

NUMERICAL EVALUATION ON THE COOLING CAPABILITY OF MEMS BASED LIQUID METAL COOLING DEVICE USED IN HARSH ENVIRONMENT

Zhong-Shan Deng, Jing Liu, Yi-Xin Zhou

Cryogenics Lab, P. O. Box 2711, Technical Institute of Physics and Chemistry,
Chinese Academy of Sciences, Beijing 100080, China

INTRODUCTION

The thermal management of the increasing fast chips has been a major concern in packaging of micro/nano systems [1]. These chips are squeezing into tighter and tighter spaces with no enough places for heat to dissipate. It is expected that heat flux levels in excess of 100 W/cm^2 for commercial electronics and over 1000 W/cm^2 for selected military high power electronics will soon become a realistic challenge to overcome. Meanwhile, high-capacity cooling options remain limited for many small-scale applications such as micro-systems, sensors and actuators, and micro/nano electronic components.

In our previous work, a MEMS based micro cooling device was presented [2], which is comprised of an active cooling substrate embedded with fluidic cooling functionality using liquid metal, to provide direct cooling to high heat flux electronics and MEMS devices. This MEMS cooling device has been proved to be effective for extremely high heat flux applications such as consumer electronics used in normal environment. However, there is also a growing demand for more sophisticated and capable electronics used in harsh environment applications such as those found in defense, space-craft, automotive and oil exploration systems [3]. The main factor that distinguishes harsh situation from normal one is the environmental temperature, either extremely high or low. Thermal management of high heat flux electronics used in such environment is even more challenging.

In this study, the cooling capability of the MEMS-based micro cooling device is evaluated for harsh environment application. Both the extremely high and low environment temperatures are considered. And the three-dimensional heat transfer process thus involved is numerically simulated. A series of calculations with different flow rates and thermal parameters are performed. For the particular applications, the results are compared with the cases of water and ethanol as working fluids, respectively. The results indicate that the

MEMS-based liquid metal cooling device has powerful cooling capability even used in harsh environment.

METHODS

Figure 1 depicts a schematic of MEMS-based cooling module (made by metal with high thermal conductivity such as copper), in which the chip device contacts with the cooling module at $x=0$. It uses a pump-driven liquid coolant that flows through its 50- to 150 μm wide channels. Consequently, the whole domain consists of heat conduction and convection domains. For the heat conduction domain, thermal equation is described by Fourier's law. For the convection domain, the temperature of cooling fluid in micro flow channel, which varies along the flow direction, is governed by the convective heat transfer equation. Readers are referred to [2] for details about the corresponding heat transfer equations, and referred to [4] for details about the numerical algorithm.

For the conventional electronics cooling methods, harsh environment usually means high environment temperature. In this study, harsh environment includes both extremely high and low environment temperature due to the particularity of liquid metal as cooling fluid (i.e., at extremely low temperature, available liquid metal will be extremely limited). As a practical cooling fluid, the metal must be at its liquid state at the possible working temperature. Based on the above consideration, gallium and mercury are particularly selected as working fluid for the applications at extremely high and low environment temperature, respectively.

RESULTS AND DISCUSSION

Figure 2 shows the transient temperatures at the center of heating surface and the outlet of fluid for the cases of gallium and water as cooling fluid at extremely high environment temperature ($T_j=50^\circ\text{C}$). Figure 3 gives the transient responses of temperatures at the center of heating surface under different

thermal loads. It indicates that liquid gallium has strong capability for extreme cooling needs even at extremely high environment temperature.

As stated above, for the applications at extremely low environmental temperature, mercury is used as working fluid. Typical results for such applications are shown in Figures 4 and 5. Figure 6 reveals the cooling capabilities of gallium, mercury, water and ethanol at high temperature.

All the above results indicate that the liquid metal based MEMS cooler has potential applications at harsh environment. Further results and detailed discussion will be presented at the conference.

ACKNOWLEDGMENTS

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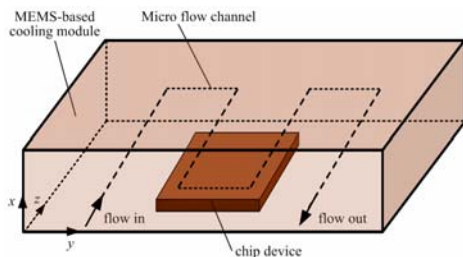


Figure 1. Schematic of MEMS-based cooling module (not to scale)

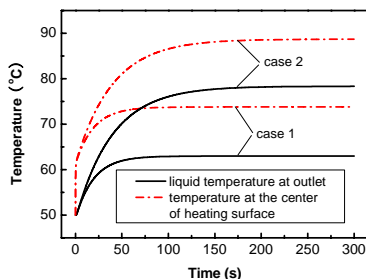


Figure 2. Transient temperatures at the center of heating surface and the outlet of fluid; Case 1 - gallium as cooling fluid, Case 2 - water as cooling fluid ($T_f=50^\circ\text{C}$; $q_c=70\text{W/m}^2$)

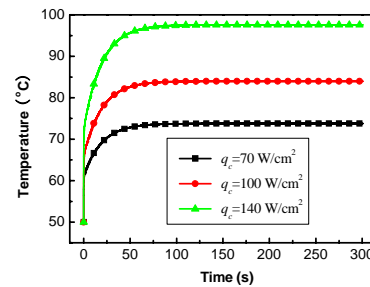


Figure 3. Transient temperatures at the center of heating surface under different heat fluxes of chip device (gallium as cooling fluid, $T_f=50^\circ\text{C}$)

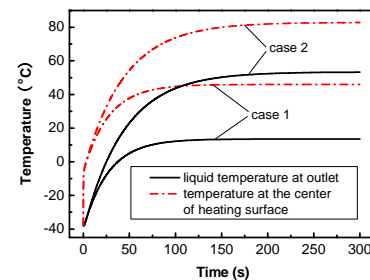


Figure 4. Transient temperatures at the center of heating surface and the outlet of fluid; Case 1 - mercury as cooling fluid, Case 2 - ethanol as cooling fluid ($T_f=-38^\circ\text{C}$; $q_c=200\text{W/m}^2$)

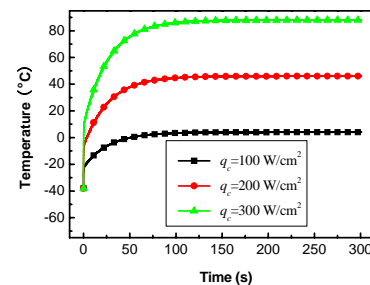


Figure 5. Transient temperatures at the center of heating surface under different heat fluxes of chip device (mercury as cooling fluid, $T_f=-38^\circ\text{C}$)

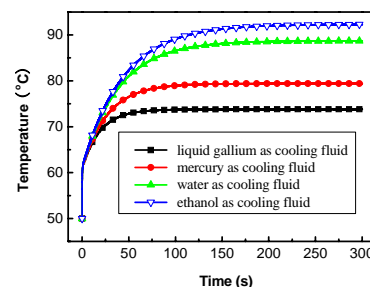


Figure 6. Transient temperatures at the center of heating surface ($T_f=50^\circ\text{C}$; $q_c=70\text{W/m}^2$)