MEMS Microphones

iPhone X

MEMS report by Audrey LAHRACH
March 2018 – version 1
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Executive Summary

This full reverse costing study has been conducted to provide insight on technology data, manufacturing cost and selling price of the three different microphones found in iPhone X.

For microphone integration in the iPhone X, Apple has chosen the market’s top three microphone suppliers: Goertek, Knowles, and AAC Technologies.

The Apple iPhone X has four MEMS microphones: a front-facing top microphone, two front-facing bottom microphones, and a rear-facing top microphone. This layout is similar to previous iPhones, but the front-facing bottom-right microphone is now integrated in the speaker module. All four microphones share the same Apple-specific package dimensions, but with a different internal structure (number of substrate metal layers, embedded capacitance, ASIC, etc.).

In the iPhone X, we’ve observed changes to the microphones provided by Apple’s three suppliers:

- Goertek, which still relies on Infineon for die manufacturing, integrates Infineon’s technology with a double backplate, delivering a differential MEMS microphone. For the ASIC, Goertek has considerably reduced the die area by around 40% compared to the previous die.

- Knowles uses the same technologies as before, but one part has a new MEMS design and another part has an existing MEMS design.

- AAC uses the same MEMS microphone die as Goertek, but with a different ASIC.

Infineon is a big winner. By providing ASIC and MEMS dies to all of Goertek’s and AAC Technologies’ products, it now possesses a large share of the MEMS microphone market.

This report includes a complete comparison of the three suppliers’ microphones in terms of structure, process, and cost.
Executive Summary

The reverse costing analysis is conducted in 3 phases:

- **Teardown analysis**
  - Package is analyzed and measured
  - The dies are extracted in order to get overall data: dimensions, main blocks, pad number and pin out, die marking
  - Setup of the manufacturing process.

- **Costing analysis**
  - Setup of the manufacturing environment
  - Cost simulation of the process steps

- **Selling price analysis**
  - Supply chain analysis
  - Analysis of the selling price
Package Views & Dimensions

- **Package**: LGA 7-pin
- **Dimensions**: 3.33 x 1.96 x 0.82mm
- **Acoustic port**: 0.36mm
- **Marking**: L 170

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Package Opening

- Package opening reveals two dies connected together and to the PCB by wire bonding process.
- The ASIC die is covered with a glob-top and glued with an xxx.
- The MEMS die is glued with an xxx.

- Wire bonding number:
  - Nb between ASIC & Package: x
  - Nb between MEMS & ASIC: x

- Material: xxx
- Diameter: xx µm
- Length: xxµm
Package Cross-Section

Package total thickness: 0.xx mm
- PCB thickness: 0.xx mm
- Microphone die thickness (without adhesive): 0.xx mm
- ASIC Die thickness (without adhesive): 0.xx mm
- Metal lid thickness: 0.xx mm

Cross-Section Overview – Optical View

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ASIC Die View & Dimensions

Die Area: \( \text{xxmm}^2 \)
(\( \text{xxx x xxxmm} \))

Nb of PGDW per 8-inch wafer: \( \text{xxxx} \)
(assuming \( \text{xx\mu m} \) scribe line)

Pad number: \( \text{x} \)
- Connected: \( \text{x} \)

PGDW: Potential Good Dies per Wafer

The die marking includes:

---

Die Overview – Optical View
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ASIC Die Process

The process uses CMOS transistors.

MOS transistor gate length: \( x \mu m \)

Minimum size (technology node): \( x \mu m \)
MEMS View & Dimensions

Die Overview – Optical View
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Die Area: $\text{xxx mm}^2$
(xx x xxmm)

Nb of PGDW per 8-inch wafer: $\text{xxxx}$
(assuming 40µm scribe line)

Pad number: x
  - Connected: x

PGDW: Potential Good Dies per Wafer

The MEMS marking includes:

xxxx

Knowles Logo

MEMS Die Markings
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MEMS Cross-Section – Bond Pad

MEMS Cross-Section Overview
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### ASIC Front-End Cost

<table>
<thead>
<tr>
<th>Front-End</th>
<th>Goertek GWM1</th>
<th>Knowles KSM1</th>
<th>AAC ALM1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cost</td>
<td>Breakdown</td>
<td>Cost</td>
</tr>
<tr>
<td>Raw wafer Cost (Si)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clean Room Cost</td>
<td></td>
<td></td>
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<tr>
<td>Equipment Cost</td>
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<td>Consumable Cost</td>
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<tr>
<td>Labor Cost</td>
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<tr>
<td>Yield Losses Cost</td>
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<tr>
<td><strong>Wafer Front-End Cost</strong></td>
<td></td>
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</tr>
<tr>
<td>Foundry Gross Profit</td>
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<td></td>
<td></td>
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<tr>
<td><strong>Wafer Front-End Price</strong></td>
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</tbody>
</table>

- The **unprobed wafer cost** is estimated at $\text{xxx}$ for GWM1 ASIC, at $\text{xxx}$ for KSM1 ASIC and at $\text{xxx}$ for AAC ALM1.

- The **main part** of all wafer cost is due to the $\text{xxxx}$ with $\text{xxx}\%$.

- We consider a **foundry gross profit** of $\text{xx}\%$ which result in a **wafer price** of $\text{xxx}$ for GWM1 ASIC, of $\text{xxx}$ for KSM1 ASIC and of $\text{xxx}$ for AAC ALM1.
ASIC Die Cost

<table>
<thead>
<tr>
<th>Goertek GWM1</th>
<th>Knowles KSM1</th>
<th>AAC ALM1</th>
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</thead>
<tbody>
<tr>
<td>Cost</td>
<td>Breakdown</td>
<td>Cost</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cost</td>
</tr>
</tbody>
</table>

- The number of **good dies per wafer** is estimated at **xxx** for Goertek GWM1 ASIC, at **xxx** for Knowles KSM1 ASIC and at **xxx** for AAC Technologies ALM1 ASIC, which results in a respectively die cost of **$xxx**, **$xxx** and **$xxx**.
MEMS Die Cost

<table>
<thead>
<tr>
<th></th>
<th>Goertek GWM1</th>
<th>Knowles KSM1</th>
<th>AAC ALM1</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cost Breakdown</strong></td>
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<td></td>
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<tr>
<td>Front-End Cost</td>
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<tr>
<td>BE: Probe Test</td>
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<tr>
<td>BE: Dicing Cost</td>
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<tr>
<td>BE: Yield losses</td>
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<tr>
<td><strong>Die Cost</strong></td>
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</tbody>
</table>

- The number of good dies per wafer is estimated at $xxx for Goertek GWM1 ASIC, at $xxx for Knowles KSM1 ASIC and at $xxx for AAC Technologies ALM1 ASIC, which results in a respectively die cost of $xxx, $xxx and $xxx.
### Package Cost

<table>
<thead>
<tr>
<th>Package Manufacturing</th>
<th>Goertek GWM1</th>
<th>Knowles KSM1</th>
<th>AAC ALM1</th>
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</thead>
<tbody>
<tr>
<td>Substrate Cost</td>
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<tr>
<td>Clean Room Cost</td>
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<tr>
<td>Yield Losses Cost</td>
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</tbody>
</table>

The packaging cost is estimated at $xxx for Goertek GWM1, at $xxx for Knowles KSM1 and at $xxx for AAC Technologies ALM1.

The largest portion of the manufacturing cost is due to xxx cost at xx%.
Component Cost

The component cost is estimated at $xxx for Goertek GWM1, at $xxx for Knowles KSM1 and at $xxx for AAC Technologies ALM1.
Estimated Selling Price

<table>
<thead>
<tr>
<th></th>
<th>Goertek GWM1</th>
<th>Knowles KSM1</th>
<th>AAC ALM1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Breakdown</td>
<td></td>
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</tr>
</tbody>
</table>

### Component cost

- xxx Gross Profit

### Component price

- We estimate that suppliers realizes a gross margin of xx% on the component, which results in a final component price estimated at $xxx for Goertek GWM1, at $xxx for Knowles KSM1 and at $xxx for AAC Technologies ALM1.

- This corresponds to the selling price for large volume to OEMs.
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- Vesper VM1000 Piezoelectric Microphone
- STMicroelectronics MEMS Microphone iPhone 7
- Knowles MEMS Microphone iPhone 7
- Goertek MEMS Microphone iPhone 7

**MARKET AND TECHNOLOGY REPORTS - YOLE DÉVELOPPEMENT**

**MEMS**
- Acoustic MEMS and Audio Solutions May 2017

**PATENT ANALYSIS - KNOWMADE**

**MEMS**
- Knowles MEMS Microphones in Apple iPhone 7 Patent
- Product-to-Product Mapping
Business Models Fields of Expertise

- Custom Analyses
  (>130 analyses per year)
- Reports
  (>40 reports per year)
- Costing Tools
- Trainings

Companies Profile
- Goertek GWM1
- Knowles KSM1
- AAC ALM1

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