EXTENDED-NANO HEAT PIPE DEVICE FOR NON-ELECTRIC COOLING

Chenxi Wang[1,2], Yutaka Kazoe[1], Yuriy Pihosh[1], Kyojiro Morikawa[1], Kentaro Kasai[1], Kazuma Mawatari[1], and Takehiko Kitamori[1]

[1] Department of Applied Chemistry, The University of Tokyo, JAPAN and

[2] State Key Laboratory of Advanced Welding and Joining, Harbin Institute of Technology, CHINA

ABSTRACT

A heat pipe device based on enhanced condensation and high driving Laplace pressure in extended-nano space (10^1-10^3 nm scale) is developed for a non-electric cooling. A vacuum system was specifically designed and established for our integrated heat pipe device. Compared to the working in ambient air, the extended-nano heat pipe is verified for proper working with higher flow rates in a vacuum environment for the first time. The cooling performance is evaluated quantitatively. Although the performance is still very low, higher performance is expected for cooling hot spots in large scale integration (LSI) by optimization of nanofabrication.

KEYWORDS: Vacuum, Streaming potential, Cooling performance, Condensation

INTRODUCTION

Conventional heat pipes that combine the principles of both thermal conductivity and vapor-liquid phase transition are extensively utilized to manage the heat transfer for efficient cooling of LSI. However, conventional heat pipes combined with large-size electric fans are difficult to integrate into portable devices. To realize further miniaturization, the condensation speed is very low, and the liquid circulation is not enough for sufficient heat exchange. On the other hand, we found unique water properties in extended-nano space (10-1000 nm), such as enhanced capillary condensation and Laplace pressure [1]. Based on these unique properties, an extended-nano heat pipe device is developed in this work [Fig. 1]. To improve the performance, a vacuum system is employed to exhaust the air in microchannels. Furthermore, streaming potential measurements [2] are utilized to evaluate of liquid transport during the heat pipe working. The cooling performance is quantitatively estimated.

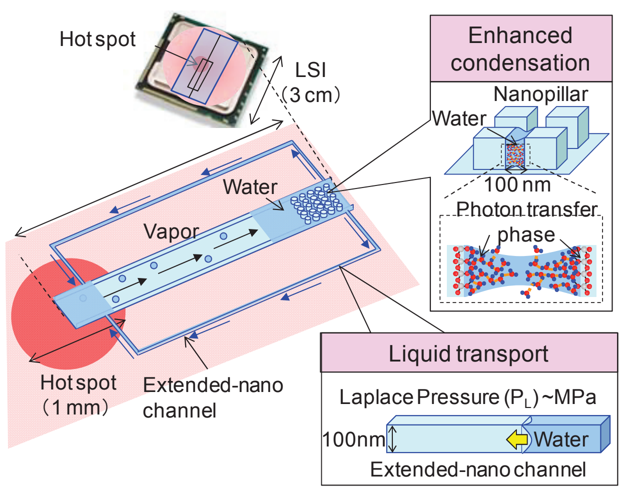

Figure 1. Concept of non-electric extended-nano heat pipe for cooling spot of LSI.

EXPERIMENTAL

The extended-nano heat pipe device was designed and successfully fabricated on glass substrates [Fig. 2(a)]. When the water at the hot spot locally heated (size: 1 mm^2), the vapor generated and condensed on 350nm-sized-pillars even with small temperature differences. With the water changed to vapor at the hot spot, the condensation water should flow along the side channels to transport heat flux. Two extended-nano channels (width: 500 μm, depth: 300 nm) are fabricated to extract water back to the hot spot efficiently with high Laplace pressure of 1 MPa.

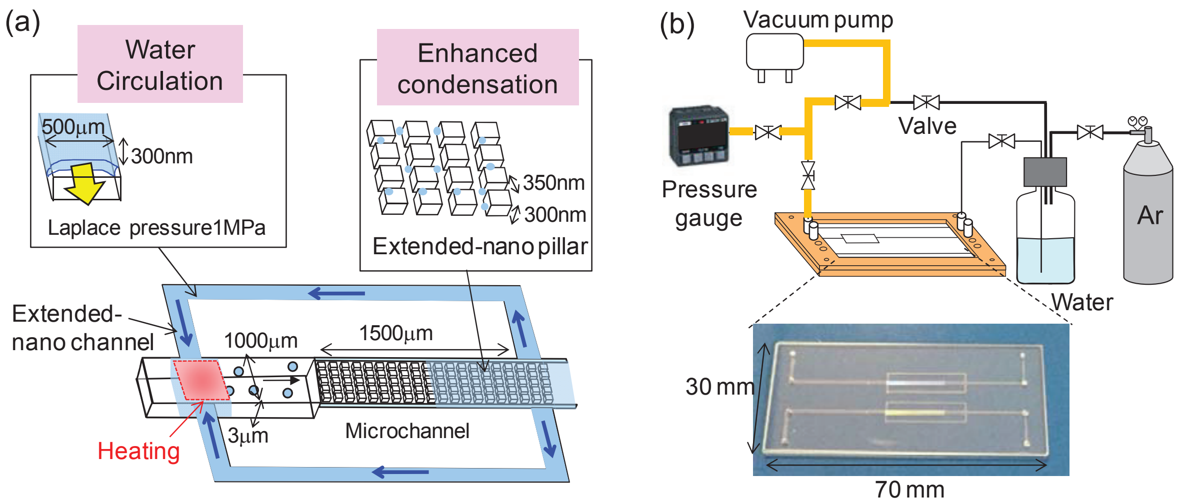

Figure 2. (a) Design of extended-nano heat pipe device with parameter and (b) Vacuum system developed for exhausting air in microchannels and introduction of water into partial channels with controlled pressure from Ar cylinder.

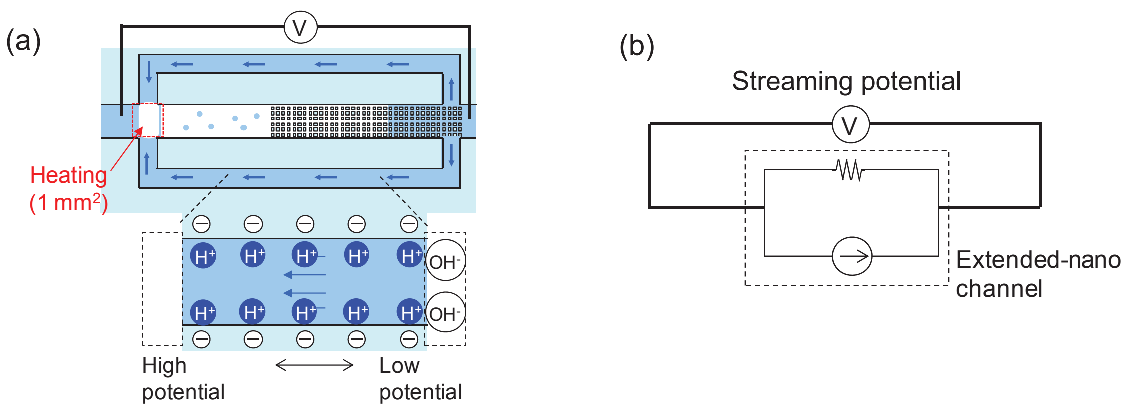

Figure 3. (a) Streaming potential measurements for monitoring of flow rate in extended -nano channel and (b) its equivalent circuit.

A vacuum system was developed for exhausting air in microchannels and introduction of degas water into partial channels with controlled pressure from Ar cylinder, as shown in Fig. 2(b). When the condensation water flows along the side channel, the glass surface charge and accumulated ions in turn generates a potential between the inlet and outlet [Fig. 3]. Streaming potential measurements were employing to monitor flow rate (~pL/s) in extended -nano channel during heat pipe working.

RESULTS AND DISCUSSION

The heating region (i.e. hot spot) was heated in the range of 50~110ºC. The water flow rates along the side nanochannels increased with an increase of heating temperature at the heating region [Fig. 4(a)], especially in vacuum environment (15 kPa). For a long-term working [Fig. 4(b] the temperature kept at 110ºC for 120 mins, the flow rate is 150 pL/s and the accumulated volume of water along extended-nano channels is >56 circulations in total. It is equivalent to a cooling performance with 3.4×10^{-4} W/cm^2, 70% of designed performance due to extremely small mass flow in 300-nm-height extended-nano channels and nanopillar. This value is expected to be significantly improved to 4.9 W/cm^2 if high aspect ratio nanopillars (height: 7 μm) are fabricated in the future work.

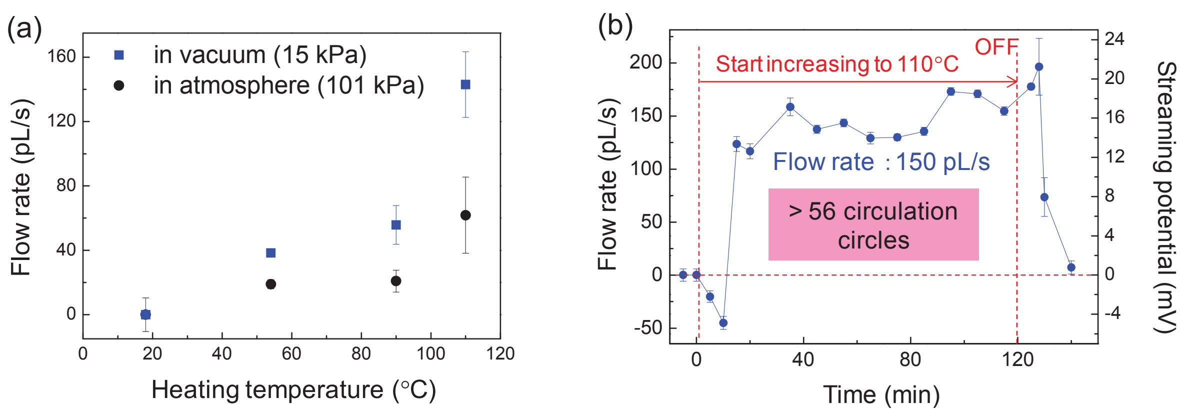

Figure 4. Flow rate along the extended-nano channel during the extended-nano heat pipe working (a) heating temperature dependence (b) time dependence

CONCLUSION

The extended-nano heat pipe device combined with the vacuum system was successfully fabricated and established for cooling the hot spot of LSI. For the performance evaluation, streaming potential measurements show flow rates in nanochannels in vacuum are 3 times higher than those in achieved atmosphere. The cooling performance is therefore significant improved, but the value is still low for the real application. We believe it has high potential to achieve a significant better performance by optimization of nanofabrication in our future work.

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CONTACT

*Chenxi Wang, Phone: +86-451-86418359; wangchenxi@hit.edu.cn