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An absorption based miniature heat pump system for electronics cooling

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ABSTRACT

The development of an absorption based miniature heat pump system is motivated by the need for removal of increasing rates of heat from high performance electronic chips such as microprocessors. The goal of the present study is to keep the chip temperature near ambient temperature, while removing 100 W of heat load. Water/LiBr pair is used as the working fluid. A novel dual micro-channel array evaporator is adopted, which reduces both the mass flux through each micro-channel, as well as the channel length, thus reducing the pressure drop. Micro-channel arrays for the desorber and condenser are placed in intimate communication with each other using a hydrophobic membrane. This acts as a common interface between the desorber and the condenser to separate the water vapor from LiBr solution. The escaped water vapor is immediately cooled and condensed at the condenser side. For direct air cooling of condenser and absorber, offset strip fin arrays are used. The performance of the components and the entire system is numerically evaluated and discussed.

Pompe à chaleur miniaturisée à absorption pour les applications électroniques

Mots clés : Refroidissement ; Composant ; Électronique ; Système à absorption ; Eau-bromure de lithium ; Conception ; Évaporateur ; Microcanal ; Calcul ; Performance

1. Introduction

Recent advances in semiconductor technologies are accompanied by an accelerated increase in power density levels from high performance chips such as microprocessors. According to the International Technology Roadmap for Semiconductors (ITRS), these chips are expected to have an average heat flux of 64 W cm^{-2}, with the maximum

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Nomenclature

A	area (m^2)
Bo	Boiling number, $q''/G\lambda$
COP	coefficient of performance
d_h	hydraulic diameter (m)
f	friction factor
G	mass flux of channel flow ($kg\,m^{-2}\,s^{-1}$)
h	convective heat transfer coefficient ($W\,m^{-2}\,K^{-1}$)
i	specific enthalpy ($J\,kg^{-1}$)
j	Colburn j factor, $St\,Pr^{2/3}$
k	thermal conductivity ($W\,m^{-1}\,K^{-1}$)
$\dot{m}$	mass flow rate ($kg\,s^{-1}$)
N	mass flux at the phase interface or membrane ($kg\,m^{-2}\,s^{-1}$)
Nu	Nusselt number, hd_h/k
P	pressure (Pa)
$\tilde{P}$	perimeter (m)
Pe	Peclet number, $d_h u/\alpha$
Pr	Prandtl number, ν/α
q	heat transfer rate (W)
q''	heat flux ($W\,m^{-2}$)
R	gas constant ($J\,mol^{-1}\,K^{-1}$)
Re	Reynolds number, $\rho u d_h/\mu$
s	channel or fin pitch (m)
St	Stanton number, $h/\rho u c_p$
T	temperature (K)
t	fin thickness (m)
u	velocity ($m\,s^{-1}$)
v	specific volume ($m^3\,kg^{-1}$)
x	mass fraction of LiBr
x^m	mole fraction of LiBr
x^v	vapor quality
z	axial coordinate (m)

Greeks

α	thermal diffusivity ($m^2\,s^{-1}$)
β	aspect ratio
δ	membrane thickness (m)
ϕ	two-phase frictional multiplier
η_o	overall surface efficiency
κ	mass transfer coefficient ($m\,s^{-1}$)
λ	latent heat of vaporization ($J\,kg^{-1}$)
μ	dynamic viscosity (Pa s)
ν	kinematic viscosity ($m^2\,s^{-1}$)
ρ	density ($kg\,m^{-3}$)

Subscripts

a	air
d	desorber
e	evaporator
h	heating fluid
l	liquid phase
m	membrane
r	refrigerant
ref	reference
rm	interface between refrigerant (water) and hydrophobic membrane
s	solution
sat	saturation
sm	interface between solution (LiBr + water) and hydrophobic membrane
triple	triple point
v	vapor phase
w	wall
wc	cooling side wall
wh	heating side wall

Superscript

*	modified

junction temperature requirement of nearly 90 °C, by the year 2009 (ITRS, 2005). Conventional chip packaging solutions, which use convective air-cooling techniques, are facing difficulties in removing such a high heat flux under the limited space allocated to thermal management. This is particularly true for portable electronics and systems operating in harsh environments.

A variety of novel alternative thermal solutions for electronics cooling have been reported and briefly reviewed in Table 1. The cooling systems can be categorized into passive and active. The passive cooling systems utilize capillary or gravitational force to circulate the working fluid, while the active cooling systems are driven by a pump or a compressor for augmented cooling capacity and improved performance. Also, the active systems driven by a compressor can be called refrigeration/heat pump systems, which may offer further increase in power removal by insertion of a negative thermal resistance into the heat flow path (Mongia et al., 2006).

This study aims at developing the design of an absorption system, which can remove 100 W of heat from electronic components with the chip junction maintained at room temperature. Among different candidate technologies, the absorption refrigeration offers the compactness, relative ease of scalability to varying cooling load, and relatively high COP, making it an attractive option for cooling of high performance electronics (Suman et al., 2004). Specifically, such a system can be considered as one of the candidates for cooling of the CPU in desktop PCs and also as a wearable cooling system, e.g., for workers exposed to hazardous materials, police wearing body armor, and military personnel exposed to nuclear, biological or chemical warfare agents (Drost and Friedrich, 1997). The working fluid is the water/LiBr pair, where water and LiBr are used as refrigerant and absorbent, respectively.

2. Principal features of absorption based heat pump system

Fig. 1 shows schematic diagram of an absorption based heat pump system, which mainly consists of an evaporator, an absorber, a desorber, a condenser, a liquid pump and expansion devices. One of the major advantages of such heat pump system is the utilization of waste heat around 90 °C, which brings about significant reduction in operating costs