ELECTRONIC COOLING SYSTEMS BASED ON FIXED-VALVE MICROPUMP NETWORKS

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Abstract

Thermal control of electronics in portable computers and space vehicles where compactness, weight, efficiency, simplicity, reliability and cost are important is an area ideally targeted for MEMS-based approaches. Micropumps based on diaphragm actuation and utilizing fixed – geometry valves have the potential to meet all the above criteria when used for fluid transport in closed-loop forced-convection thermal management systems. To investigate this potential application , an integrated cooling module was designed, fabricated and tested. It consisted of a network of four planar micropumps fabricated in plastic and a copper microchannel heat sink. Plastic allowed rapid prototyping and resulted in a multilayer pump network 32x32 by 11 mm thick. Other materials could reduced the total thickness significantly. To our knowledge this work is the first application of a scalable network of micropumps. Thermal power handling of 35 Watts was possible with average pump power of 35 – 39 mW at a flow rate of 11 ml/min using water as the coolant.

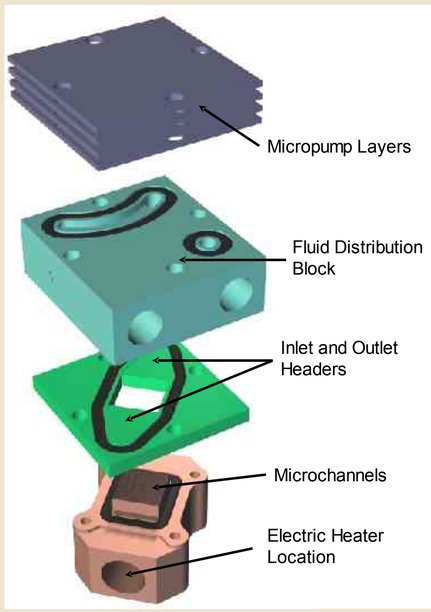

Fig. 1
Schematic of the prototype pump/heat sink assembly. The pump1 network consisted of a stacked array of micropumps to demonstrate scalability of fluid transport without increase in footprint size.

Micropump-Heat Exchanger Module

One overall goal of this project was to develop a compact micropump/heat exchanger unit, the design of which is shown in Fig. 1. For this initial study v-shaped channels approximately 60 μm wide and 200 μm deep produced with laser micromachining were utilized. For this study a network of four micropumps each with a 20 mm pump chamber diameter arranged in parallel was used to attain relatively high flow rate. The pump that was developed is shown in Fig. 2. The piezoelectric drivers were arranged electrically in pairs as shown schematically in Fig. 3. Figure 4 shows two pump layers, each utilizing different Tesla-type valves designs. The one used in the pump labeled fvp1 has been used in a number of other pump designs, while that used in pump fvp2 was determined from a computational fluid dynamics-based optimization process that substantially improved single-chamber pump performance.** Two machined 1.6 mm acrylic layers of the type shown in Figs. 4(a) and (b) were used in each of two pump pairs. Shown in Fig. 7 is a model of the test system containing the micropump and microchannel heat exchanger. Tubing carried heated coolant from the microchannel heat exchanger to a macroscopic fan-driven heat exchanger in which the fluid temperature was returned to the ambient level. Characterization of the test loop was performed with a syringe pump.

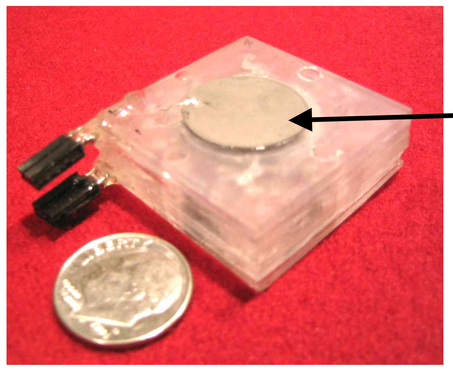

Fig. 2
Eight-layer, four-pump network fabricated in polycarbonate and acrylic for rapid prototyping. The actuator diameter is 20 mm, and total thickness is approximately 11 mm.

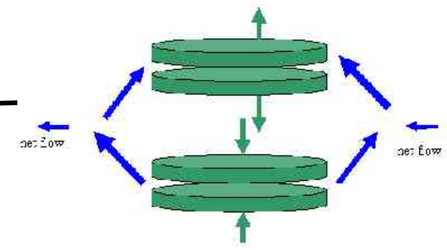

Fig. 3
Schematic of how two pairs of actuators operating out of phase with the elements in each pair operating in phase and deliver steady flow at the network outlet. Two pump chambers are positioned in between each pair of actuators. Arrows are shown for one half of a pump cycle, with relative flow magnitudes into and out of each pump chamber shown.

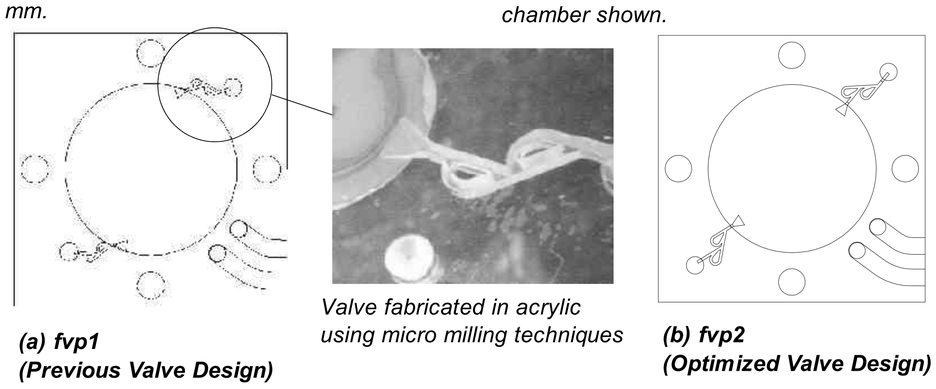

Fig. 4
Valve-pump chamber layers for micropump network. Shown are 20 mm diameter pump chambers two-element valves, each having a transverse dimension of 300um: (a) the Tesla-type A for the previous design and (b) the Tesla-type G for the optimized design. Also shown are four through holes for attachment to the heat exchanger and channels at the lower-right corner for routing electrical connections

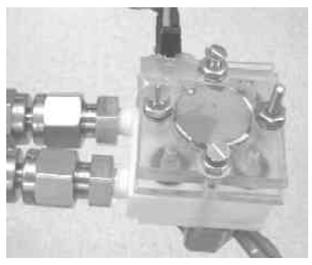

Fig. 6
The pump network/heat exchanger assembly incorporated into the closed-loop test system. Electrical leads to a 400W, 33ohms cartridge heater can be seen below the assembly

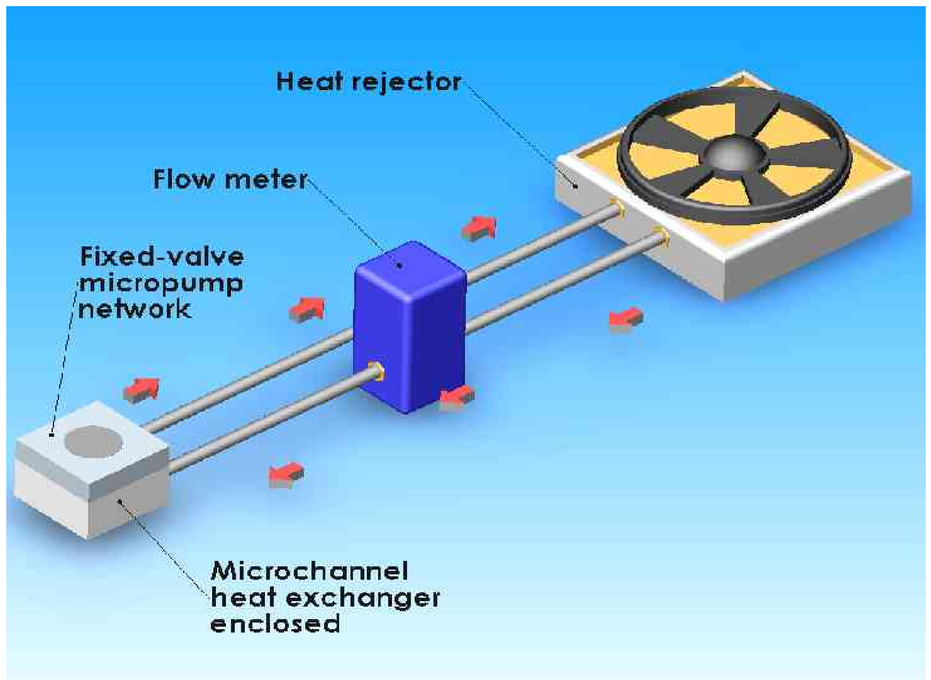

Fig. 7
A model of the test system. The micropump network and microchannel heatsink were fabricated as an integral unit to demonstrate one unit of a distributed cooling system.

Performance Comparison

	Pump-Type	Exterior Size	Net Pump Power	Max Flow Rate	Test Chip Size	Heat Removed	Junction – Ambient Thermal
Jiang et al.***	Electroosmotic	27 cm³	2000 mW	7 ml/min	1 cm²	38 W	2.5 K/W
University of Washington	Fixed-Valve	11 cm³	35 mW	11 ml/min	1 cm²	35 W	2.3 K/W

Results and Discussion

Pump fvp1 produced a no-load flow rate of approximately 11 ml/min at 100 V and 330 Hz, which was close to model predictions. Data were taken for the remaining pump over four days with the system running for up to six hours, which demonstrated that dissolved gas did not pose a problem. Flow rates delivered by pump fvp1 to the microchannel heat exchanger versus heater input are shown in Fig. 8 for various pump excitation voltages. The microchannel heat exchanger temperature T_s versus heater input is shown in Fig. 9 for the corresponding pump excitation levels. The maximum thermal power transferred to the fluid was approximately 35 W at 11 ml/min with average pump power of 35 mW. Some boiling occurred at all three pump excitation levels for T_s > 100 ºC. The junction-ambient thermal resistance for the highest micropump excitation level for T_s < 100 ºC., i.e. q < 25 W, was approximately 3 K/W. At 35 W it was approximately 2.3 K/W. The heat transfer coefficient for microchannel array ranged from 400 to 1000 W/m²K over the range of heater input and pump excitation levels considered.

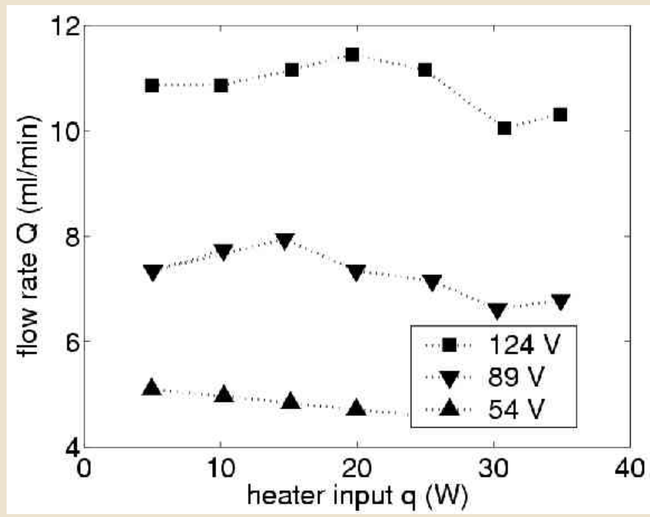

Fig. 8
Flow rate delivered by micropump fvp1 at three different excitation voltage levels versus electrical power to heater. Lines added for clarity.

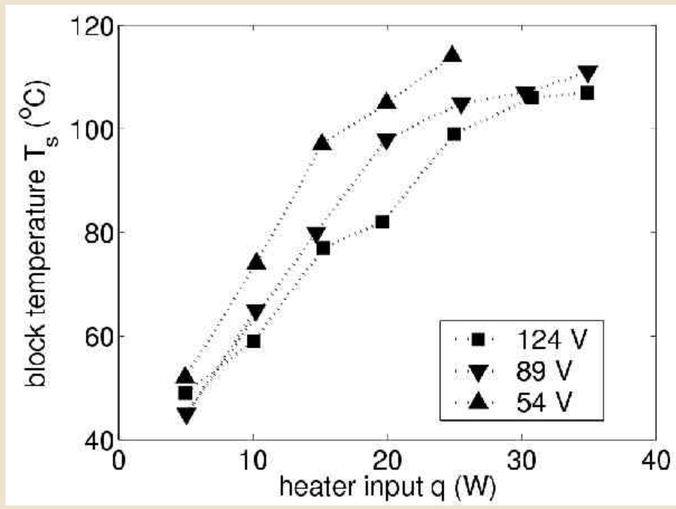

Fig. 9
Heat exchanger temperature versus electrical power to heater for a range of micropump excitation voltages applied to pump fvp1. Lines added for clarity.

Conclusion

We have demonstrated that a fixed-valve diaphragm micropump network used in conjunction with a microchannel array was capable of handling thermal loads of 35 W and 35 W/cm². The prototype system, when fabricated in plastic, produced a stacked four-micropump network with a total thickness of 11 mm. With stiffer materials, such as metal for the diaphragm, and better packaging, the overall size could be reduced significantly. Lastly, it was estimated that the net power consumption was approximately 35 mW. Thus, on the basis of these results, this approach for cooling appears to be attractive in terms of size, weight, efficiency and simplicity. Further work is needed to investigate these attributes more quantitatively along with evaluation of reliability and cost.

References

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