Thin Film Packaging For MEMS

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Outline

- MEMS requirements
- Thin Film Packaging an attractive solution
- What’s the TFP state of the art?
- TFP and low pressure specifications
- TFP vs wafer bonding: comparative cost analysis
- Conclusion
Leti at a Glance

1,700 researchers
190 PhD students + 34 post PhD with 70 foreign students (30%)

Over 1,700 patents
265 generated in 2010
40% under license

250 M€ budget
~ 40M€ CapEx

37 start-ups
& 265 industrial partners

200 and 300mm Si capabilities
8,000 m² clean rooms
Continuous operation
Problematic of MEMS packaging

MECHANICAL PROTECTION

- Particles
- Humidity
- Vibration
- Mechanical shock
- Thermal stress
- EM waves...

PHYSICAL / CHEMICAL IN (Sensor)

- Light
- Gas
- Pressure
- Acceleration
- Electromagnetic field...

ELECTRICAL IN

MOVING PARTS

VACUUM

GAS

FLUID

ELECTRICAL OUT

PHYSICAL OUT (Actuator)

Require specific & complex packages => Important overcost
Objective: To manage specificity at the wafer level (collective process)
Thin Film Packaging an attractive solution

- Many advantages compare to other packaging techniques:
  - Reduced area required for packaging
  - Very low thickness – tens of µm
  - Contact pad opening easy – no need for TSV
  - Process with standard equipments
  - No need for bonding tool
  - No need for second wafer

63% saving

33% saving
Thin Film Packaging categories

- Two main types of TFP depending on the sacrificial layers:
  - Mineral sacrificial material (most of the time the same as MEMS)
  - Organic sacrificial material

RF switches and accelerometers TFP with SiO$_2$ sacrificial layer [1]

- Organic sacrificial material

RF variable capacitor with 8 µm polymer sacrificial layer [3]

RF BAW filter with polymer sacrificial layer [4]

Resonator TFP with SiO$_2$ sacrificial layer [2]

RF BAW resonator with polymer? sacrificial layer [5]
LETI Thin Film Packaging process flow

- LETI mainly focus their developments with organic sacrificial layer to:
  - Minimize the thermal budget of the TFP process (<350 °C)
  - Be compliant with topology on MEMS substrate
  - Be less aggressive during the release process

- Schematic process flow:
  - Polymer sacrificial layer deposit & patterning
  - Sacrificial layer curing
  - Cap deposition
  - Release hole etching
  - Cap release
  - Cap sealing

- But what is the state of the art of this technology?
  - Back-end compatibility, mechanical structure, reliability, outgassing...
TFP and Back-end compatibility

- Electrical performances on BAW resonator [6]

Same electrical performances before and after TFP + back-end processes

But reinforcement layer mandatory to be compatible with overmolding (100 bars / 200 °C)
TFP and Overmolding compatibility

- LETI developed different reinforcement processes

- BAW resonator electrical performances not affected by 100 bars and 185 °C overmolding [6]

![Cap reinforcement with metal [6]](image1)
![Cap reinforcement with epoxy [6]](image2)
![Cap reinforcement with localized metal [7]](image3)

![Resonator + TFP + Cu 23µm](image4)
![Molding epoxy](image5)

- $F_{\text{series}} = 2.134 \text{ GHz}$
- $Q_{\text{series}} = 1200$
- $K_p^2 = 5.4\%$
TFP and low pressure specifications

- Impact of package miniaturization
  - Pressure increasing can come from:
    - Outgassing from materials inside TFP cavity (major factor)
    - $\mu$leak
    - Permeation

$$\frac{\text{Surface}}{\text{Volume}} = f(\text{Length}; \text{Height})$$

- Possible schemes to reach low pressure TFP cavities:
  - Optimized materials and outgassing process before sealing the cap
  - Implement getter materials
TFP and low pressure specifications

- Optimized materials and outgassing process before sealing the cap
  - Materials outgassing properties, one of the key parameter [8]

- Outgassing properties depend on: material itself, deposition process, thermal and process history...
  - Outgassing is critical above their thermal deposition temperature (mostly for PECVD materials)
  - SiN is a good outgassing barrier
TFP and low pressure specifications

- Optimized materials and outgassing process before sealing the cap
  - Chemical composition outgassing is another key parameter → RGA analysis mandatory

Sealed MEMS put in a High vacuum chamber

Open cavity in the chamber

Mass spectrometer

Analyze gas present in the chamber

Best outgassing process can now be defined
(max temperature, temperature ramp up, process time...)

2 benches available at Leti
(Resolution N₂ 0.3 - Ar 0.02pmoles)
TFP and low pressure specifications

- Implement getter materials

- But getter effect depends on gas present inside the cavity (better the outgassing, better the getter)

- Tunable activation temperature (to fit with sealing process)

Getter properties

N$_2$ sorbing capacity mbar.cm$^3$/cm$^2$

Activation temperature °C

<table>
<thead>
<tr>
<th>Getter</th>
<th>Activation Temperature °C</th>
<th>N$_2$ Sorbing Capacity mbar.cm$^3$/cm$^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>AuSi</td>
<td>200, 250, 300, 350, 400</td>
<td>0.15, 0.2, 0.25</td>
</tr>
<tr>
<td>AuSn</td>
<td>200, 250, 300, 350, 400</td>
<td>0.15, 0.2, 0.25</td>
</tr>
<tr>
<td>Anodic</td>
<td>200, 250, 300, 350, 400</td>
<td>0.15, 0.2, 0.25</td>
</tr>
<tr>
<td>SDB</td>
<td>200, 250, 300, 350, 400</td>
<td>0.15, 0.2, 0.25</td>
</tr>
</tbody>
</table>

Getter material is able to pump residual gases [13]

Leti catalog of getters
TFP and low pressure specifications

- **TFP sealing layer(s)**
  - Polymer sealing for device not working under vacuum (i.e BAW)
  - Metal(s) sealing is the most used sealing layer(s) for vacuum specs

**Polymer**

**Metallic sealing materials [9], [10]**

**SiO₂ sealing**

**Ti/Cu sealing materials [7]**

**Al sealing materials [8]**
TFP pressure performances summary

- Pressure measurement: Q factor monitoring
  - Few results published!

![Diagram showing TFP pressure performances with different thermal budgets and pressures.](image)
Comparative cost analysis

- Comparing between Wafer Level Packaging methods
  - Thin film packaging (standard) ~ 30 steps
  - Thin film packaging (with reinforcement) ~ 40 steps
  - Si cap packaging (polymer bonding) ~ 40 steps
  - Si cap packaging (with TSV) ~ 60 steps

- Evaluations based on a cost model taking into account:
  - Global process (die area, yields...)
  - Process flows (equipments CoO, operator time, consumables,...)
  - Clean room environment (HU, depreciation, footprint, production capacities...)
Comparative cost analysis: die area

Thin film packaging

Si cap packaging

1000µm X 700µm

1100µm X 800µm

Layout based on different constraints for the same design rules:

- Same electrical contacts geometries (120*120 µm) excepted for Cap with TSV
- Same distances between cutting line and electrodes
- Sealing strip 60µm thick

About 20% gain in die area achieved
Comparative cost analysis: results

Relative cost analysis

<table>
<thead>
<tr>
<th>Packaging technology</th>
<th>Relative cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>TFP</td>
<td>1.0</td>
</tr>
<tr>
<td>TFP reinforced</td>
<td>1.5</td>
</tr>
<tr>
<td>Si Cap (STR)</td>
<td>3.5</td>
</tr>
<tr>
<td>Si cap with TSV</td>
<td>4.0</td>
</tr>
</tbody>
</table>

- Thick Cu ECD
- TSV DRIE Align / Bonding
- Align / Bonding
Conclusion

Today Thin Film Packaging:
- Low cost packaging technique
- Clearly compatible with device working at near atmospheric pressure (depending on the atmosphere specs)
- Overmolding compatible
- Vacuum packaging demonstrated until $10^{-3}$ mbar [9]

Trends:
- Optimize TFP to be compatible with vacuum devices (gyro, accelerometer...)
- Develop TFP with controlled atmosphere
- Perform reliability testing
References