASECL, ASEK, ASEM)
ASE production experience

ASE MEMS & sensors package platforms (% per month)

- LGA overmold: 53%
- SO: 16%
- WLCSP: 13%
- Cavity QFN (exposed die): 7%
- QFN overmold: 4%
- LGA with Cap: 7%

ASE MEMS & Sensors by application (% per mth)

- Inertial (Accelero, gyro): 63%
- Temperature / Humidity sensors: 7%
- Microphone: 7%
- Oscillators: 13%
- Others: 10%
ASE MEMS packaging mature solutions

- **Premold**
  - Wafer Saw
  - Premold
  - Die Attach
  - Wire Bond
  - Gel Fill
  - Lid Attach
  - Marking, T/F/S

- **Overmold Package**
  - (Multi die SiP: Repeat DB & WB)
  - Wafer
  - Wafer Back-grinding
  - Substrate
  - 1st Die Attach
  - 2nd Die Attach
  - Wire Bond
  - Mold, Marking
  - Singulation

- **Cavity mold (new)**
  - Wafer Saw
  - Die Attach
  - Wire Bond
  - Mold/PMC
  - Pin
  - Singulation

© ASE All rights reserved 2013
ASE MEMS packaging examples

• Side by side 3x3 LGA 16L for accelerometer + ASIC

![Actual Device]

• Stacked Oscillator on ASIC in a 2x2 QFN 4L with COL (Chip on Lead) for size reduction

![Actual Device]
ASE LGA cavity for Si microphone

**Current solution:** 2 or 4 layers LGA, top or bottom hole using adapted silicon gel. Lid available in stainless steel or plastic + metallization

Lid 3 substrate layers

(2) Metal lid
ASE Open Cavity for MEMS & Sensors

- Opening die surface with FAM (Film Assist Mold)
- Die exposed to outer environment
- Suitable for Humidity/Temperature sensor, Gas detection sensor, TPMS, Proximity sensor, Optical sensor ...
- QFN2X2 in Production since Jan.’13

Example for TPMS / Humidity Sensor

© ASE All rights reserved 2013
MEMS packaging evolution

- Market demand for integration of multiple MEMS devices: accelerometer, magnetometer, gyroscope & controller in the same package
- Heterogeneous integration - CMOS logic, memory, MEMS, passives, battery - is becoming key for communicant & autonomous MEMS SiP
- New requirements for safety devices are appearing – die redundancy within the same package
- There is a clear needs for high functionality package solutions (multi die – stack or side-by-side, thinner, heterogeneous integration, etc...) at reasonable cost & small size
- Wafer Level Packaging and more specifically WLP with 3D interconnection (TSV, TGV) are drive integration for size reduction, better electrical connection and cost
- Standardization will come from the 3D WLP toolbox
New needs:
- Wafer level capping
- W2W or C2W assembly
- Vertical interconnection (TSV, TGV)
- Wafer level redistribution and balling
Capping & TSV technologies are key for size & cost reduction. Both enables large scale collective manufacturing. Thin film capping can offer more degree of liberty (cap size ≠ device size) and thickness reduction benefit.
Evolution = Wafer Level Packaging

- MEMS & sensors integration requires active/sensing parts protection:
  - Growing need for Wafer Level capping either by wafer to wafer bonding or thin film wafer capping (bourgeoning)

- MEMS assembly is key:
  - Chip to chip is costly and technically limited
  - WLCSP is definitely a key advantage for size and cost reduction (e.g. magnetometer)
  - 3D WLP is the new big opportunity for size and cost reduction of complex devices

- Due to various functional requirements and device complexity → “standardization” will come from the 3D WLP ToolBox
ASE MEMS packaging toolbox evolution

Die attach (MEMS or ASIC) to wafer (MEMS or ASIC):
- WB (epoxy or tape attach), Cu or Au wires
- FC attach MR or TNCP, solder or Cu pillar, MUF, CUF

Wafer Level Molding:
- Wafer scale molding after either FC or WB

Wafer to wafer bonding (device capping):
- Top wafer: Si, Glass, active die wafer (dev)
- Bottom wafer: Si
- Bonding technology: polymer, glass frit
- On going (dev): metal bonding (solder, eutectic), thin film capping, wafer scale LCP lid

Molded wafer after die to wafer attachment
ASE MEMS packaging toolbox evolution

Capability to temporary bond wafer on carrier:
- Carrier type: Si
- Temporary adhesive material: spin coated polymer
- Max T: 220°C
Example: MEMS in CoW – In production

<table>
<thead>
<tr>
<th>Material</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Die thickness</td>
<td>Mother die (ASIC): 300 mil</td>
</tr>
<tr>
<td></td>
<td>Daughter die (MEMS): 200um</td>
</tr>
<tr>
<td>Bump pitch (MEMS)</td>
<td>145 um</td>
</tr>
<tr>
<td>Bump No.</td>
<td>ASIC: 6 / MEMS: 5</td>
</tr>
<tr>
<td>Application</td>
<td>oscillator</td>
</tr>
</tbody>
</table>

Bottom Die (RDL) (1.5x2.1 mm)

Top Die (FOC) (0.44x0.44 mm)

© ASE All rights reserved 2013
MEMS & sensor packaging & integration

3D WLCSP with 3D TSVs in MEMS

MEMS die

cap

MEMS die

3D Wafer-level capping with 3D TSV ASE cap

Thin film capping (overmoldable)

MEMS die

ASE Vision - MEMS & sensor packaging & integration

MEMS & sensor Capping by ASE

MEMS / sensor die

Clear compression molding (Optical DFN)

Exosed die flip chip QFN/LGA

MEMS / sensor die

Open QFN/LGA (open pre-molded plastic cavity)

MEMS / sensor die

Open cavity by FAM (overmold open cavity)

MEMS die

cap

MEMS die

chip on chip WLCSP

MEMS die

ASIC

WLCSP, MEMS capped at the wafer level by same size ASIC with TSV

WLCSP, any size MEMS on any size ASIC with TSV

Double flip chip QFN

LCP lids QFN/LGA

Antenna on package

aEASI 3D embedded

*note: in many of these figures, the ASIC and the MEMS positions can be interchanged

Exposed die flip chip QFN/LGA, TSVs in ASIC

Chip on Chip WLCSP, MEMS capped at the wafer level by same size ASIC with TSV

2012 2013 2014 2015

HVM readiness

© ASE All rights reserved 2013
ASE MEMS packaging evolution

Past

- Ceramic package for hermetic request
- Bulky form factor
- Solder sealing
- High cost
- Custom package

Present

- Device capping for hermetic or protection
- MEMS level capping
- Metal seal ring for bonding
- Over mold for final package

Present - Future

- NEW package for MEMS
- Open cavity package for consumer, automotive, industry (with MEMS capping)
- Lid package for mass production (MEMS microphone or pressure sensor)
- WLCSP MEMS – ASIC + MEMS: size reduction
- W2W MEMS capping
- 3D WLCSP (C2W)
- Wafer level sealing (W2W, metal bonding and sealing)
- 3D WLCSP for heterogeneous chip integrating (C2W)
- TSV implementation when needed
- Thin film level capping
- Size/cost reduction
- 3D WLP ToolBox “standardization”
Conclusion

- MEMS packaging accounts for 20-60% of the MEMS device BOM and is a key part of the MEMS function and design
- Packaging creates additional value as the MEMS device is integrated into a system (SiP, module)
- Standardization enables high volume production (second sourcing, cost efficiency through technology sharing)
- However, standardization is limited by large breadth of MEMS applications with specific requirements
- Standardization and differentiation are expected by the market → contradictory requirements
- Cost effective integration are achieved with MEMS Wafer Level Package
- Each MEMS WLP is unique. Standardization is in the toolbox
- ASE aims at helping to set the standard with differentiating solutions: WLP and 3D
Thank You

www.aseglobal.com