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Mini-channel evaporator/heat pipe assembly for a chip cooling vapor compression refrigeration system

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ABSTRACT

We investigate a novel evaporator design for a small-scale refrigeration system whose function is to assist the existing heat pipe technology currently used in chip cooling of portable computers. A heat transfer model for the evaporator/heat pipe assembly was devised specifically for sizing the evaporator in order to keep the chip surface temperature below a certain value. A prototype was tested with R-600a at saturation temperatures of 45 and 55 °C, mass flow rates between 0.5 and 1.5 kg h^{-1} and heat transfer rates between 30 and 60 W. The experimental results demonstrated that the average refrigerant-side heat transfer coefficient is more sensitive to a change in the refrigerant mass flux than to changes in the saturation temperature and heat transfer rate. The agreement between the calculated heat transfer coefficient and the data was within ±10% for the conditions evaluated.

Dispositif consistant en un évaporateur à microcanaux/à caloduc pour un système frigorifique à compression de vapeur utilisé pour refroidir une puce

Mots clés : Refroidissement ; Compresseur ; Électronique ; Conception ; Évaporateur ; Microcanal ; Expérimentation ; Isobutane

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Nomenclature

Roman

A	Area [m^2]
C	Constant [–]
D	Diameter [m]
F_E	Enhancement factor [–]
F_S	Suppression factor [–]
f	Friction factor [–]
G	Mass flux per minichannel [kg m^{-2} s^{-1}]
h	Heat transfer coefficient [W m^{-2}°C^{-1}]
i	Specific enthalpy [J kg^{-1}]
k	Thermal conductivity [W m^{-1}°C^{-1}]
L	Length [m]
$\dot{m}$	Total mass flow rate [kg s^{-1}]
Ma	Mach number [–]
N	Number [–]
p	Perimeter [m]
P	Pressure [Pa]
q''	Heat flux [W cm^{-2}]
$\dot{Q}$	Heat transfer rate [W]
R	Thermal resistance [°C W^{-1}]
r	Radius [m]
Re	Reynolds number [–]
$\Re$	Gas Constant [J kg^{-1} K^{-1}]
S	Shape factor [m]
T	Temperature [°C]
t	Thickness [m]
x	Quality [–]
X_{tt}	Martinelli parameter [–]
z	Axial coordinate [m]

Greek

γ	Ratio of specific heat capacities [–]
Δ	Difference [–]
φ	Porosity [–]
μ	Viscosity [kg m^{-1} s^{-1}]
ρ	Density [kg m^{-3}]

Subscripts

a	Adiabatic region
al	Aluminum
c	Condensing region
cap	Capillary
cb	Convective boiling
ch	Channel
con	Container
cont	Contact
cu	Copper
e	Evaporating region
ef	Effective
evap	Evaporator
exp	Experimental
ext	External
exit	Exit
h	Hydraulic
hou	Housing
hp	Heat pipe
i	Interface
int	Internal
l	Liquid
lv	Liquid–vapor
nb	Nucleate boiling
num	Numerical
proc	Processor
ref	Refrigerant
tp	Two-phase
v	Vapor
va	Vapor duct
w	Wall
wa	Water

1. Introduction

The thermal management of computer chips is one of the most challenging and critical tasks associated with the development of faster processors and more compact electronic devices. As far as the cooling of portable (laptop) computers is concerned, heat pipes are widely employed for being a passive, reliable, efficient and inexpensive cooling technology. However, as the need for more efficient cooling increases to meet the demands of the next generation of computer chips, the conventional technologies may prove to be no longer practical and will have to be replaced by or combined with active cooling techniques, such as vapor compression refrigeration.

The main function of a heat pipe is to transfer the rejected heat from the processor (the heat source) via the evaporation region of the heat pipe to the surrounding air (the heat sink). The fan-assisted forced convection of air through the finned surface of the heat pipe condenser is the most common configuration of the heat sink arrangement in portable computers, as illustrated in Fig. 1. As pointed out by Mongia et al. (2007), the largest thermal resistance in the heat pipe arrangement is the one associated with the air convection on the heat pipe condenser (typically 60% of the total thermal resistance). Due to space and noise level limitations, the use of more robust fans to increase the thermal conductance turns out to be impracticable.

Several studies of miniature and small-scale refrigeration systems have been published in recent years. Shannon et al. (1999) and Shannon (2002) developed a micro-miniature cooler from polymer composites via thin film layered-manufacturing techniques. Each active cooler consists of a square patch of approximately 100 mm side and 2.5 mm thickness, and has been designed to produce a cooling capacity of 3 W while operating under a standard vapor compression refrigeration cycle between 20 °C (evaporation temperature) and 50 °C (condenser temperature) using R-134a. The coolers can be interconnected to form a flexible