Disruptive Cold Plate configuration with self-adaptive fins for local control of heat extraction capacity

David Beberide
Universal Smart Cooling S.L
Lleida, Spain
david.beberide@uniscool.tech

Montse Vilarrubí
Universal Smart Cooling S.L
Lleida, Spain
montse.vilarrubi@uniscool.tech

Jaume Camarasa
University of Lleida
Lleida, Spain
jaume.camarasa@udl.cat

Manel Ibáñez
University of Lleida
Lleida, Spain
manel.ibanez@udl.cat

David Sancho
Universal Smart Cooling S.L
Lleida, Spain
david.sancho@uniscool.tech

Jérôme Barrau
University of Lleida
Lleida, Spain
jerome.barrau@udl.cat

***Abstract*— Nowadays, with the irruption of AI and other cutting-edge technologies, data processing needs have dramatically grown. Consequently, energy consumption in data centres has become a major concern, with cooling accounting for 30-40% of total use. This work presents a market-ready, fully validated, patented direct-to-chip liquid cooling technology for advanced electronics, offering 60% higher energy savings in cooling compared to the current state-of-the-art, and ensuring superior heat extraction under any variable heat load in time and space.**

***Index Terms*— liquid cooling, data centre, sustainability, self-adaptive fins.**

I. Introduction

Advanced thermal management is crucial in data centers due to the rising power of chips and processors, which greatly increase energy consumption and cooling demands as heat dissipation grows beyond Dennard scaling limits.[1].

Actual cooling solutions of 3D integrated circuits (3D-IC) do not provide systems able to adapt their behaviour to changing boundary conditions in time and space, which leads to overcooling when refrigerating demands are low. That implies additional pressure drops in the fluid channel and so, oversized pumping consumption for changing conditions. Also, in current solutions, the surface temperature uniformity of the chip can be optimized, when done, only for a given heat load distribution and cannot handle variable heat load scenarios [2].

This paper describes the experimental validation of a patented technology [3] developed by Universal Smart Cooling SL (UniSCool) which is designed with self-adaptive fins acting as thermal actuators to provide both an improved temperature uniformity of the electronics for spatially and temporally varying heat load, and a reduction of the hydraulic consumption as they are only activated when there is a cooling need[4], [5].

II. Working principle

The technology developed is based on self-adaptive Shape Memory Alloy (SMA) fins acting as vortex generators. The fins are used to maintain constant temperatures of the cooled device by affecting the convective local heat transfer of a liquid-cooled channel.

The principle of phase change of the materials is responsible for the smart behaviour of these fins, which are activated, without any external excitation, in function of their temperature. The demonstrated capability of flow-disturbing elements inside microchannels to enhance locally the heat extraction capacity is used only for high cooling demands; otherwise, the fins will remain in the flat position, reducing the pressure drop inside the cooling device. With this solution, the system can tailor its internal geometry to time-dependent and non-uniform heat flux distributions, optimizing the local heat transfer enhancement and the pressure drop to the instantaneous cooling need distribution and thus, reducing the needed pumping power for a more energy-efficient cooling system (Fig. 1).

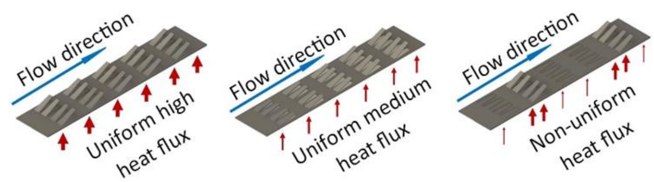

Fig. 1. Working principle of the cooling channel with SMA fins.

III. Results

First, a test has been carried out with a single fin to validate its performance to uniform the temperature and reduce pressure drop, and hence the pumping power. To do so, the heat flux is increased from 0 to 67 W/cm^2 and then reduced back to 0 W/cm^2. The inlet coolant temperature and the flow rate are maintained constant (Tin = 3 °C; Q = 320 ml/min). The temperature evolution as a function of heat flux is shown in Fig. 2. The temperature results are taken by a thermocouple located between the heater and the fin.

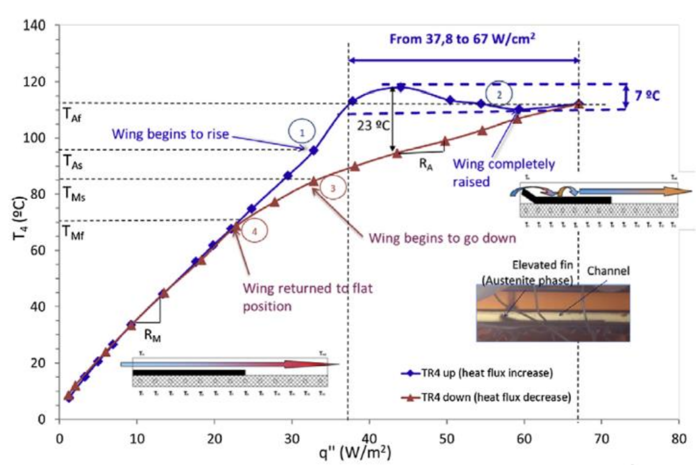

Fig. 2. Temperature evolution under varying heat flux.

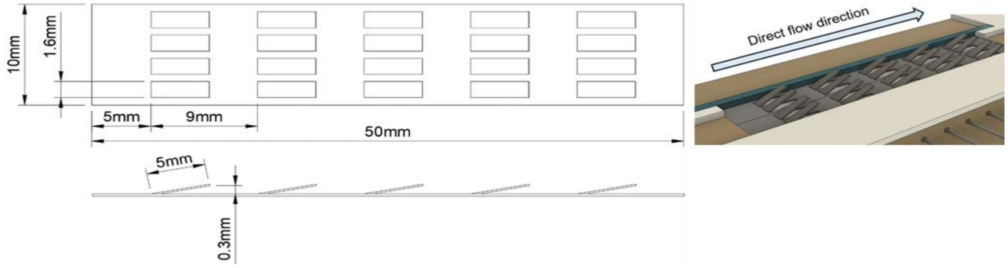

Fig. 3. Schematic of the liquid-cooled channel (left side) and isometric image of the SMA fins sample in austenitic phase (right side).

For fixed inlet coolant temperature and flow rate, the cooling device can maintain the temperature within an interval of 7 °C for heat flux variations from 32.8 to 67 W/cm2, compared to an expected increase of more than 85 °C without self-adaptation.

After the first validation, a second test is performed on a 1 mm channel height with a sample of 5 rows with 4 flaps each as shown in Fig. 3 **¡Error! No se encuentra el origen de la referencia.**. In their austenitic form, the fins can reach 30 % of the height of the channel.

This design is compared to a flat channel. A fixed flow rate of 285 ml/min is applied, with a water inlet of 62 °C and heat loads of 3 and 9 W/cm^2. The device with the self-adaptive fins manages to maintain a temperature gradient of 2 °C, which is much smaller than that obtained with the flat channel, which is 5,4 °C (Fig. 4).

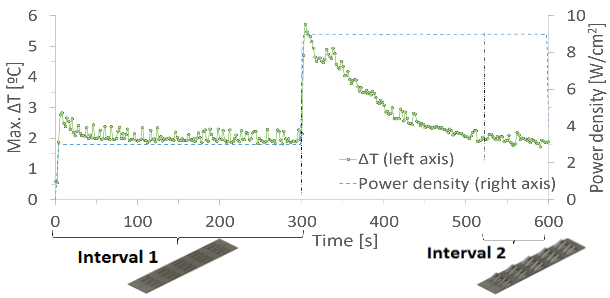

Fig. 4. Experimental maximum temperature difference along the channel with SMA fins when applying heat loads.

The heat transfer enhancement is also determined. When a low heat flux (interval 1) is applied, the SMA fins remain in a flat position resulting in the same convection coefficient as within a plain channel without fins. However, when high heat flux is applied (interval 2) the SMA fins rise to 30 % of the channel height resulting in a heat transfer enhancement about 50 % higher (Fig. 5).

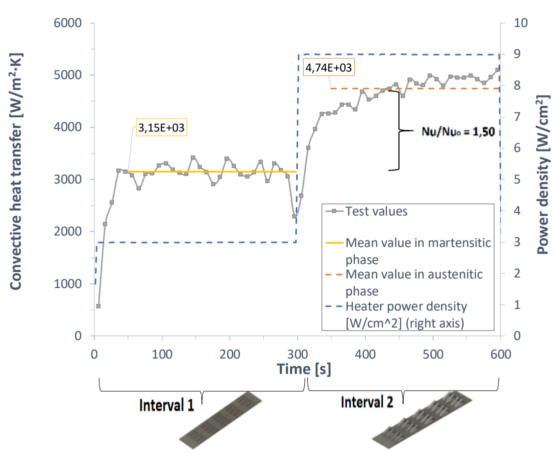

Fig. 5. Experimental convective heat transfer coefficient for a channel with SMA fins in martensitic and austenitic phases.

The self-adaptive behaviour of the fins implies that the actuators are in their raised shape only during high thermal load scenarios, thus reducing the time with additional pressure drop inside the cooling channel. Consequently, the use of self-adaptive fins offers savings in pumping power as the pressure drop is reduced to 1/3 during low thermal load scenarios compared to a system with static fins.

IV. Conclusions

The ability of UniSCool fins to maintain uniform wall temperature under varying heat flux distributions has been experimentally validated, demonstrating both enhanced convective heat transfer when fins are activated and reduced pumping power thanks to the self-adaptive mechanism. In initial validation tests, a 63% reduction in thermal resistance and a 60% reduction in pressure drop were achieved, resulting in improved temperature uniformity and significant energy savings.

Compared to current state-of-the-art technologies such as jet impingement or microchannels, this solution enables up to 60% cooling energy reduction, offering a much more sustainable approach for data centers. Its disruptive architecture, fundamentally different from conventional designs, addresses key limitations in thermal management for advanced microelectronics and high-density computing. After successful validation, the technology is now fully developed and scheduled for market launch this summer, with the potential to generate substantial impact in the data center sector.

References

[1] R. H. Dennard, F. H. Gaensslen, H. N. Yu, V. L. Rideout, E. Bassous, and A. R. Leblanc, "Design of Ion-Implanted MOSFET's With Very Small Physical Dimensions," *IEEE J Solid-State Circuits*, vol. 9, no. 5, pp. 256–268, Oct. 1974, doi: 10.1109/JSSC.1974.1050511.

[2] R. Kong, H. Zhang, M. Tang, H. Zou, C. Tian, and T. Ding, "Enhancing data center cooling efficiency and ability: A comprehensive review of direct liquid cooling technologies," *Energy*, vol. 308, p. 132846, Nov. 2024, doi: 10.1016/J.ENERGY.2024.132846.

[3] L. G. Frechette, J. Barrau, and M. Vilarrubí, "Deformable fin heat exchanger," WO/2019/165558, 2019

[4] M. Vilarrubi *et al.*, "Numerical evaluation of bimetallic self-Adaptive fins acting as flow disturbing elements inside a microchannel," *InterSociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems, ITHERM*, vol. 2022, p. 2022, Jan. 2022, doi: 10.1109/iTherm54085.2022.9899648.

[5] M. Vilarrubí, D. Regany, J. Camarasa, M. Ibañez, J. I. Rosell, and J. Barrau, "Numerical evaluation of doubly clamped self-adaptive fins acting as vortex generators inside micro heat sinks (MHS)," *Int J Heat Mass Transf*, vol. 220, p. 124931, Mar. 2024, doi: 10.1016/j.ijheatmasstransfer.2023.124931.