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Performance evaluation of plate-fins and pin-fins under natural convection: A review

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Abstract

This paper mainly discusses an analysis at its very initial condition by taking into account the heat that has been transferred from micro pin-fins. Under natural convection condition, a performance analysis of thermal properties of arrays of plate as well as pin type of micro-fins is experimentally carried out. The heating surface is kept same for the comparative study of the plate and pin fins. The results show that the pin micro-fins can be preferred over plate micro-fins as they have better thermal properties like higher value for heat transfer coefficient and lower for thermal resistances, by incorporating minimum material. Thereby the total weight of the pin fin is reduced and improvements in the thermal characteristics can be achieved. The upward facing and downward facing effect on the thermal characteristics is also studied.

Keywords: Natural convection, Plate-fin, pin fin.

1. Introduction

Cooling of electronic components is one of the major issues for its efficient working. If the cooling is not proper, then the overheating of electronic components may take place which will affect the thermal performance of the components. Producers and consumers are interested in less expensive, more efficient and compact electronic components. So, micro-sized components are preferred as it is compact in size with minimum material usage without affecting the performance. As the size of electronic components is decreasing day by day, more and more micro-components are brought in market and there is less space for the dissipation of heat to take place from the components. Thus, cooling is an important issue for proper functioning of the electronic components. This cooling can be done by two methods. One is active and the other is passive. An electrical power as input is required for the active but a passive does not require any power in input. Passive system like extended surfaces or fins is preferred over active because of its advantages like simplicity in design, reliability, less expensive, noiseless and powerless operation and ease of implementation. The fins are of various types but the most common are the plate type of fins and pin type of fins. Plate type of fins exchange heat with the surroundings only in one direction but the pin fins dissipate heat in all the directions to the flowing fluid around its surface. Even when the heat transfer coefficient is an important parameter, other parameters like weight, thermal resistance, cost, availability cannot be neglected for analyzing the performance of the fin array.

Nagarani et al. on combining numerous researches regarding fins grouped into two categories for its ease of analysis and experimentation as well. The two main categories as per his research focus on fin dimension along with its desired cooling rate and fin profile. An investigation carried out by Mehrtash et al. evaluated that the performance of fin at its elevated orientation with respect to heat sink.

Sparrow et al. concluded a higher value of heat transfer coefficient for pin fin over plate fin for the same thermal exchange surface. A comparative study of the thermal performances of the plate and pin type of heat sinks is done. For both the geometries, the heat sink parameters like fin thickness, fin spacing, base thickness and height of the fin is kept constant to analyze the thermal performance characteristics. Even when the fin spacing and thickness is same for both arrays, the heat transfer phenomenon is different in nature. The space between adjacent fins is filled with air which acts like insulation whereas the heat is transferred from the tip of the fins to the ambient air. A case study is taken to study the various thermal parameters of heat transfer by using the plate and pin type of fins.

The heat transfer from the plate fins takes place as shown in the figure below. The heat dissipation takes place in unidirectional mode.

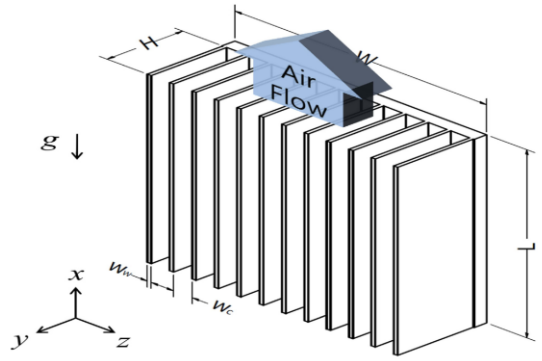

Fig.1Heat transfer from plate fin (Source: Y. Joo et al. 2015)

The heat transfer from the pin fins takes place as shown in the figure below. The heat dissipation takes place in omnidirectional mode.

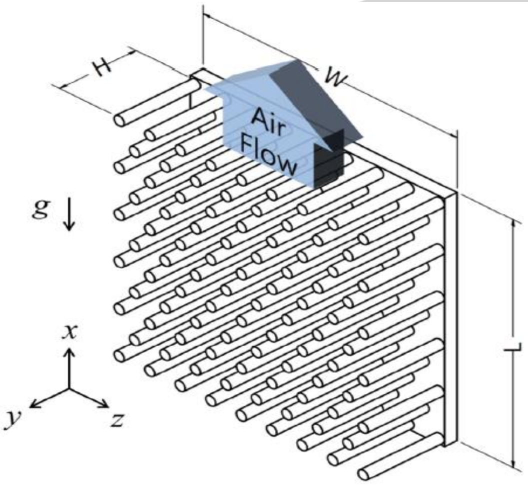

Fig.1Heat transfer from pin fin (Source: Y. Joo et al. 2015)

The case study is based on the following assumptions:
(1) The room temperature is assumed to be constant having a value of 25^0 C.
(2) the experiment is carried out at steady-state.
(3) the fins are isothermal and are non-radiating.
(4) the surrounding medium is large and black body so its temperature is equal to that of ambient.

Experimental setup

In this experimental study, two types of geometries is studied: plate and pin fin heat sink. (Fig.3). A Square silicon flat wafer of side 5 cm having thickness 1.4 mm is used as baseplate. Geometrical parameters of the heat sink dimensions are reported in Table 1. As the fin thickness and fin spacing is equal, there is no surface difference between the plate and pin fin heat sinks.
The fin arrays have been placed in an insulating case made of a 1 cm-thick fibre thermal material, covered by another 1 cm-thick polystyrene layer. An electrical heater having the specifications (Omega KHLV-202/2.5) has been used as heat source, operated through a DC power supply. Two digital multimeters are used to measure the current and the voltage input.

The fin heat sinks are placed inside a 25 cm× 25 cm × 25 cm box open on top for the experimentation.
A thermal imaging camera is used to record the temperature of the heat sink. (FLIR T425), considering a constant temperature across the fin array and the fin height. The fin heat sinks are tested in both the orientations, upward as well as downwards. Power inputs of 5W, 7.5W and 10W have been supplied to have heating power densities of 2.0 kW/m^2, 3.0 kW/m^2 and 4.0 kW/m^2 respectively.

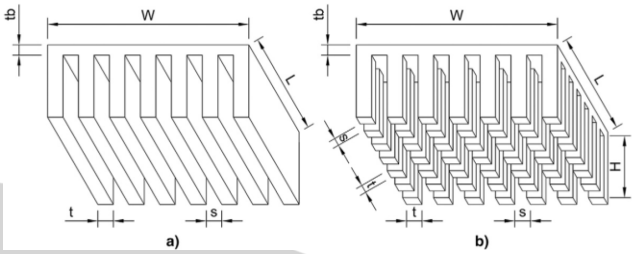

Fig.3 Geometrical parameters of plate and pin fin (Source: L. Micheli et al. 2015)

The experimental setup used is shown in the figure below:

	W=L(mm)	t	s	H	t_b	Number of fins(platefins-pin fins)
Geometry 1	50	200	200	600	800	121-15376
Geometry 2	50	400	600	800	800	61-3844

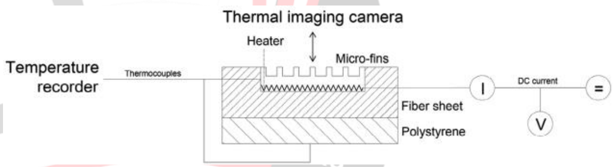

Fig.4 Experimental model (Source: L. Micheli et al. 2016)

The dimensions of the heat sink used for the experimentation is tabulated below in the table.

Table.1. Fin dimensions (Source: L. Micheli et al. 2016)

Data analysis

The power input (Q_{in}) to the heat sink is dissipated by three ways: convection from the fin (Q_c), radiation from the fin (Q_r) and combined convective/ radiative losses through the insulating case (Q_{loss})
$Q_{in} = Q_c + Q_r + Q_{loss}$
The heat dissipated by radiation can be calculated by using the Stefan–Boltzmann equation:

$$Q_r = \sum_i \varepsilon \cdot \sigma \cdot A_i \cdot F_{i,amb} \cdot \left(T_{fins}^4 - T_{amb}^4\right)$$

where ε is emissivity of silicon (0.78), σ,Stefan–Boltzmann constant (5.67 X 10^{-8} Wm^{-2} K^{-4}), A_i is the area of each i-surface of the fins, $F_{i,amb}$ is the view factor between the i-surface and the ambient and T_{fins} and T_{amb} are the temperatures of the fins and the ambient respectively.

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The heat transfer by convection mode can be calculated by knowing the input power, the losses and the radiative component of heat transfer. The value for average convective heat transfer coefficient can be calculated as follows:

$$h_{fins} = \frac{Q_c}{A_{fins} \bullet (T_{fins} - T_{amb})}$$

where, A_{fins} is the area of the finned surface.

Thermal resistance

Thermal resistance in heat transfer is same as electrical resistance in an electrical circuit. It is the obstruction for the flow of heat in the presence of difference in temperature gradient. It can be calculated as:

$$R_{fins} = \frac{(T_{fins} - T_{amb})}{Q_c}$$

Mass specific heat transfer coefficient

It is the characteristic parameter to measure the promotion in heat transfer and is expressed as:

$$h_m = \frac{Q_c}{V_{fins} \bullet \rho_{fins} \bullet (T_{fins} - T_{amb})}$$

Where, V_{fins} represents the volume and ρ_{fins} the density of the heat sink.

Individual fin effectiveness (ε_f)

It is the ratio of heat transfer by a single fin to that of heat transfer from the surface without the fin. The more the value for the better is the heat transfer.

The overall fin effectiveness (ε_{fins}), measure of enhancement in performance expresses the ratio between the heat transferred by the fins to that of without fins. $\varepsilon_{fins} = \frac{Q_c}{Q_{flat}}$

where, Q_{flat} is the heat transferred by convection from the unfinned flat surface.

Results and Discussions

Heat transfer coefficient

The heat transfer coefficient (HTC) is a coefficient that determines the heat flux when there is a difference in temperature of a heat exchanging surface and fluid flowing around the surface. It depends on velocity of the fluid flow, the fluid properties as well as the pattern of the flow and the geometry of the surface. In the present investigation, for the same input power and upward-facing orientation of pin fin heat sink, the value for heat transfer coefficient is more than that of the plate fins. It means that as the area for air flow is increased, the heat transfer rate is also increased.

When the arrays are oriented in downward direction, the improvement in the performance of HTC is seen as high as 20%.

Mass specific heat transfer coefficient

The mass specific heat transfer coefficient of the pin fin arrays is more than the plate ones. The values are as high as about 20% to 40%. These high values of pin fins are due to the increased heat transfer and the reduced volumes compared to that of the plate fins. The results are shown in the Fig.5 and Fig.6 below.

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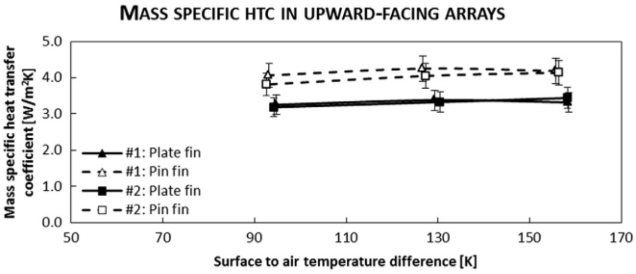

Fig.5. Mass specific HTC of upward-facing orientation of heat sink (Source: L. Micheli et al. 2016)

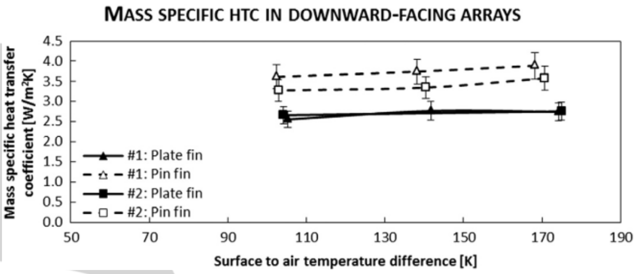

Fig.6. Mass specific HTC of downward-facing orientation of heat sink (Source: L. Micheli et al. 2016)

Thermal Resistance

The variation in thermal resistance is shown in Fig. 7 and Fig. 8. for upward and downward orientations. It's value depends on the power input. The thermal resistance of the pin fins is found to be lower than the plate fins. Pin fins dissipate more heat than plate fins.

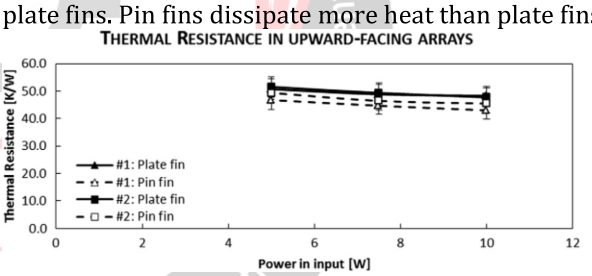

Fig.9. Thermal Resistance of upward-facing orientation (Source: L. Micheli et al. 2016)

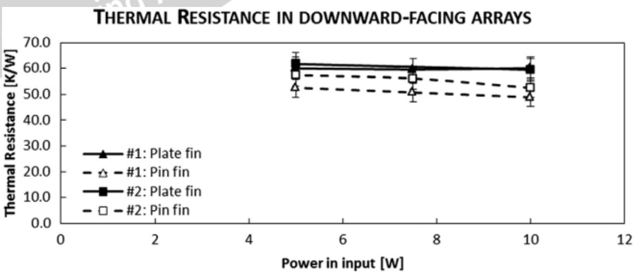

Fig.10. Thermal Resistance of downward-facing orientation (Source: L. Micheli et al. 2016)

Contribution of radiation

The heat transfer by radiation mode is generally neglected in natural convection. But studies reveal that at micro-sized heat sinks, the heat transfer by radiation mode is as high as about 55 to 70% of the heat dissipated by the fins, due to the two factors high temperature difference and high value for emissivity of silicon. For upward orientation this value is lower than that in downward orientation (Fig. 11) as the radiation is independent of the orientation. But when the heat sink is downward oriented, a decrease in convection mode of heat transfer is seen. For the same temperature difference, the contribution of radiation is more in downward orientation than in upward. The contribution of radiation increases with the difference in temperature because it depends on the fourth power of the temperatures, whereas the convection on the first power only.

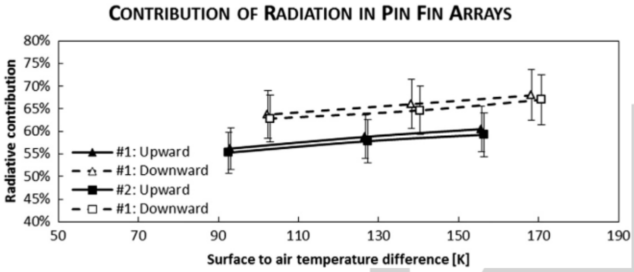

Fig.11. Radiation contribution of pin fin heat sink (Source: L. Micheli et al. 2016)

Conclusion

The study is based on experimental investigation on various parameters on the micro-fin heat sink. It compares the performance of plate and pin micro-fins on various thermal parameters. Experimental results have resulted in the conclusion that the pin fins have better results than plate ones due to the higher heat transfer coefficients Also the heat transfer coefficient depends on the geometry as well as on the orientation of the heat sink. Overall fin effectiveness is enhanced by using pin fins over plate ones. In the light, pin fins use less material so have less weight and volume with an increase in the heat transfer than that of the plate ones. The studies show that the orientations of the heat sinks, material used for the heat sink, and non uniform heating source have great impact on the thermal performance of the heat sink and hence a lot of work is to be expected in the future studies in this regard.

References

Leonardo Micheli, K.S. Reddy, Tapas K. Mallick, (2016) "Thermal effectiveness and mass usage of horizontal micro-fins under Natural convection" *Applied thermal engg* 97 39-47.

Leonardo Micheli, K.S. Reddy, Tapas K. Mallick, (2015) "General correlations among geometry, orientation and thermal performance of natural convective micro-finned heat sinks" *International Journal of Heat and Mass Transfer* 91 711–724.

Leonardo Micheli, K.S. Reddy, Tapas K. Mallick,(2015) "Plate micro-fins in natural convection: an opportunity for passive concentrating photovoltaic cooling" *Energy Procedia* 82 301 – 308

R.A. Pulavarthy, M.T. Alam, M.A. Haque, (2014) "Effect of heated zone size on micro and nanoscale convective heat transfer" *International Communications in Heat and Mass Transfer* 52 56–60.

Leonardo Micheli, K.S. Reddy, Tapas K. Mallick, (2016) "Experimental comparison of micro-scaled plate-fins and pin-fins under natural convection" *International Communications in Heat and Mass Transfer 75*59-66.

N. Nagarani, K. Mayilsamy, A. Murugesan, G.S. Kumar, (2014) Review of utilization of extended surfaces in heat transfer problems, *Renew. Sustain. Energy* Rev. 29 604–613

I. Tari, M. Mehrtash, (2013) Natural convection heat transfer from horizontal and slightly inclined plate-fin heat sinks, *Appl. Therm. Eng.* 61 728–736

Younghwan Joo, Sung Jin Kim, (2015) Comparison of thermal performance between plate-fin and pin-fin heat sinks in natural convection*, International Journal of Heat and Mass Transfer* 83 345–356

S. Mahmoud, R. Al-Dadah, D.K. Aspinwall, S.L. Soo, H. Hemida, (2011) Effect of micro fin geometry on natural convection heat transfer of horizontal microstructures,

Appl. Therm. Eng. 31 627–633

R.A. Pulavarthy, M.T. Alam, M.A. Haque, (2014) Effect of heated zone size on micro and nanoscale convective heat transfer, *Int. Commun. Heat Mass Transf*. 52

56–60

L. Micheli, N. Sarmah, X. Luo, K.S. Reddy, T.K. Mallick, (2013) Opportunities and challenges in micro- and nano-technologies for concentrating photovoltaic cooling: a review, *Renew. Sustain. Energy* Rev. 20 595–610

A. Bar-Cohen, M. Iyengar, A.D. Kraus, Design of optimum plate-fin natural convective heat sinks, J. Electron. Packag. 125 (2003)

Y.A. Cengel, Introduction to Thermodynamics and Heat Transfer, second ed., McGraw-Hill, 2008.