International Communications in Heat and Mass Transfer 86 (2017) 174–180

Contents lists available at ScienceDirect

International Communications in Heat and Mass Transfer

journal homepage: www.elsevier.com/locate/ichmt

The heat transfer characteristics of liquid cooling heat sink with micro pin fins

Han-Chieh Chiu[a], Ren-Horn Hsieh[a], Kai Wang[b], Jer-Huan Jang[c,d,*], Cheng-Ru Yu[c]

[a] Department of Mechanical Engineering, Taipei City University of Science and Technology, Peitou, Taipei 112, Taiwan
[b] Shenyang Institute of Automation, Chinese Academy of Sciences, Shenyang 110016, Liaoning, China
[c] Department of Mechanical Engineering/Battery Research Center of Green Energy, Ming Chi University of Technology, Taishan, New Taipei City 243, Taiwan
[d] Department of Mechanical Engineering, Chang Gung University, Gueshan, Taoyuan 333, Taiwan

ARTICLE INFO

Keywords:
Micro pin fins
Porosity
Liquid cooling
Effective thermal resistance
Averaged heat transfer coefficient

ABSTRACT

This paper numerically and experimentally investigated the liquid cooling efficiency of heat sinks containing micro pin fins. Aluminum prototypes of heat sink with micro pin fin were fabricated to explore the flow and thermal performance. The main geometry parameters included the diameter of micro pin fin and porosity of fin array. The effects of the geometrical parameters and pressure drop on the heat transfer performance of the heat sink were studied. In the experiments, the heat flux from base of heat sink was set as 300 kW/m^2. The pressure drop between the inlet and the outlet of heat sink was set < 3000 Pa. Numerical simulations with similar flow and thermal conditions were conducted to estimate the flow patterns, the effective thermal resistance. It was found that the effective thermal resistance would reach an optimum value for various pressure drops. It was also noted that the effective thermal resistance was not sensitive to porosity for sparsely packed pin fins.

1. Introduction

Efficient cooling technologies have been developed to meet the heat dissipation of high heat flux of electronic devices, e.g. projector, LED, graphic chip, high power laser etc. Among them liquid cooling with heat sinks containing mini/micro structures is a promising solution. During the past two decades, many efforts have been dedicated to heat transfer and flow performance of liquid cooling with micro/mini channels [1–8]. Comparatively, the performance of micro pin fins received less attention. Pin fin heat sinks have been widely used at conventional scale in industry [9–12], while limited studies on heat sinks with micro/mini scale pin fins have been conducted [13–19]. Micro pin fins own the advantages of low flow resistance and high heat transfer surface, liquid cooling with micro pin fins has the potential of being a candidate for solving high heat flux problems in electronic components due to recent development of micro-fabrication technology.

Marques and Kelly [13] made use of micro circular fin pins in gas cooling heat exchanger. The pin fins were made with Nicole through LIGA process. Both the diameter and spacing are 0.5 mm. Peles et al. [14] constructed the correlation of thermal resistance and geometrical design, i.e. porosity and aspect ratio. The averaged heat transfer coefficient was estimated through iterative solution for fin efficiency equation and power dissipation relation. Experiments were conducted on pin fin array fabricated on silicon wafer. The circular pins were about 0.5 mm in diameter and 0.25 mm in height, corresponding to very low aspect ratio. The pressure drop of micro pin fin array was between 20 kPa and 200 kPa. The lowest thermal resistance reached about 0.04. Their result showed that micro pin fin array could perform well under appropriate conditions.

The arrangement and shape of micro pin fin are important factors on the heat transfer performance of heat sink with micro pin fin. Prasher et al. [15] experimentally explored the heat transfer and friction factor of staggered arrays. In their study, MEMS technologies were employed on silicon wafers to form circular and square micro pin fins with porosity higher than 80%. Qu and Siu-Ho [16] investigated heat transfer and flow characteristics of staggered square fin arrays under heat flux as high as 100 W/cm^2. The fabrication of micro pin fin is also used MEMS technology. Kosar and Peles [17,18] surveyed various staggered arrays of fins, e.g. rectangular, circular, and hydrofoil, and cone-shaped. It was found that square fin array performed better under low pressure drop while high pressure drop was in favor of streamline fins. Liu et al. [19] studied diamond shape micro pin fins of copper material. The aspect ratio in their investigation was about 6. Recently, Ndao et al. [20] experimentally investigated the effects of cross flow area and pin fin shapes on the single-phase impingement point heat transfer coefficients of jet impingement on micro pin fins. The micro pin

* Corresponding author at: Department of Mechanical Engineering/Battery Research Center of Green Energy, Ming Chi University of Technology, Taishan, New Taipei City 243, Taiwan.
E-mail address: jhjang@mail.mcut.edu.tw (J.-H. Jang).

http://dx.doi.org/10.1016/j.icheatmasstransfer.2017.05.027

Nomenclature

D	pin fin diameter (m)
e	porosity of pin fin array
H	equivalent height of water level for pre-set pressure drop (m)
h	local heat transfer coefficient
h_{avg}	averaged heat transfer coefficient of pin fin array (W/°C m^2)
P	pressure drop (Pa)
p	perimeter of single pin fin (m)
$\dot{Q}$	heat flux (W)
R_{th}	effective thermal resistance of heat sink (°C/W)
S_{tot}	total surface area of pin fin walls (m^2)
T_{in}	temperature of incoming water (°C)
T_J	the junction temperature of heat sink (°C)
x, y, z	basis of Cartesian coordinates (m)
Δ	difference

fins were circular, hydrofoil, square, and elliptical pin fins with characteristic lengths ranging from 50 μm to 125 μm.

Numerical methods were also employed to explore the effect of pin fin configuration. Khorunzhii et al. [21] numerically studied the entire thermal fluid field of heat sink containing miniature pin fins with finite element method. In their investigation, the volume flow rate is very high for more than 50 ml/s. The averaged Nusselt number was found to be proportional to the power of averaged Reynolds number with index of 0.6. However, in some studies [16,17,19], this value ranges from 0.33 up to 0.99. This indicates that there is no clear trend to identify the value of index with different geometry. John et al. [22] investigated in line pin fin array with finite volume method. Only one line fins were simulated since the fins were in line. The size of fins ranged from 75 μm to 150 μm. The thermal resistances were found to be close at the same Reynolds number. The porosity in this research was large thus the geometrical effects were not apparent. In practice, the working fluid in a liquid cooling module is normally driven by a pump with low water head. In the recirculation system of liquid cooling module, the thermal field of the working fluid is determined under a specific mild pressure drop rather than a specific high Reynolds number.

The objective of present study is to investigate numerically and experimentally the flow and heat transfer characteristics of heat sink with micro pin fin array. The pressure drop was set as low as less than 3000 Pa during experiments. Heat sinks of aluminum containing pin fins with diameter ranging from 0.45 mm to 0.66 mm were under evaluation. The geometrical parameters, i.e. porosity, of staggered pin fin array were specified to estimate the flow and thermal performance of heat sink.

2. Design and fabrication of the heat sinks with pin fins

Fig. 1(a) shows the schematics of a heat sink used in this research. The porosity, ε, of the heat sink was set by adjusting spacing of pin fin centers, shown in Fig. 1(b). Fig. 1(c) is the over view of a heat sink drawing. The channel area is defined as the total area of the pin fin array region subtracted by the total cross-sectional area of the pin fins. Therefore, the porosity is calculated as the channel area divided by total area of the pin fin array region from top view. The total thickness of the

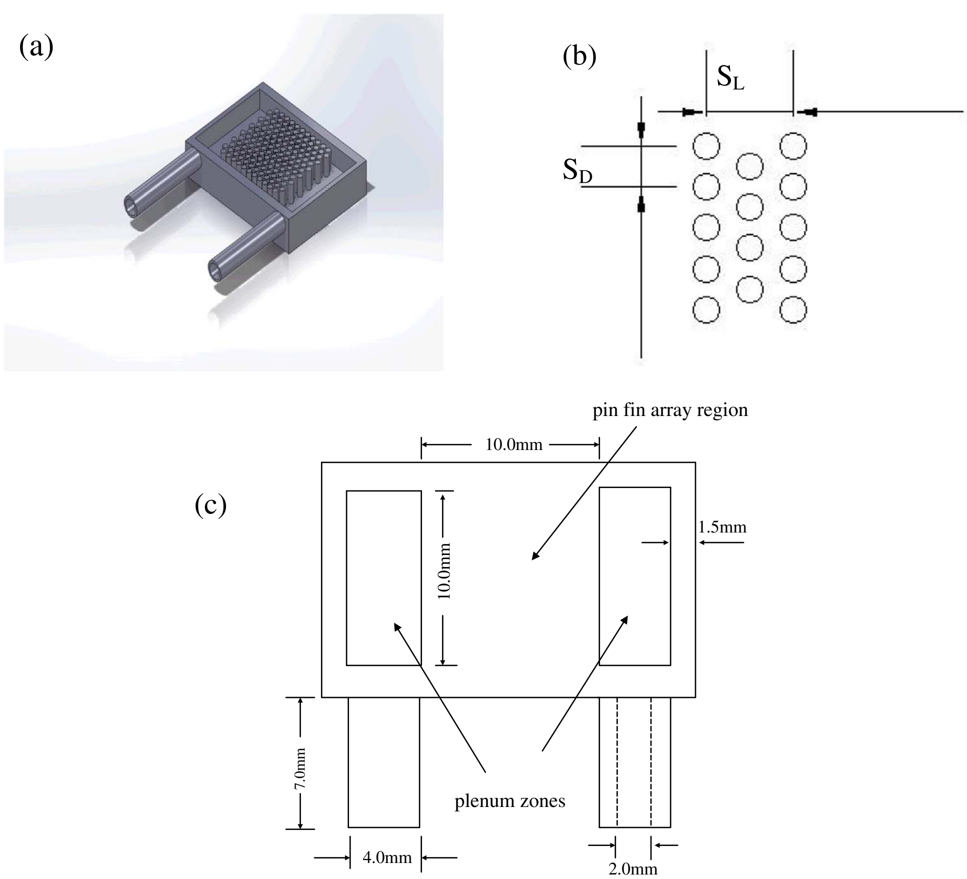

Fig. 1. Model of a heat sink containing micro pin fins: (a) schematic of a heat sink containing micro pin fins; (b) pin fin spacing; (c) dimensions of the heat sink.