MULTIPLY YOUR INNOVATION
AND MAXIMIZE YOUR POTENTIAL

MULTIPLY YOUR KNOWLEDGE

Intel Developer FORUM
Non-conventional cooling solutions for low power components

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Agenda

• Drivers and background

• Piezo cooling capability

• Technology advancements:
  • Low voltage operation
  • Size reduction
  • New materials

• Cost data

• Call to action
Technology Drivers and Background

- Moore’s law
- ITRS Road Map
- Piezo introduction
- Piezo advantages
Background

• Conventional air cooling continues to work for Intel mainstream CPU products due to a combination of new architecture and 45 nm.

• Intel is committed to enable innovative cost effective energy efficient cooling solutions.

• Market diversification brings unique challenges.

• Cost and size reduction are technology drivers for some market segments.

• Intel has continued to develop new innovative demonstrations cases using the Piezo technology.
Moore’s Law

“Will it be possible to remove the heat generated by 10’s of thousands of components?”
G. Moore, *Cramming more components onto integrated circuits*, Electronics, Volume 38, Number 8, April 19, 1965

*Moore’s Law is still working!*
Drivers: ITRS 2005 Road Map - Mobility

Increased performance with low system cost is needed!

*Data adapted from the 2005 International Technology Road Map for Semiconductors*
A piezoelectric material changes its dimensions and can bend a substrate under an electric field.

Resonant vibration of small plates generate airflow!
Why Consider Piezo?

- **Low cost**
  - Made of inexpensive ceramic
  - No rotary parts (i.e. no bearings)
  - Simple circuitry

- **Low power & Low noise**
  - Power Consumption < x10 vs. conv.
  - Efficiency conversion > 99%
  - Operate at < 100 Hz

- **Performance & Reliability**
  - Can cool low power components
  - Accommodate low z-height
  - Preliminary reliability promising
Piezo – Area of Investigation

Thermal Design Power Distribution
Some Typical Component Power

Piezo Applications

Source: Intel

Piezo Technology - investigated for low power components!
Piezo Cooling Phenomena

**Air Flow generation**
Resonant blades movement generate air flow
Generates low pressure air
Piezo flow may be add to existing system flow

**Direct thinning of the boundary layer**
“Rake Piezo”- blades intertwined between fins
Blade disturbs the thermal boundary layer
Low cost single piezo patch used

**Impingement flow**
Piezo blowers & Synthetic Jets use diaphragms
Accommodate low z-height
Skin cooling
Localized cooling of small power components

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Piezo cooling capability

- Small form factor data
- Comparison vs. Conventional Fan
Piezo Small Form factor - Test set-up

(A) Six exposed Dies in enclosure 46 x 96 x 12 mm

(B) Heat Pipe Spreader

(C) Micro Heat Sink (MHS)

Components (x6)

Vents

Enclosure

Piezo Actuator

* Photos used with permission from Fujikura Ltd.
Cooling capability data point

Piezo can bring significant improvements in SFF!

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Piezo Large Form factor - Test set-up

**Conventional solution**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heater size</td>
<td>10 x 10 mm</td>
</tr>
<tr>
<td>Heat input</td>
<td>35 W</td>
</tr>
<tr>
<td>Piezo voltage</td>
<td>115 V</td>
</tr>
<tr>
<td>Piezo frequency</td>
<td>60 Hz</td>
</tr>
<tr>
<td>Rotary fan voltage</td>
<td>8 V (DC)</td>
</tr>
</tbody>
</table>

**Piezo fan solution**

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Test Results- Piezo vs. Axial Fan

**Comparison of power consumption,**
10x10 mm heater, Q=35 W

**Comparison of Fan noise,**
10x10 mm heater, Q=35 W

*Piezo - Low power consumption at reasonable performance!*

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Thermal test setup in a chassis

**Heat sink proto-types**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat sink dimension</td>
<td>36x66x35 mm</td>
</tr>
<tr>
<td>Fin plate thickness</td>
<td>0.5 mm</td>
</tr>
<tr>
<td>Heat sink material</td>
<td>Aluminum</td>
</tr>
<tr>
<td>Heater size</td>
<td>10 x 10 mm</td>
</tr>
<tr>
<td>Heat input</td>
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</tbody>
</table>

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Optimum fin gap

Optimum fin gap 2.0 mm was confirmed in this test!

Thermal Performance, Q=35W, MCH-HS, In chassis, Vertical, Crimped, 4 Blades

Optimum performance

CPU Fan rpm
- 0 rpm
- 1200 rpm
- 2500 rpm

Optimum fin gap 2.0 mm was confirmed in this test!

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Thermal performance enhancement

**Piezo can bring major improvements at no or low air flow!**

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Technology Advancements

- Low Operating Voltage
- Small size
- Drag reduction
- Cost reduction
Elongation = N * Strain * V

where:
N = the number of stacked piezoelectric layers,
Strain = the piezoelectric strain coefficient,
V = the applied voltage.

### Multilayer Piezo Fan Concept/Test Data

<table>
<thead>
<tr>
<th>Piezo</th>
<th>Voltage $[V_{pp}]$</th>
<th>Frequency $[Hz]$</th>
<th>Blade stroke $[mm]$</th>
<th>Power $[mW]$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Layer</td>
<td>65</td>
<td>46</td>
<td>26</td>
<td>7</td>
</tr>
<tr>
<td>10 layer</td>
<td>6.3</td>
<td>41.5</td>
<td>25</td>
<td>6</td>
</tr>
<tr>
<td>30 layer</td>
<td>12</td>
<td>43.5</td>
<td>26</td>
<td>82</td>
</tr>
<tr>
<td>50 layer</td>
<td>10</td>
<td>44.5</td>
<td>13.5</td>
<td>98</td>
</tr>
</tbody>
</table>

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The multi layer piezo performance

Multilayer: Significant voltage reduction & better stroke!

Amplitude vs. Input Voltage at resonance frequency

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"Rake Piezo" performance summary

[Bar chart showing "Rake Piezo"-thermal performance:
- Piezo Off: 2.5°C/W
- Piezo On (No Gap Optimization): >200% Improvement on 2.5°C/W
- Piezo On (Gap Optimization): 0.5°C/W

Significant performance improvements!

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Rake Piezo – Combined with existing Air Flow

Significant thermal improvements at low air flow!
Problem when using piezo fans between side walls

Air drag increases as side gap decreases.

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Problem when using piezo fans between side walls

Air drag increase by side walls makes amplitude smaller.

Blade length: 20mm

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Air drag reduction (1): Blade with slit

Air drag decreases with slit

Slit in blade reduces air drag.

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Reduction of Air Drag Effect (2): weight on tip

Optimizing blade shape enables large amplitude. It eventually enables size reduction or voltage reduction.

Input Voltage [V] vs. Amplitude of Blade Tip [mm]

Side Gap: 0.5mm

Further Improvement

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Improvement of Heat Transfer: Blade with Slit

Temperature distribution without blade

Temperature distribution with moving slit blade

Vibration of the blade with a slit enhances heat removal > x2.

Q_{wall} = 410 [W/m^2]

Q_{wall} = 850 [W/m^2]

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## Cost of Piezo

<table>
<thead>
<tr>
<th>Size</th>
<th>60×45×0.5mm</th>
<th>6.5×4×0.15mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>&lt; $ 0.8</td>
<td>&lt; $ 0.3</td>
</tr>
</tbody>
</table>

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**Cost is low!**
Summary- Piezo Cooling

• Intel, along with its major suppliers such as Fujikura, Furukawa and Murata, is developing trouble-free non-conventional thermal solutions

• Significant cooling performance at low cost

• Novel “Rake Piezo” is effective in performance

• Novel designs can make it short length with large amplitude

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Additional sources of information on this topic:

This Session presentation (PDF) is available from www.intel.com/idf. Some sessions will also provide Audio-enabled presentations after the event.
Call to Action!

• OEMs/ODMs – engage with Intel to evaluate piezo for cooling low power components or skin cooling.

• Piezo integrators and suppliers - form complex teams of materials, thermal and mechanical engineers to focus on the piezo challenges.

• Interact with Intel to develop and apply trouble free cooling solutions.

• You have been presented an alternative low cost cooling solution.

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Thanks to all contributors!

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Backup Slides
Thermal performance definition

\[ \theta_{sr} = \frac{T_s - T_{room}}{P[W]} \]

- \(T_s\) = Sink Temperature [°C]
- \(T_{room}\) = Room temperature [°C]
- \(P\) = Chipset Power [W]