Micro Heat Pipe: Performance Characterization

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The silicon-based micro oscillating heat based on a dual-diameter design showed an improvement of thermal conductivity compared to the un-patterned substrate. The orientation independence was demonstrated for several fluids at different power inputs.

High energy physics (HEP) experiments and space missions impose stringent thermal management requirements. Single-phase and two-phase microchannel cooling represents an attractive solution for the thermal management of silicon pixel detectors [1] and high-performance electronics [2]. Two-phase cooling systems exhibit a better temperature uniformity and a minimal load-driven temperature variation over their single-phase counterparts. Integration of these micro channels at chip level can increase the cooling efficiency by reducing the thermal pathway between the heat source and the heat extractor. Fluidic connections and interconnections for micro channel cooling circuits remain a great challenge in particular for HEP and aerospace applications.

New modularity concepts with potential simplification of maintenance and re-workability procedures are enabled by creating two separate cooling loops. The primary cooling loop refers to the main cooling circuit, while the secondary cooling loop is formed of one, or more, micro heat pipes which are thermally and mechanically coupled to the primary loop.

Micro heat pipes come in various configurations and among them micro Oscillating Heat Pipes (µOHPs) [3] have been identified as the most promising technology to offer two-phase cooling [4]. A µOHP consists of a wickless meandering of channels partially charged with a fluid. High thermal conductivity, fast thermal response and reduced thickness are the main characteristics of the µOHPs.

The heat pipe's orientation affects its thermal performance as gravity influences it. This is also true for µOHPs with single hydraulic diameter channels. However, the dual-diameter design, as shown in Figure 1, allows orientation-independent operations when the maximal capillary driving pressure forces exceed the frictional pressure drop [5]. Figure 1 also shows a microfabricated prototype of µOHP with 400 µm deep micro channels etched in silicon and closed by a glass lid. It relies on a dual-diameter design with channel widths of 400 µm and 225 µm.

Figure 2 illustrates the thermal performance of the designed µOHP for various orientations with three different working fluids (isopropyl alcohol (IPA), acetone and C_6F_{14}) charged at 50% with the condenser's temperature set at 20°C. The thermal performance of the microfabricated device is displayed as a function of the heat input, fluid type and its orientation in four different directions. First, the addition of liquid and micro channels increases the equivalent thermal conductivity compared to a plate of glass and silicon with the same dimensions. Second, the equivalent thermal conductivity is dependent on the input power and on the fluid filling and type.

The performance in the worst orientation, when the heater is above the condenser and the µOHP is filled with acetone, is dependent on the power input: seven Watts of heating have to be supplied to activate the oscillations. Similarly, each fluid has a threshold above which the oscillations start and lead to an increase in thermal performance.

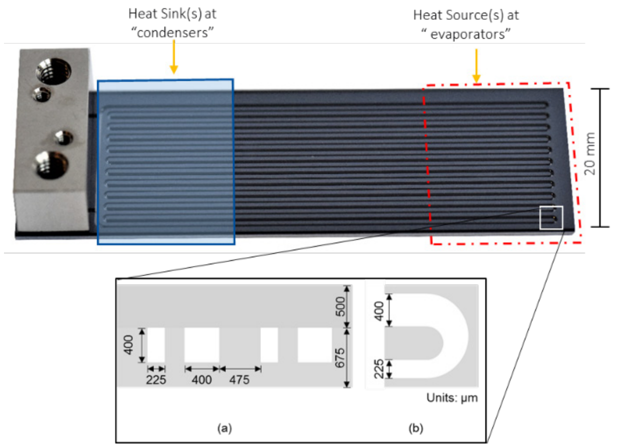

Figure 1: Prototype of the dual-diameter µOHPs. The connector is thermo-compressed to the glass using a gold-gold bond. It is used to connect the filling system. Schematic diagrams of a (a) partial cross section of micro channels with geometrical parameters and of a (b) dual-diameter turn seen from the top.

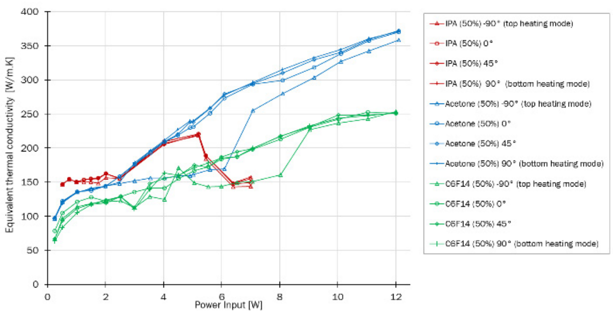

Figure 2: Apparent thermal conductivity in function of power input for one µOHP charged with IPA and acetone at various orientations for channels 400-225 µm wide and 400 µm deep tested with the condenser's temperature set at 20°C.

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