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Performance of piezoelectric fins for heat dissipation

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ABSTRACT

In this study, a conceptual design employs the piezoelectric patch to a copper plate to form a so-called piezoelectric fin applicable for heat dissipation. A total of nine piezoelectric fins subject to various bonding and piezoelectric patch are made and tested. A piezoelectric fin array is also fabricated as a substitute of heat sink under natural convection. It is found that the tip displacement and the decay of performance of piezoelectric fin are intimately related to the bonding glues. The bonding glues with a higher Young's modulus lead to a larger fin tip displacement. The tip displacement increases with applied voltage and the length of piezoelectric patch and a maximum tip displacement of 10.9 mm is observed for TCE bonding under a 100 V power source. A maximum 64% heat transfer augmentation at a supplied power of 5 W is encountered for the piezoelectric fin array. The corresponding fin displacement in the fin array is suppressed owing to the resistant interactions amid adjacent piezoelectric fins. The heat transfer augmentation is moderately reduced to about 40% when the supplied power is raised to 15 W.

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1. Introduction

The piezoelectric fans had received many attentions in recent years applicable for electronics cooling. These fans employ reversed piezoelectric effect to convert electrical energy into mechanical energy. By supplying an alternating voltage to the piezoelectric patch brings about periodic contractions/expansion alongside the lengthwise direction, thereby resulting in oscillating motion at the same frequency when the piezoelectric patch is attached to a blade. This oscillatory motion drives the air flow which can be exploited for cooling. The merits of piezoelectric fans include light weight, compact, simple structure, energy saving and noiseless.

Toda and Osaka [1] used the piezoelectric polymer PVF_2 as an actuator of the fan. The fans were mounted on television receiver, and it showed that the fin temperature of the assembly dropped from 66 to 49 °C when the fans were turned on. The air velocity at each fan tip was 1.4 m/s, and the input power was 14 mW. Yoo et al. [2] proposed an equation applicable for resonant frequency of the piezoelectric fan. It was found that the resonant frequency of the vibrating plate increase with the addition of its thickness and decreases with its length. The fan was made from phosphor bronze shim and the highest value of fan tip displacement of 35.5 mm and it produced a wind velocity of 3.1 m s^{-1} at a supplied power of 220 V and 60 Hz. Acikalin et al. [3] tested the cooling feasibility of the fans in an enclosure of a cellular phone and a commercially available laptop computer. They showed that the convection heat transfer coefficient can be enhanced by 100% in association with natural convection. The flow visualization indicated that the piezoelectric fan can generate a pair of counter-rotating vortices under each oscillation period. Liu et al. [4] examined the arrangement and location of the piezoelectric fan on the thermal performance of piezoelectric fans. It was found that the enhancement of the heat transfer came from the entrained airflow and the jet-like air stream at the fan tip. Acikalin et al. [5] showed that the fan frequency might offset the cooling capacity significantly. A small deviation of 5% in frequency could result in reduction of the temperature difference amid the ambient and the heat source by more than 10 °C. Kimber et al. [6,7] used the infrared camera technique to quantify the local heat transfer coefficients of piezoelectric fans. The distribution of the local heat transfer coefficients ranged from a lobed shape at a small distance to an almost circular shape at intermediate distances. At a larger distance, elliptical shape distribution for the heat transfer coefficient prevailed. They also proposed the correlations to predict the heat transfer rates of piezoelectric fans. When a fan is operated at a particular distance between the fan tip and the heated surface, the heat transfer rate is dependent only on the frequency and amplitude of oscillation. Sufian et al. [8] applied dual piezoelectric fans for microelectronic cooling performance numerically and

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Nomenclature

A	surface area (m^2)
D	tip displacement (mm)
E	Young's modulus (Pa)
fr	resonant frequency (Hz)
g	gravity ($m\ s^{-2}$)
h	heat transfer coefficient ($W\ m^{-2}\ K^{-1}$)
k	thermal conductivity ($W\ m^{-1}\ K^{-1}$)
l	length (mm)
N	number
Nu_s	Channel Nusselt number, $\equiv hs/k_a$, dimensionless
P	power consumption (mW)
Q	heat transfer rate (W)
Ra_s	channel Rayleigh number, $\equiv \rho g \beta s^4 \Delta T/\mu\alpha w_b$, dimensionless
s	plate spacing (mm)
T	temperature (°C)
t	thickness (mm)
V	voltage (V)
w	width (mm)

Greek symbols

α	thermal diffusivity of air, ($m^2\ s^{-1}$)
β	coefficient of thermal expansion, (K^{-1})
Δ	difference
η_o	overall surface efficiency
μ	dynamic viscosity ($N\ s\ m^{-2}$)
ν	Poisson's ratio, dimensionless
ρ	density ($kg\ m^{-3}$)
τ	shear strength (Pa)
ξ	enhancement ratio, dimensionless

Subscripts

a	air
b	blade
c	convection
ins	insulation
$natural$	natural convection
o	overlap
p	piezoelectric patch
$piezo$	piezoelectricity
r	radiation
t	total

Superscript

—	average quantity

experimentally. The results showed that in-phase vibration had a larger stream area and a higher wind velocity than that of out-of-phase vibration. The heat transfer enhancement for single fan was approximately 2.3 times higher than that in free convection. By contrast, the dual piezoelectric fans enhanced the heat transfer performance by approximately 2.9 and 3.1 times as compared to those of out-of-phase vibration and in-phase vibration respectively. Ma et al. [9] applied the magnetic force and PZT force to construct the multiple vibrating-fan system. The temperature of the heat sink dropped from 67 °C to 50 °C at a 50 V operation.

The types of bonding glues used for piezoelectric fans cast significant influence on the thermal performance. Sheu et al. [10] investigated the influence of bonding glues on the vibration of piezoelectric fans experimentally and theoretically. For the same glue, tip displacement increased with decreasing thickness of glues. While maintaining the thickness, tip displacement increased with the hardness of glues, suggesting a more pronounced influence of the hardness than thickness.

In addition to imposing an external piezoelectric fan for heat dissipation, an opposite way is to oscillate the heat dissipating devices. Lemilich and Rao [11,12] examined the enhanced heat transfer performance by imposing transverse vibration of the heating rods relative to that in natural convection. The convection heat transfer coefficient was found to increase with the vibrating frequency and amplitude, and they observed a 4-fold increase of heat transfer coefficient in air and a 10 times rise of heat transfer coefficient in water or aqueous glycerol. Soria and Norton [13] applied a 60 Hz oscillation to a flat plate in a wind tunnel and the local Nusselt number was found to be increased as large as 290% relative to the local Nusselt number in absence of plate vibrations.

Rather than to vibrate the whole heat sink, a much simple approach is to place some specific element (e.g. PZT) on the base of fin surface. Through this design, direct cooling by periodic fin oscillation can be found and the consumed power is estimated to be much lower. This design can significantly reduce the mechanisms needed for the cooling systems. Dey and Chakrborty [14] numerically investigated the heat transfer performance of an oscillating fin. They found that the cooling ability can be significantly augmented when the frequency and amplitude had reached the threshold values. Ma et al. [15] also simulated the performance of the vibrating fins. The effects of dimensions, vibrating frequency, pitch, and amplitude of fins were reported. Park [16] attached the PZT actuator to the heat sink to simulate the performance of the piezoelectric fans. The results showed that the cooling performance of the piezoelectric heat sink was doubled when compared to that of natural convection.

From the foregoing discussions, it appears that employs the piezoelectric patch to the heat dissipation may be feasible in practice. This is because it can effectively reduce the installation space requirement, yet the piezoelectric patch may be firmly attached to the fin base to reduce the power consumption and to ease the reliability concerns. Hence, it is the objective of this study to provide some heat transfer performance in association with the natural convection.

2. Experimental setup

In this study, performance of a single piezoelectric fin and fin arrays are made and tested. Fabrication of the single piezoelectric fin with various piezoelectric patch geometries and bonding glues are tabulated in Table 1 while the definitions of relevant geometric parameters are given in Fig. 1. The piezoelectric patch is attached

Table 1
Details of tested piezoelectric fins.

	l_p	w_p	t_p	l_b	w_b	t_b	l_o	Plate	Glue
Fin #1	10	12	0.2	60	45	0.15	5	Copper	Epoxy
Fin #2	19	12	0.2	60	45	0.15	5	Copper	Epoxy
Fin #3	28	12	0.2	60	45	0.15	5	Copper	Epoxy
Fin #4	10	12	0.2	60	45	0.15	5	Copper	Acrylic
Fin #5	19	12	0.2	60	45	0.15	5	Copper	Acrylic
Fin #6	28	12	0.2	60	45	0.15	5	Copper	Acrylic
Fin #7	10	12	0.2	60	45	0.15	5	Copper	TCE
Fin #8	19	12	0.2	60	45	0.15	5	Copper	TCE
Fin #9	28	12	0.2	60	45	0.15	5	Copper	TCE

Unit: mm

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