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Leap ahead

MULTIPLY YOUR INNOVATION
AND MAXIMIZE YOUR POTENTIAL

MUTIPLY YOUR KNOWLEDGE

Intel Developer
FORUM

Agenda

- **Drivers and background**

- **Piezo cooling capability**

- **Technology advancements :**
  - Low voltage operation
  - Size reduction
  - New materials

- **Cost data**
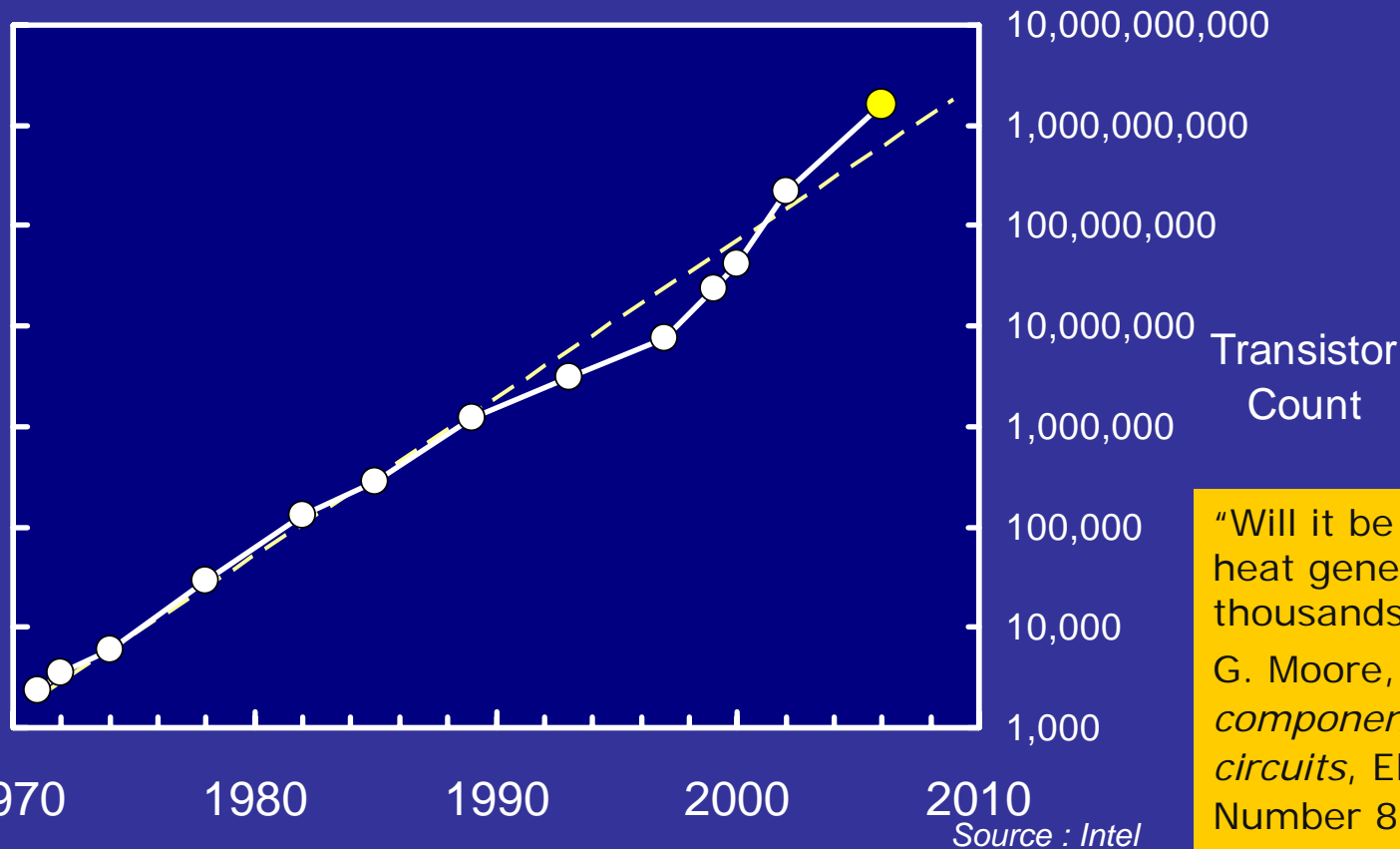
- **Call to action**

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

10,000,000,000
1,000,000,000
100,000,000
10,000,000
1,000,000
100,000
10,000
1,000

Transistor Count

1970   1980   1990   2000   2010

Source : Intel

"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
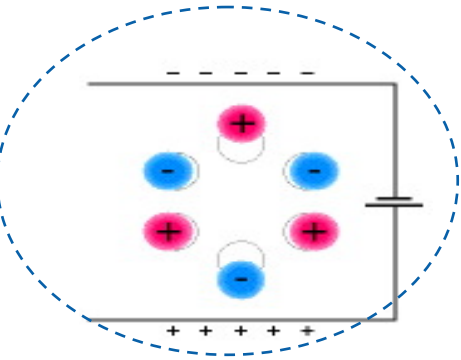
Moore's Law is still working!
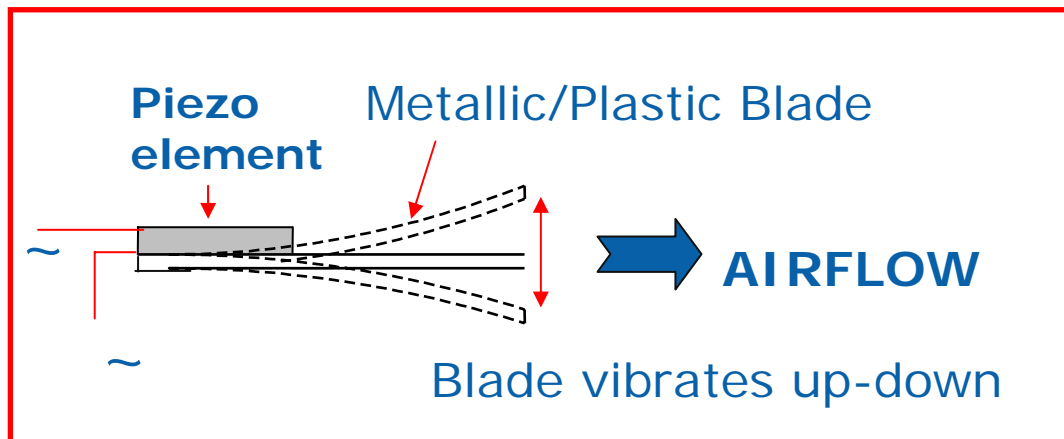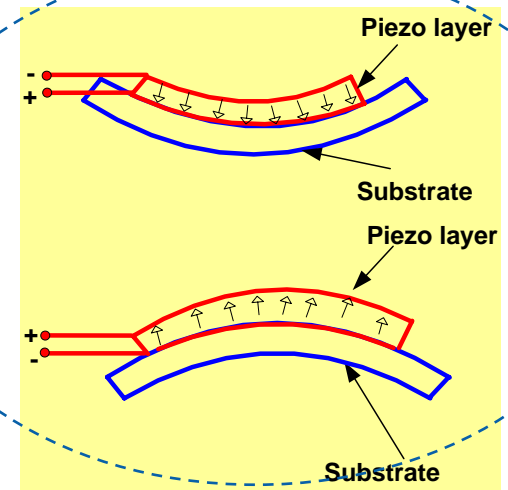
Drivers : ITRS 2005 Road Map- Mobility
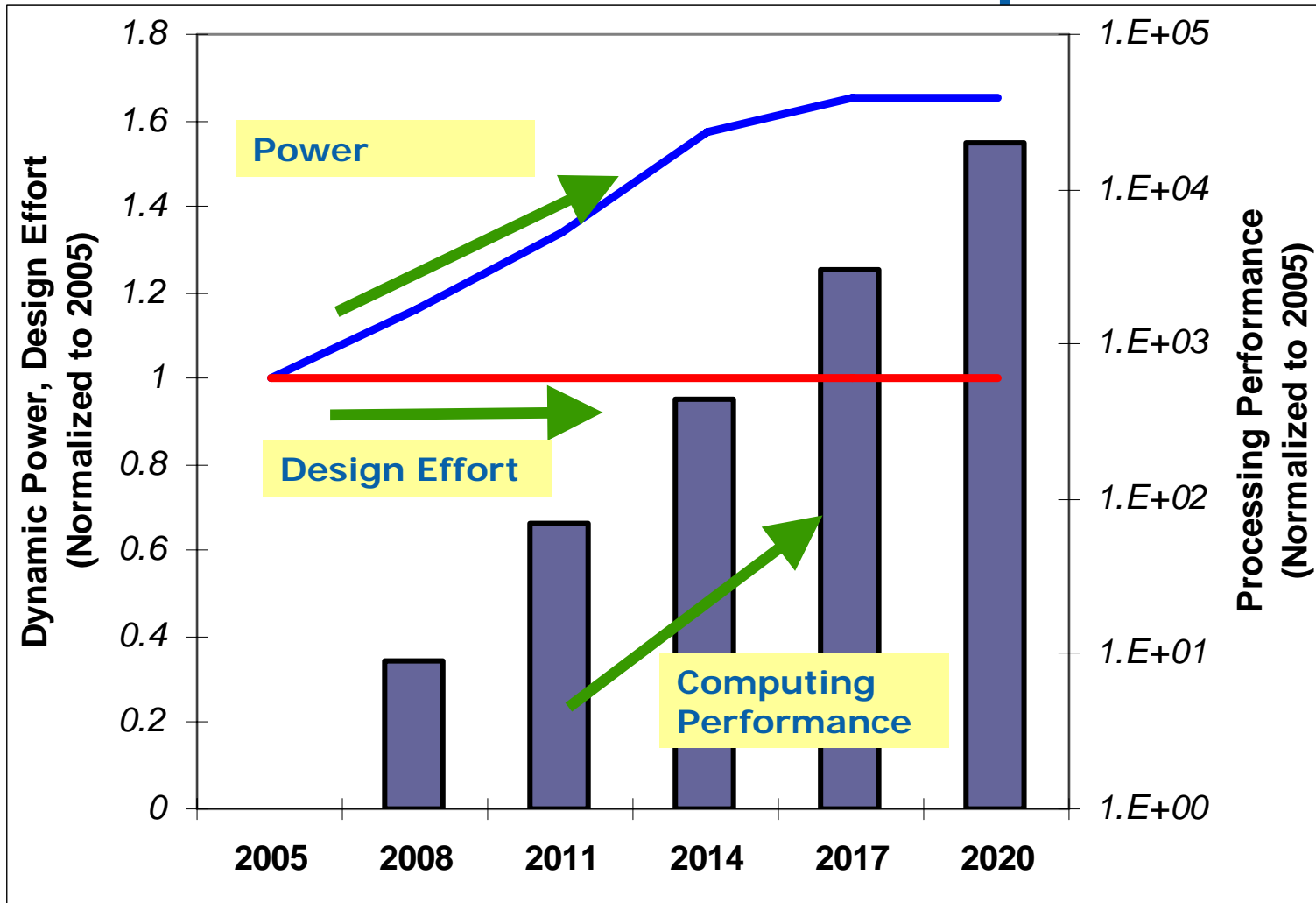
Increased performance with low system cost is needed!

"Data adapted from the 2005 International Technology Road Map for Semiconductors

Technology Introduction

A piezoelectric material changes its dimensions and can bend a substrate under an electric field

Piezo layer

Substrate

Piezo layer

Substrate

Piezo element

Metallic/Plastic Blade

~

~

AIRFLOW

Blade vibrates up-down

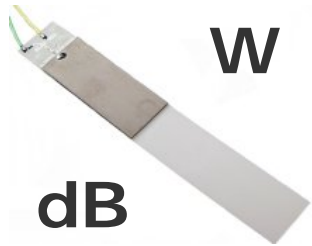*Resonant vibration of small plates generate airflow!*

Why Consider Piezo ?

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

W **Low power
&
Low noise**

dB ▶ **Power Consumption < x10 vs. conv.
Efficiency conversion > 99%
Operate at < 100 Hz**

°C/W **Performance
&
Reliability**

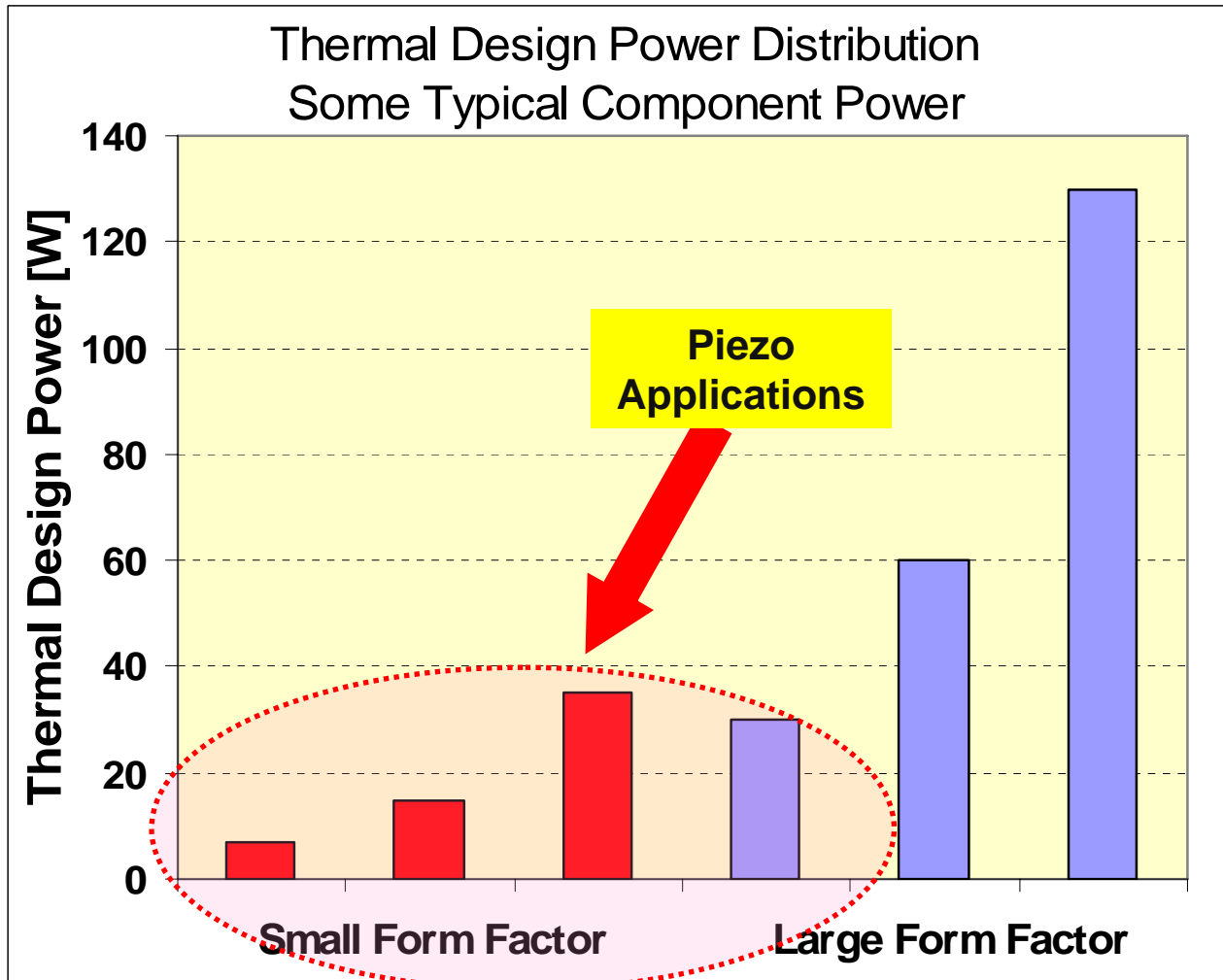**Life** ▶ **Can cool low power components
Accommodate low z-height
Preliminary reliability promising**

Piezo – Area of Investigation

Thermal Design Power Distribution
Some Typical Component Power
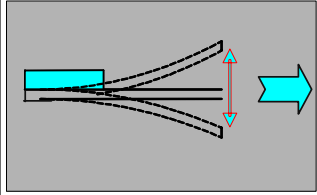
Piezo Applications

Small Form Factor
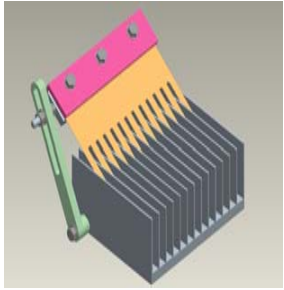
Large Form Factor

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
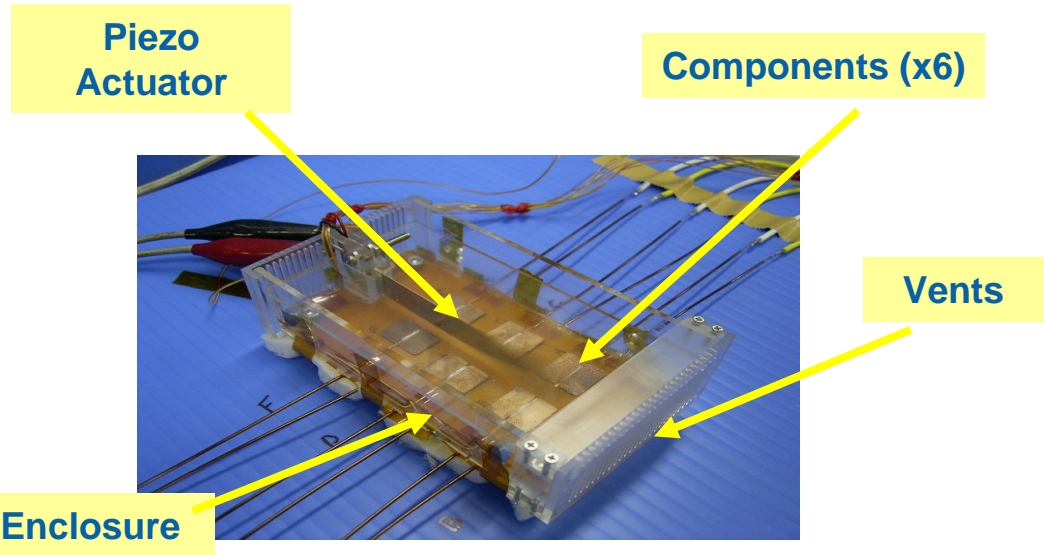Localized cooling of small power components

* Photos used with permission from Furukawa Ltd. , Fujikura Ltd., Murata Ltd.

Piezo cooling capability

- **Small form factor data**

- **Comparison vs. Conventional Fan**

Piezo Small Form factor -Test set-up

Dimensions: 26.04, 8, 7.25, 16.65, 36.8, 36.5, 56.4, 96, A, B, C, D, E, F, 10.37, 28.05, 46

Piezo Actuator

Components (x6)

Vents
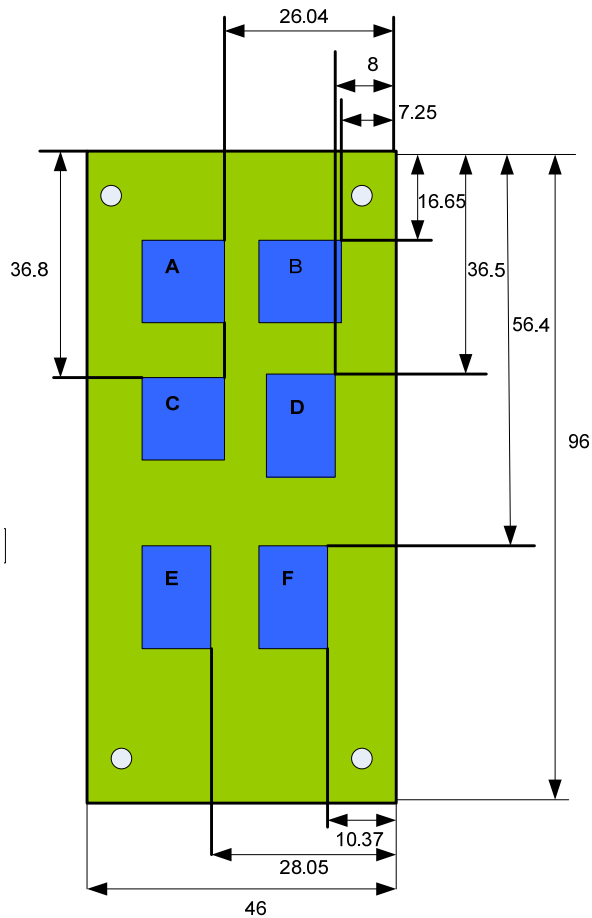
Enclosure

(A) Six exposed Dies in enclosure 46 x 96 x 12 mm
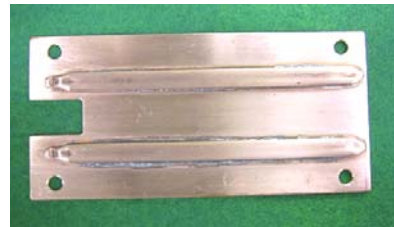
(B) Heat Pipe Spreader

(C) Micro Heat Sink (MHS)

" Photos used with permission from Fujikura Ltd.

Fujikura

Cooling capability data point

" Photos used with permission from Fujikura Ltd.

Power Dissipation Capability
- Components/Skin Cooling -
Enclosure data - Tj=100 deg. C; Ta=40 deg. C

Source : Intel

Chart: Power Dissipation Capability [W] (y-axis 0.0 to 9.0)

Legend: Component Power, Total Power

Category	Component Power	Total Power
No Piezo (bare)	~0.65	~2.9
Piezo (bare)	~1.1	~4.9
Piezo (MHS)	~2.2	~7.15
Piezo(Spreader)	~2.6	~8.5
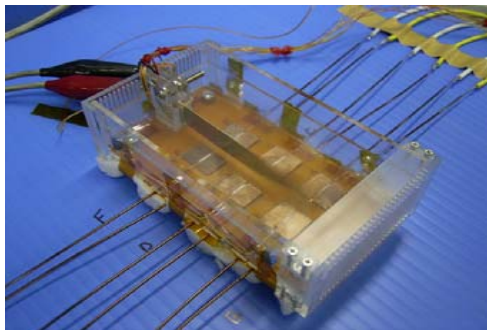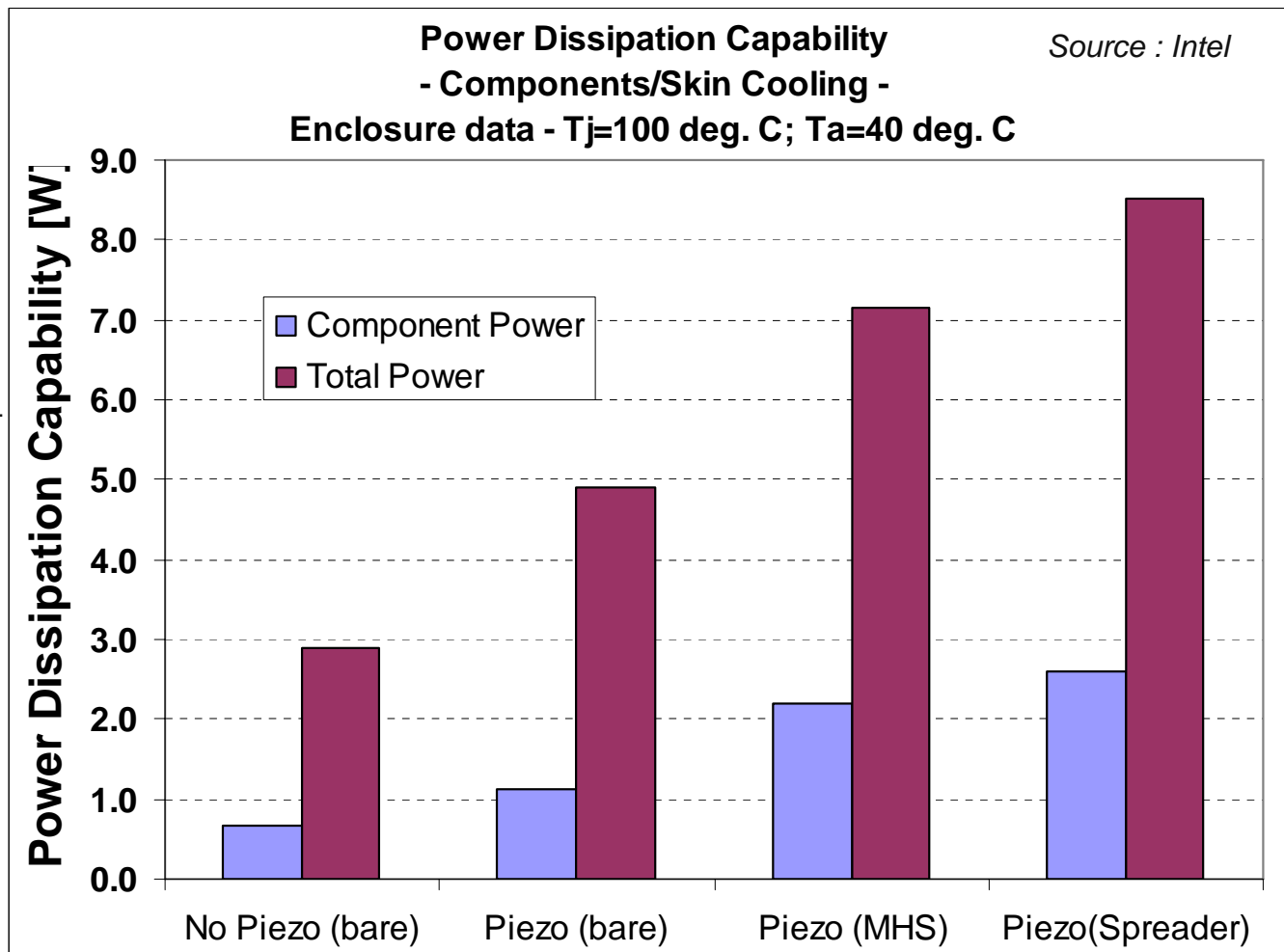
Piezo can bring significant improvements in SFF!

Fujikura

Piezo Large Form factor -Test set-up

Rotary fan

Heat sink

Single fan

Piezo fan

Heat sink
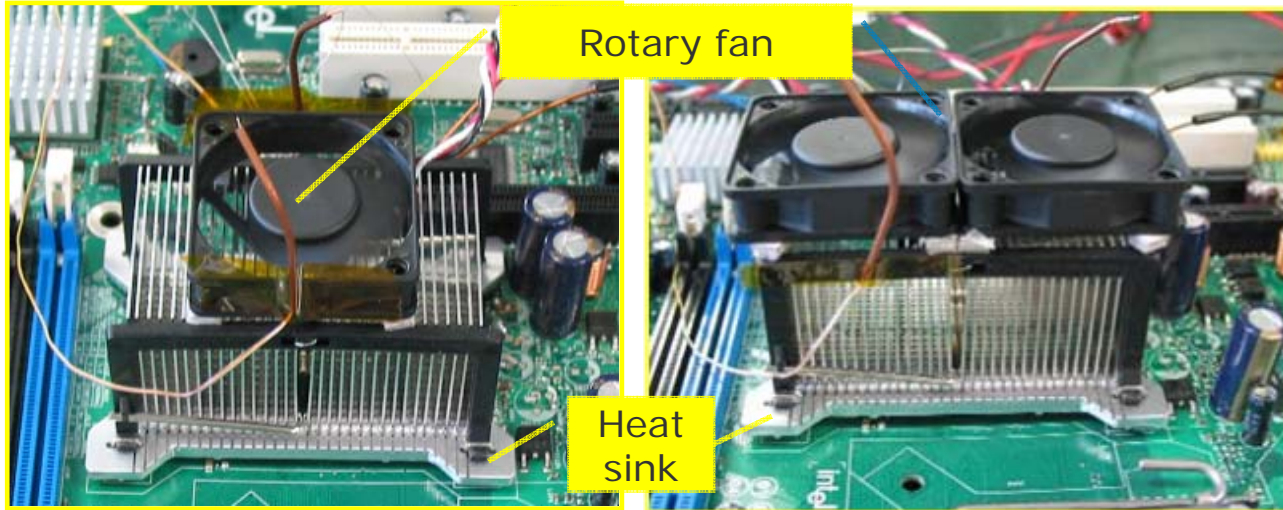
Twin fan

Conventional solution

Piezo fan solution

Heater size	10 x 10 mm
Heat input	35 W
Piezo voltage	115 V
Piezo frequency	60 Hz
Rotary fan voltage	8 V (DC)
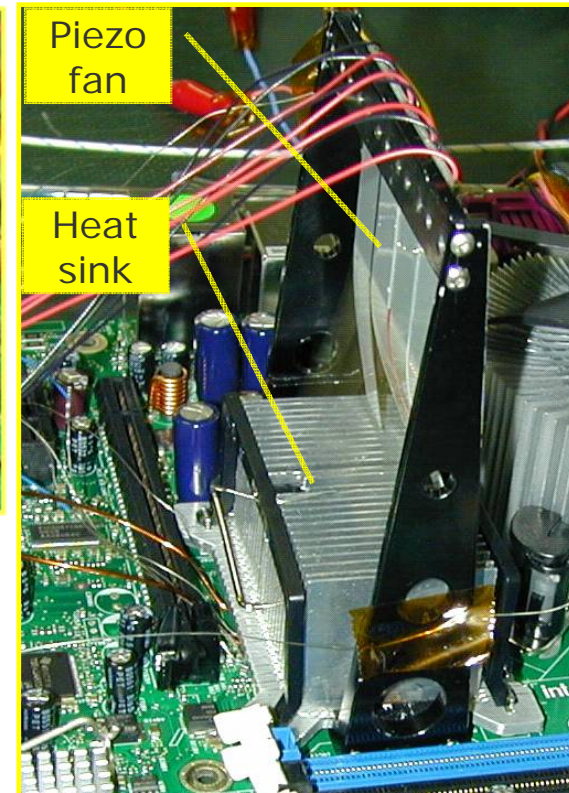
" Photos used with permission from Furukawa Ltd.

Test Results- Piezo vs. Axial Fan

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

- Power consumption
- Thermal performance

50% Improv.
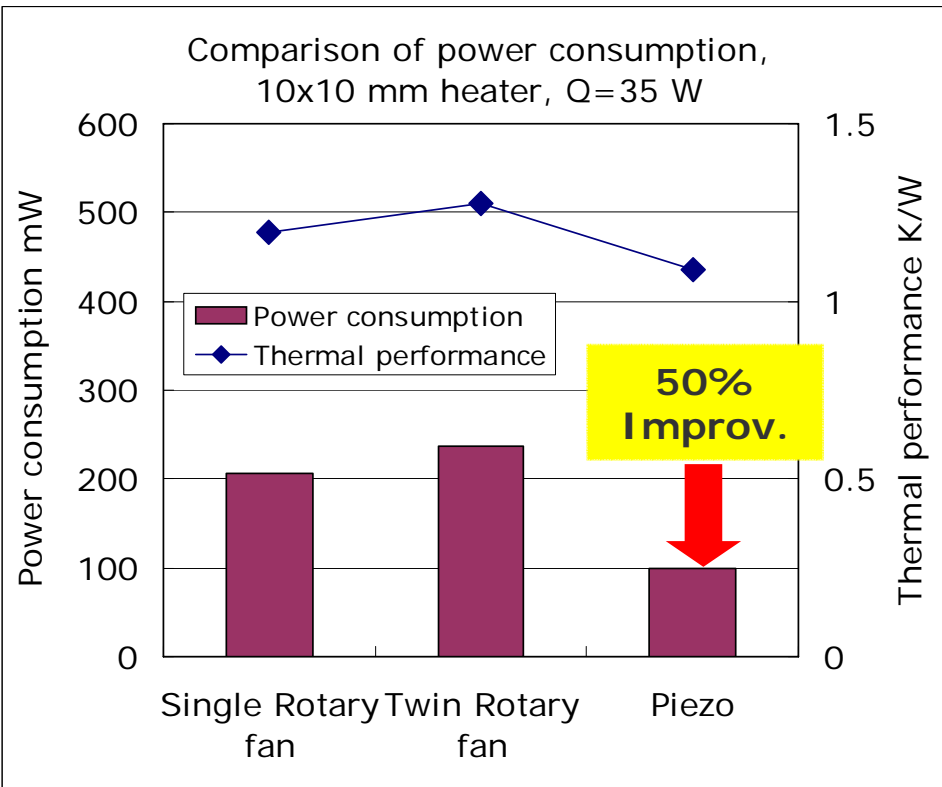
Fan power and thermal resistance

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

Similar performance

- Fan noise
- Thermal performance
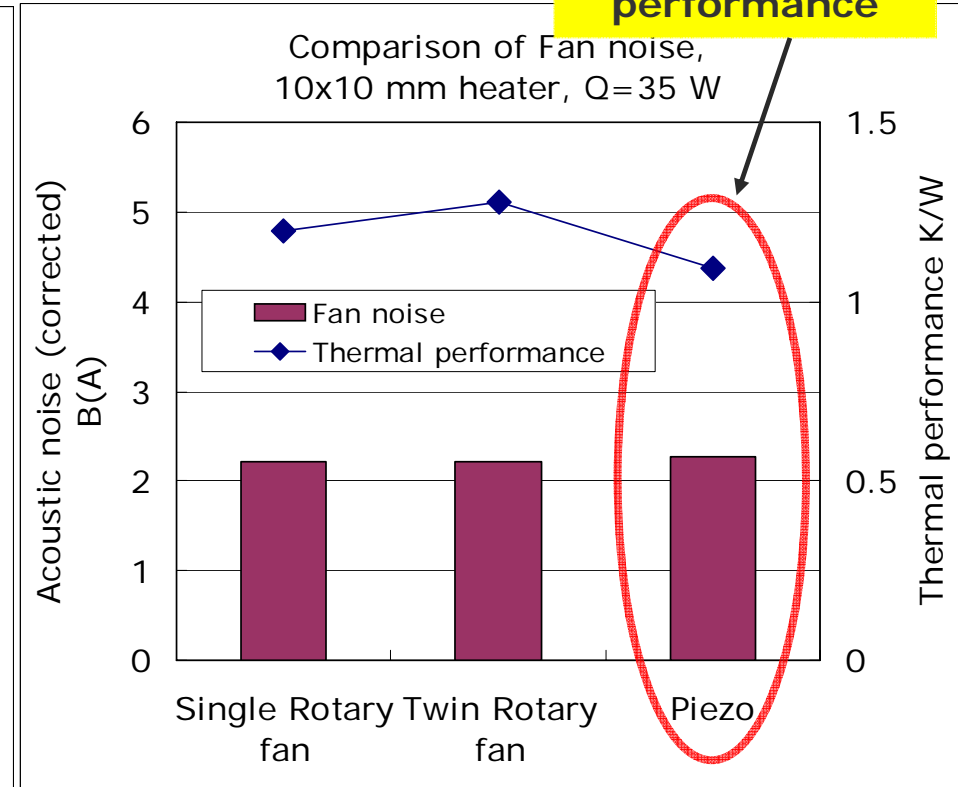
Fan noise and thermal resistance

Piezo - Low power consumption at reasonable performance!

"Data used with permission from Furukawa Ltd.

Thermal test setup in a chassis
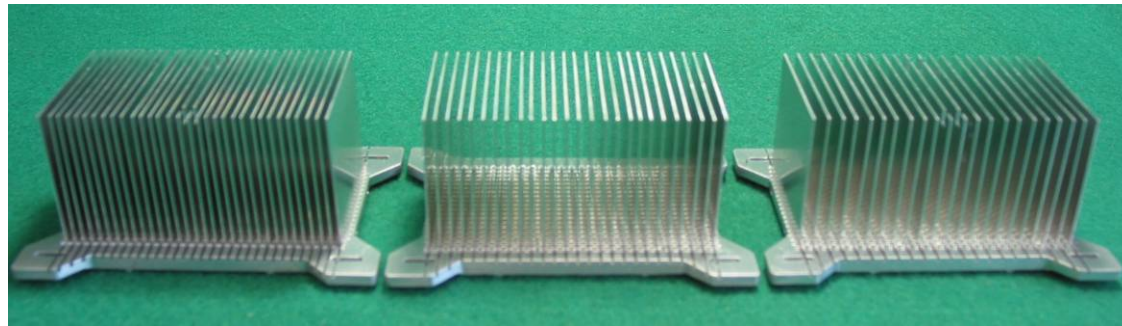
Gap 1.5 mm   Gap 2.0 mm   Gap 2.5 mm

Heat sink proto-types

Heat sink dimension	36x66x35 mm
Fin plate thickness	0.5 mm
Heat sink material	Aluminum
Heater size	10 x 10 mm
Heat input	35 W
Piezo voltage	115 V
Piezo frequency	60 Hz
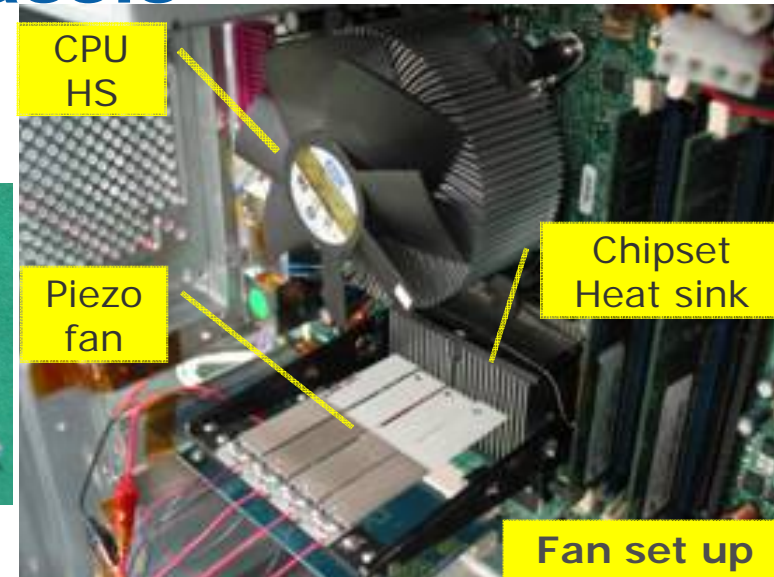
" Photos used with permission from Furukawa Ltd.

CPU HS
Piezo fan
Chipset Heat sink
Fan set up

System Test setup

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Optimum fin gap

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

CPU Fan rpm
- ◆ 0 rpm
- ■ 1200 rpm
- ● 2500 rpm

Optimum performance

X-axis: Fin gap [mm]
Y-axis: Thermal Performance [K/W]
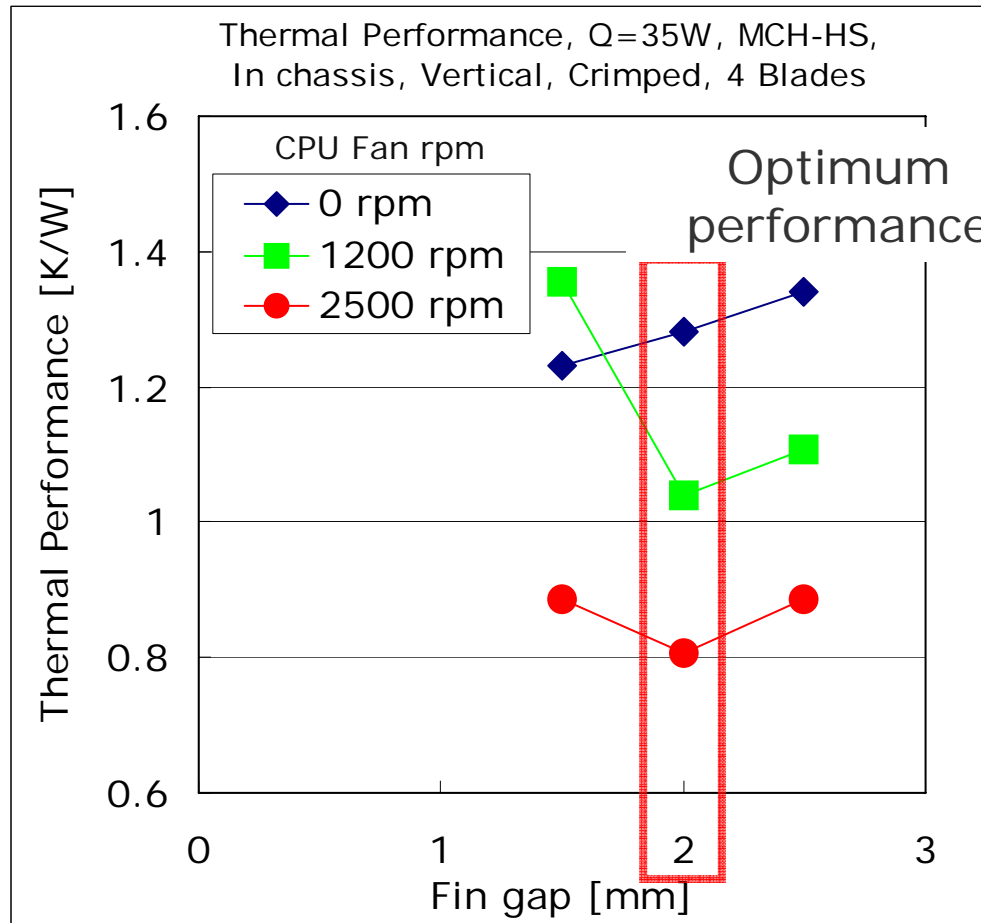
Optimum fin gap 2.0 mm was confirmed in this test!

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Thermal performance enhancement

Thermal Performance, Q=35W, MCH-HS, In chassis, Vertical, Crimped, 2.0mm gap

Legend:
- ■ With Piezo
- ● W/o Piezo

~4x Improvements

> 10 % Improvements

X-axis: CPU Fan speed [rpm]
Y-axis: Thermal Performance [K/W]
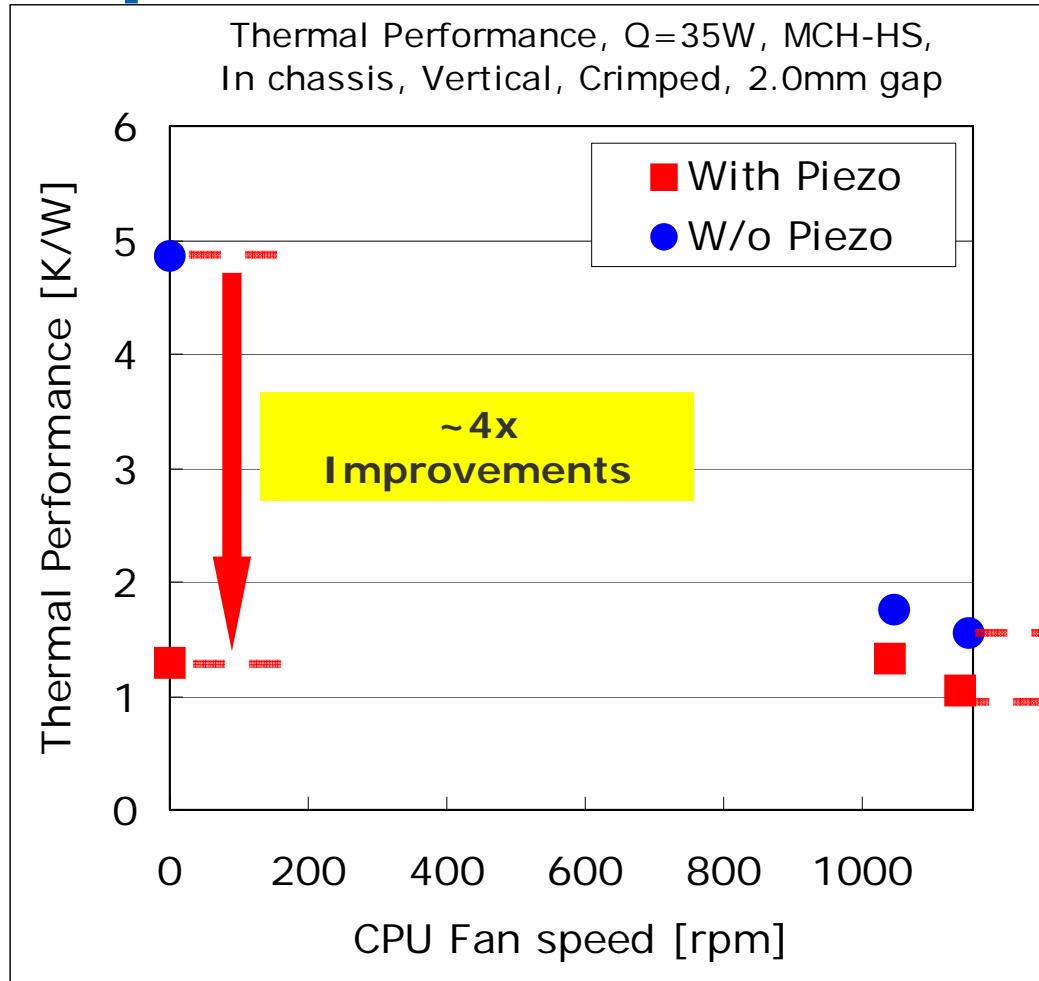
Piezo can bring major improvements at no or low air flow !

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Technology Advancements

- **Low Operating Voltage**

- **Small size**

- **Drag reduction**

- **Cost reduction**

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Multilayer Piezo Fan Concept/Test Data

Electrode
PZT
Electrode
PZT
Electrode
PZT
Electrode
PZT
Electrode

Blade   Epoxy

Not to scale
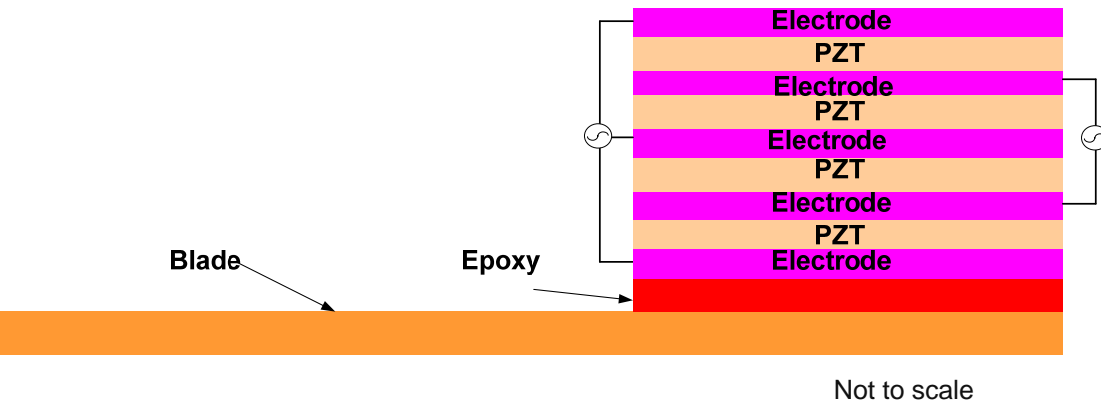
10 layers at 15V

Elongation = N * Strain * V

where:

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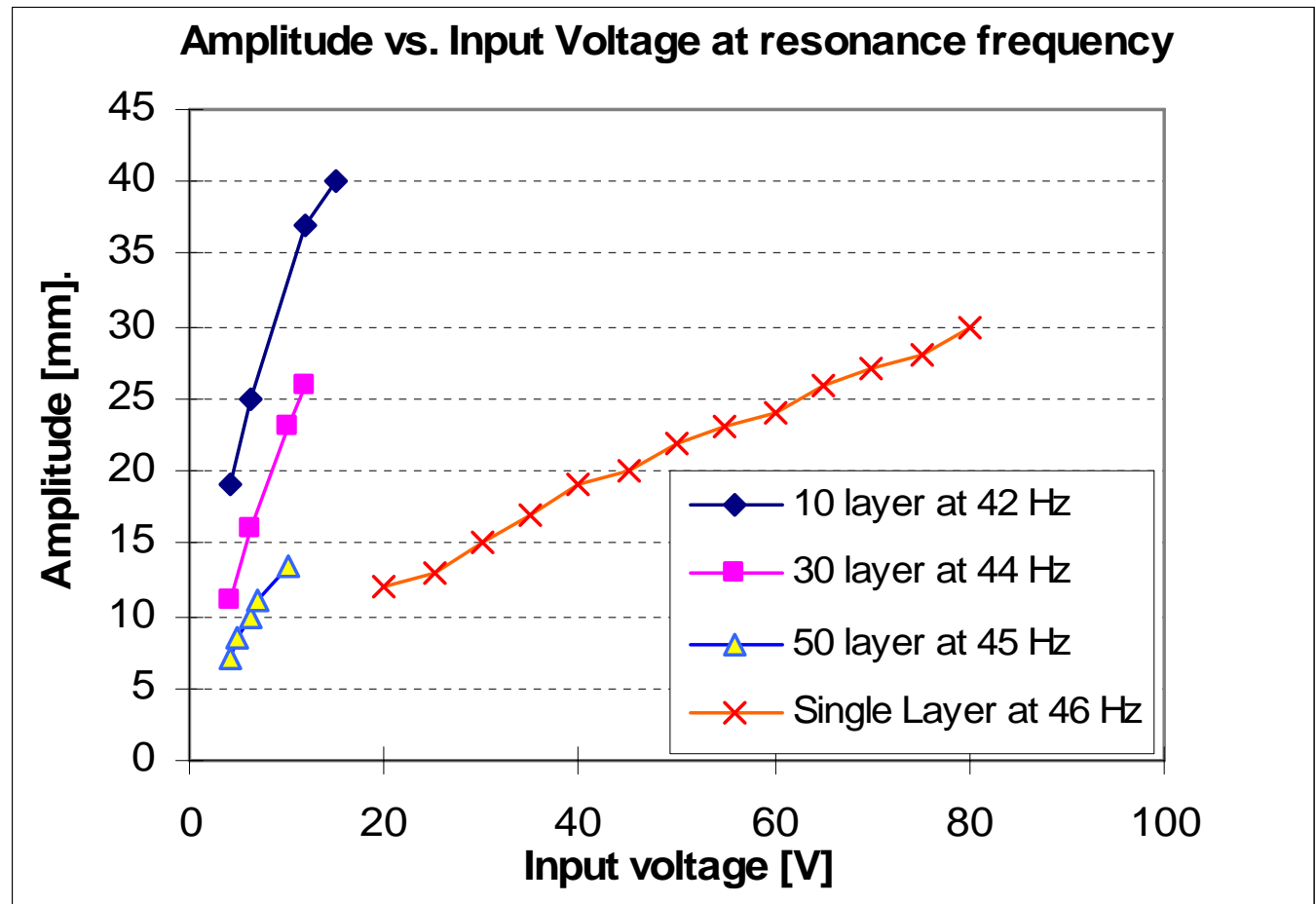V = the applied voltage.

Piezo	Voltage [V_{pp}]	Frequency [Hz]	Blade stroke [mm]	Power [mW]
Single Layer	65	46	26	7
10 layer	6.3	41.5	25	6
30 layer	12	43.5	26	82
50 layer	10	44.5	13.5	98

Multilayer may significantly reduce voltage!

"Photographs and data used with permission from Fujikura Ltd.

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The multi layer piezo performance

Amplitude

Amplitude vs. Input Voltage at resonance frequency

Amplitude [mm].

Input voltage [V]

- ◆ 10 layer at 42 Hz
- ■ 30 layer at 44 Hz
- △ 50 layer at 45 Hz
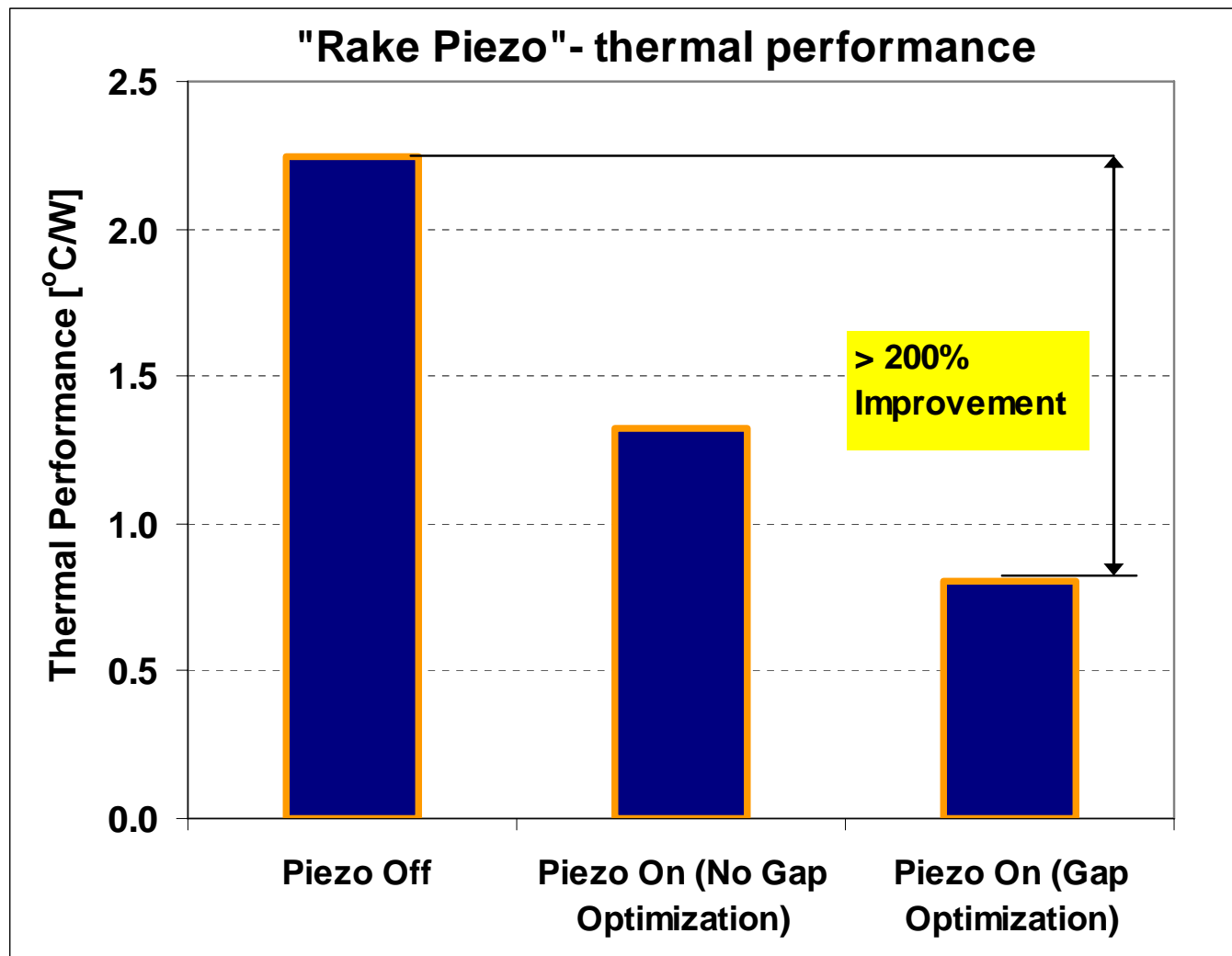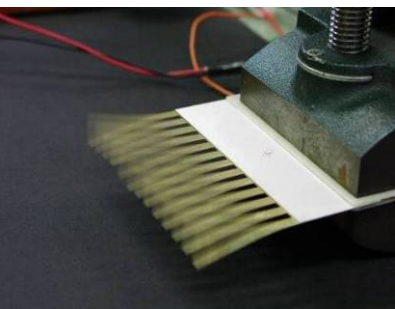- ✕ Single Layer at 46 Hz
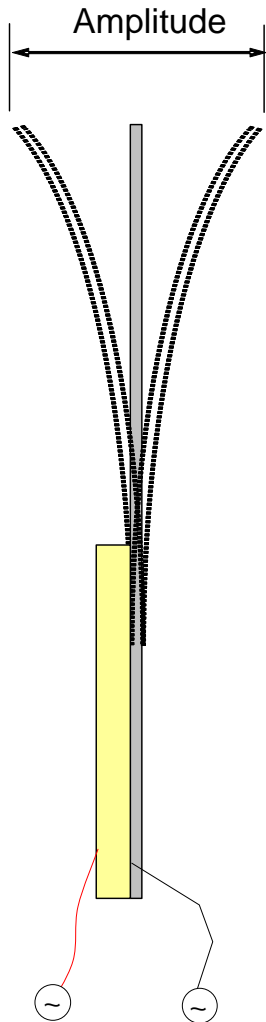
"Data used with permission from Fujikura Ltd..

Multilayer : Significant voltage reduction & better stroke!

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"Rake Piezo" performance summary

Raked-Piezo actuator

"Rake Piezo"- thermal performance

Thermal Performance [°C/W]

> 200% Improvement

- Piezo Off
- Piezo On (No Gap Optimization)
- Piezo On (Gap Optimization)
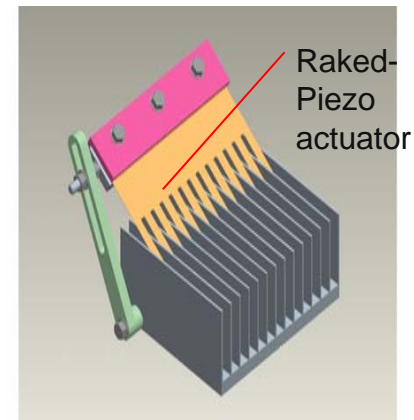
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Significant performance improvements!

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Rake Piezo – Combined with existing Air Flow

Air from Axial Fans

Rake Piezo

Piezo Attached to the heat sink

Air flow

CPU Heat Sink

TTV

TTV

Thermal Performance [C/W] vs Additional Air Flow [CFM]

Additional Air Flow [CFM]	No Piezo	With Piezo
5	1.01	0.84
15	0.74	0.65
30	0.60	0.55
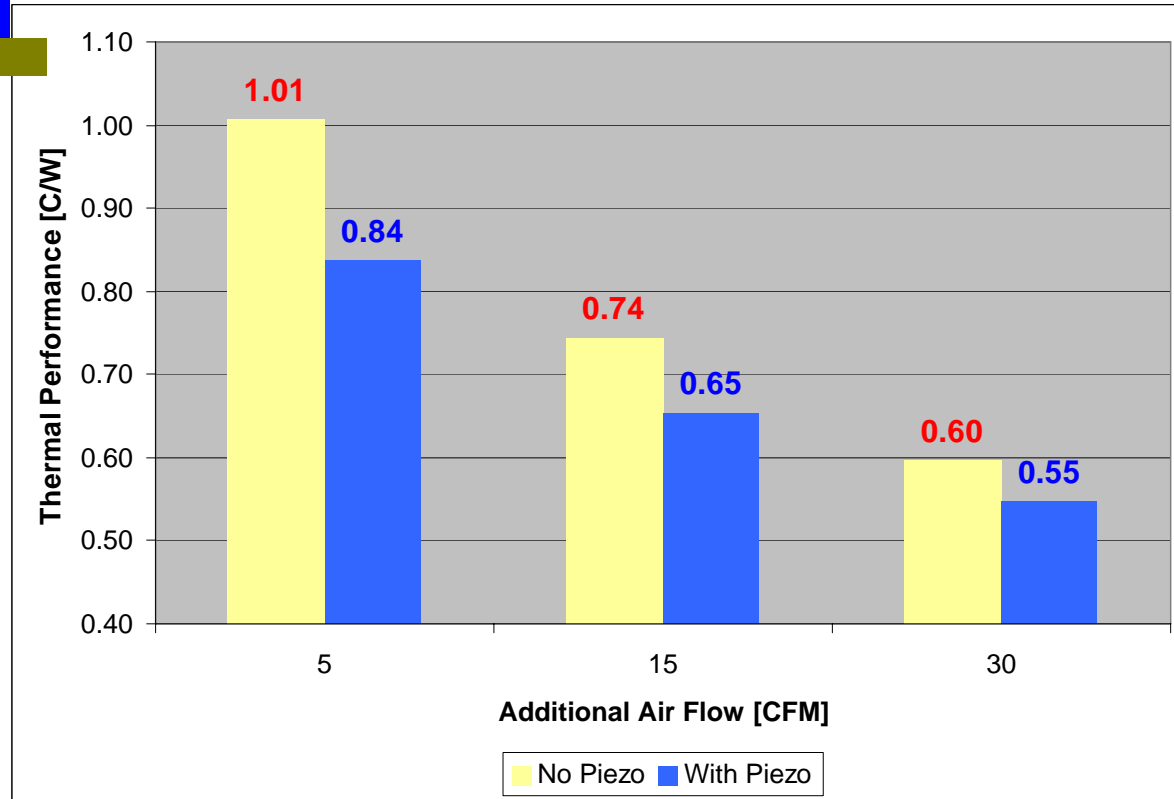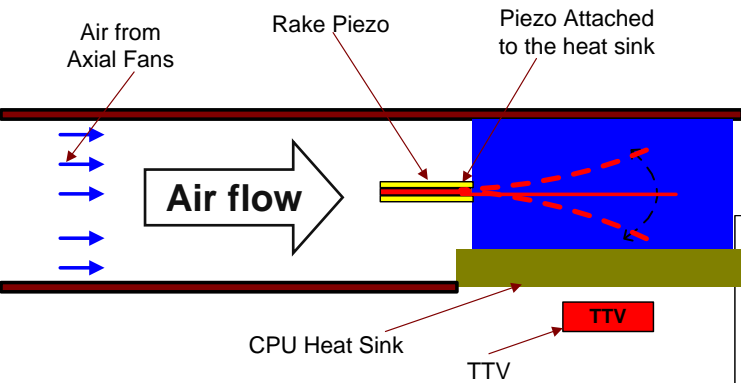
"Data used with permission from Fujikura Ltd.

Significant thermal improvements at low air flow!

Problem when using piezo fans between side walls

top view

piezo element

blade

piezo fan (top view)

side gap

wall

Average Pressure on Blade [Pa]

Side Gap [mm]

Large Air Drag

Narrow Side Gap
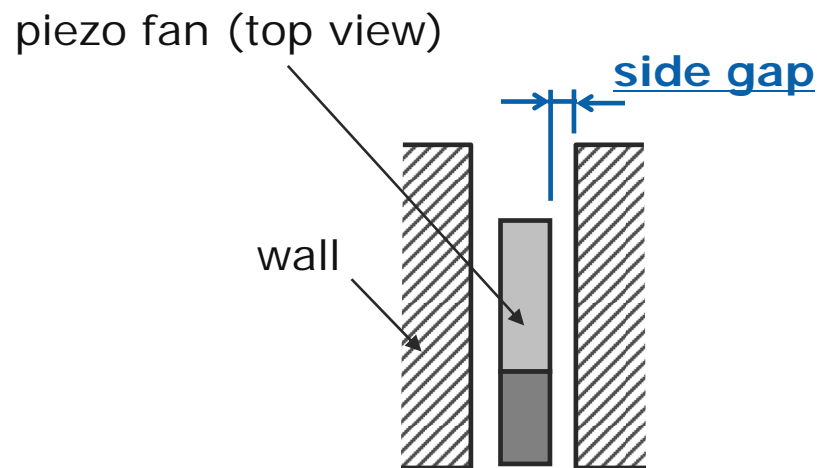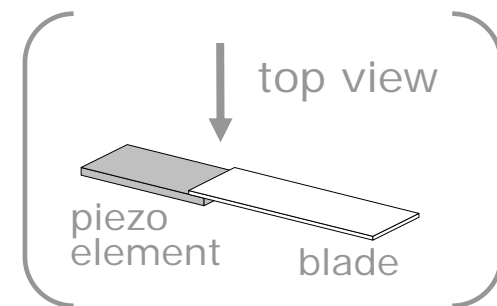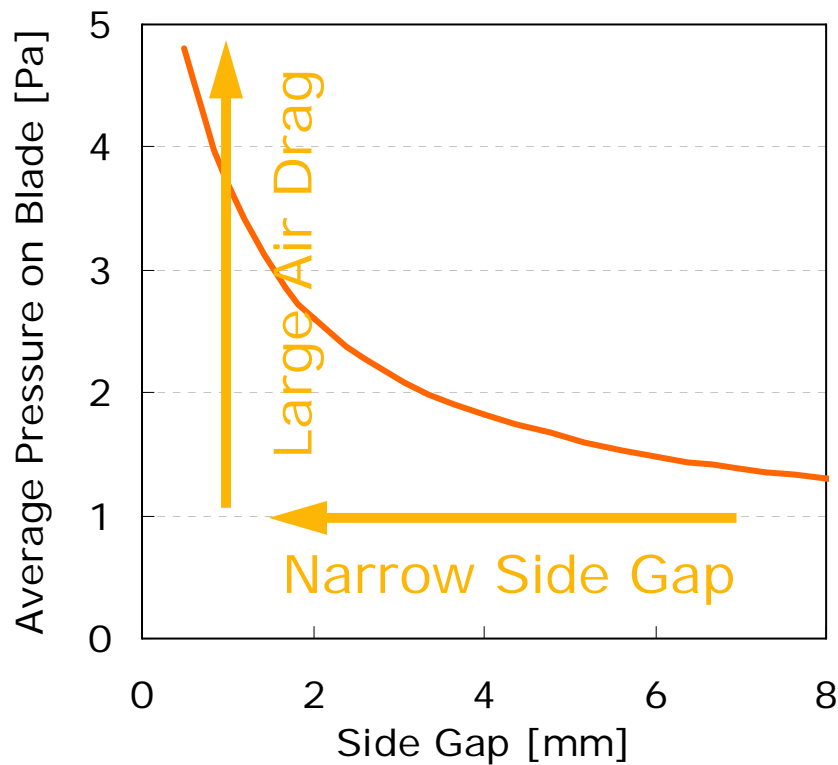
Air drag increases as side gap decreases.

"Data used with permission from Murata Ltd.

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Problem when using piezo fans between side walls

Blade length: 20mm
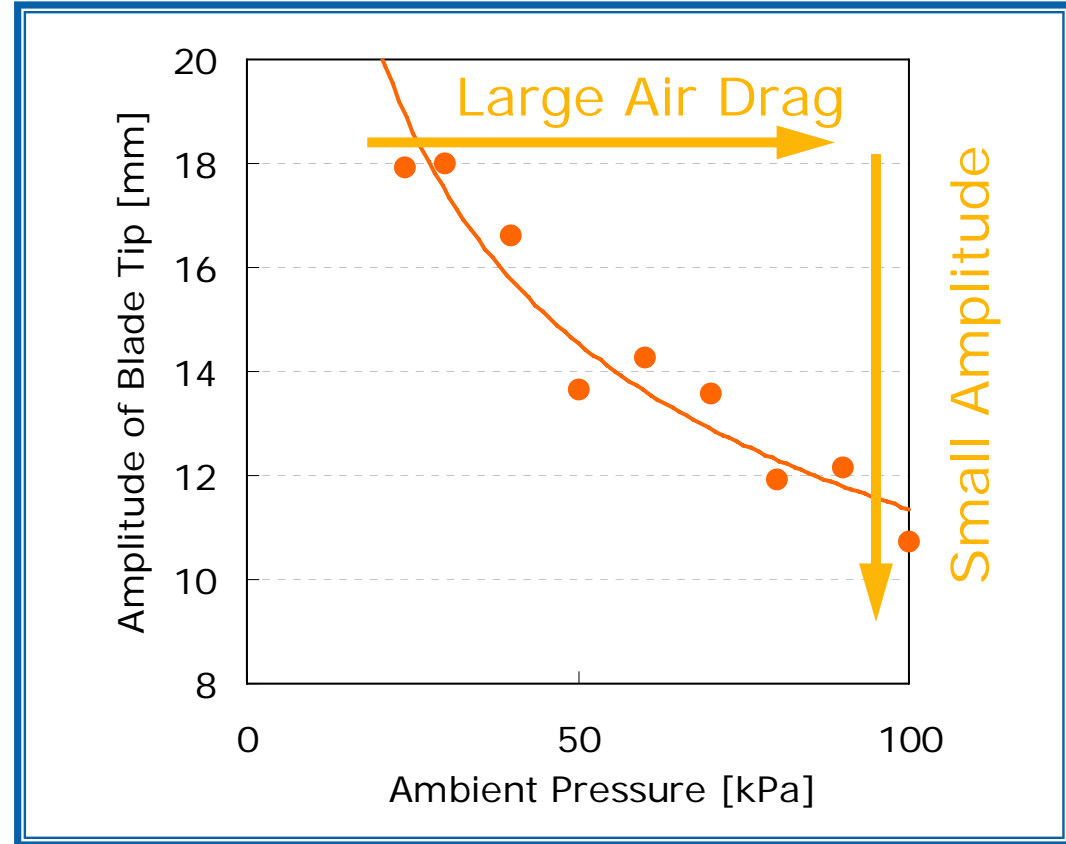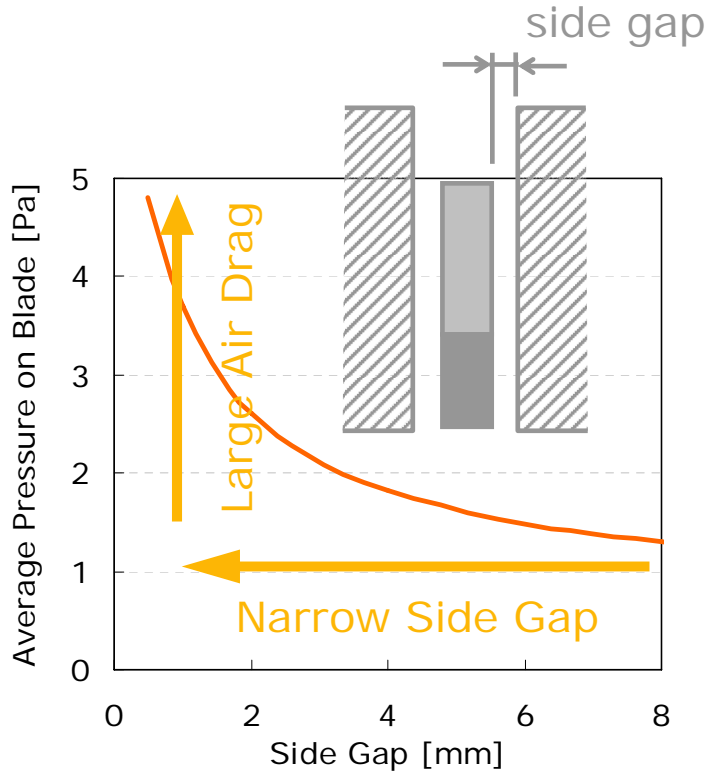
Air drag increase by side walls makes amplitude smaller.

"Data used with permission from Murata Ltd.

Air drag reduction (1): Blade with slit

Air drag decreases with slit

Average Pressure on Blade [Pa] vs Side Gap [mm]
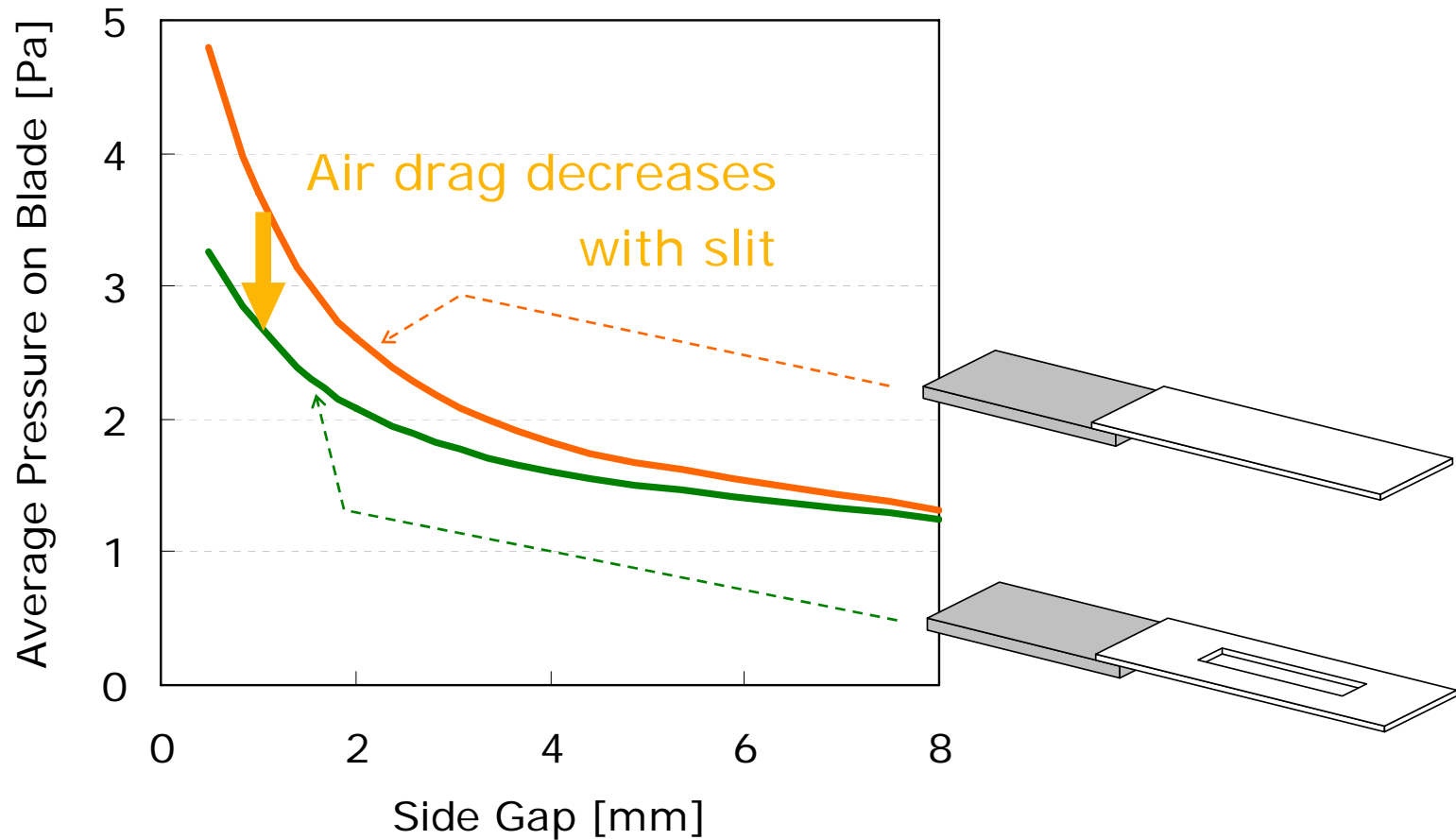
Slit in blade reduces air drag.

"Data used with permission from Murata Ltd.

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

Further Improvement

Amplitude of Blade Tip [mm]

Side Gap: 0.5mm

Input Voltage [V]

20mm

"Data used with permission from Murata Ltd.
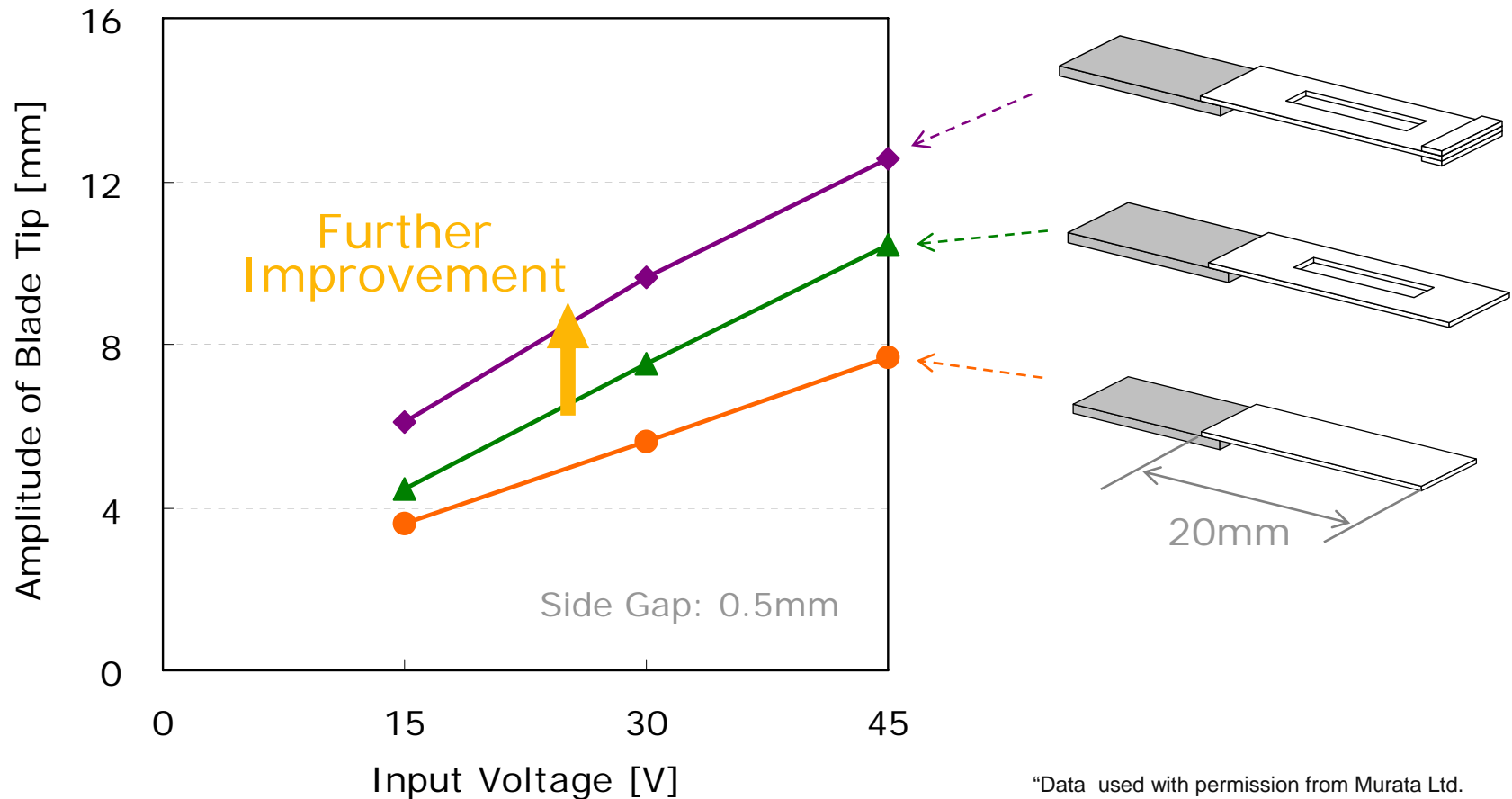
Optimizing blade shape enables large amplitude.

It eventually enables size reduction or voltage reduction.

Improvement of Heat Transfer: Blade with Slit

Temperature distribution without blade
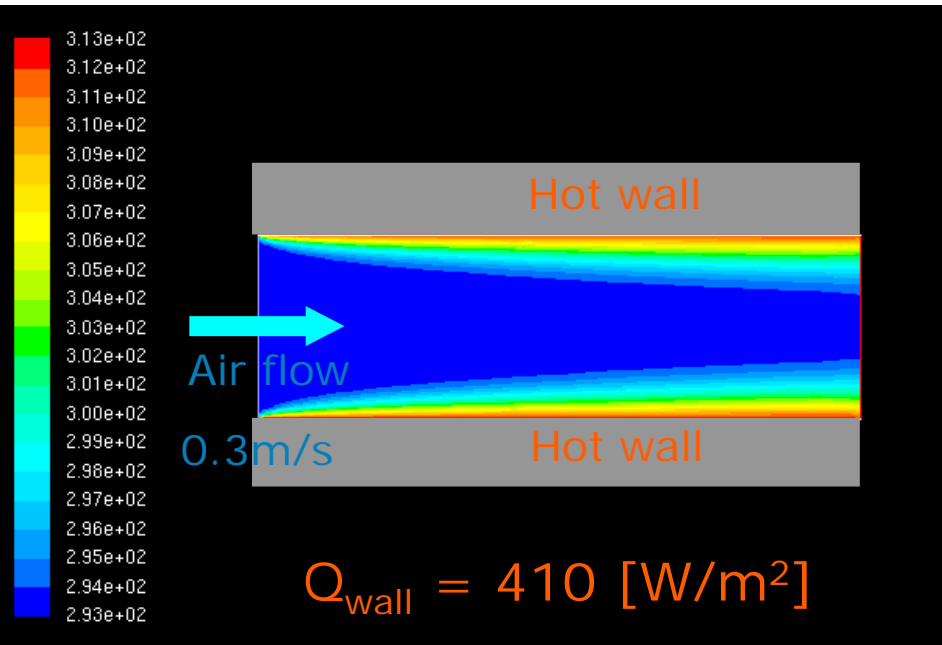
Temperature distribution with moving slit blade

blade with a slit
(moving back and forth in ↔ direction)

Hot wall

Hot wall

Air flow

0.3m/s

Hot wall

Hot wall

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

$$\overline{Q}_{wall} = 850 \ [W/m^2]$$

Contours of Static Temperature (k)

Contours of Static Temperature (k)
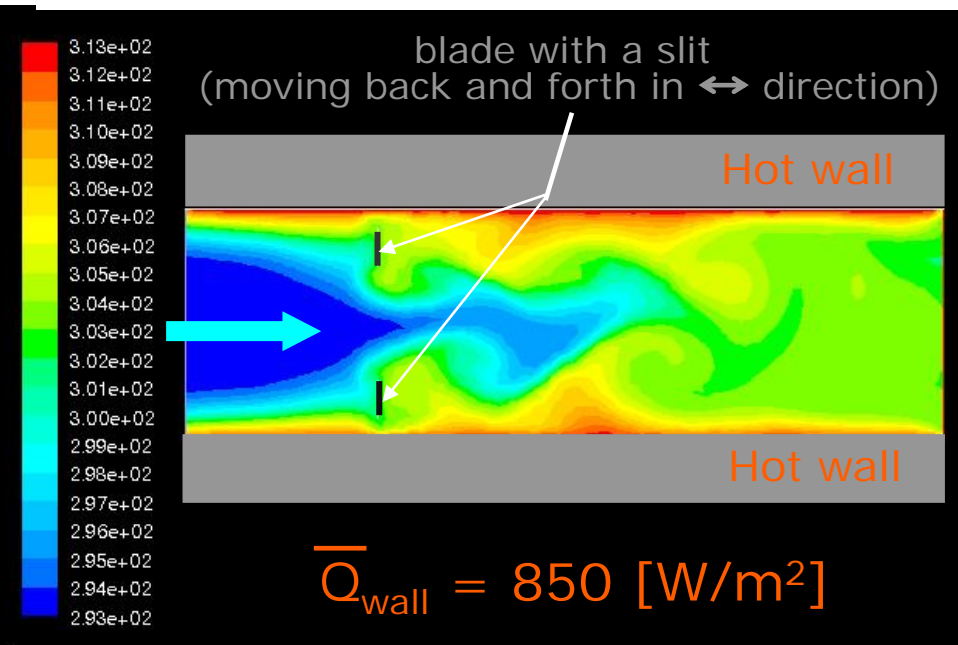
Vibration of the blade with a slit enhances heat removal > x2.

"Data used with permission from Murata Ltd.

Cost of Piezo

Size	60x45x0.5mm	6.5x4x0.15mm
Cost	< $ 0.8	< $ 0.3

"Data used with permission from Fujikura Ltd.

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**

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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Thermal performance definition

$$theta\_sr = \frac{T_s - T_{room}}{P[W]}$$

Ts= Sink Temperature [°C]
T_{room}= Room temperature [°C]
P= Chipset Power [W]