

THESIS IN HEAT TRANSFER

Experimental and theoretical studies of flat plate heat pipes made of innovative capillary structures: application to the cooling of electronic components

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Substrates with high thermal conductivity are continually under development to meet the demand of increasing power density on electronic devices. Diamond is the material having the highest thermal conductivity, but it is very expensive. Such or higher thermal conductivities can be obtained at a lower cost using a flat plate heat pipe machined in a cheaper substrate of high conductivity material like copper or silicon.

A FPHP is a cavity of small thickness, which is filled with a two-phase working fluid. In the field of electronic cooling, it is used to transport heat from electronic components to a cold source, which is generally a fan cooler. Heat sources are generally electronic components but can be any system dissipating high heat fluxes and having to be maintained at a low or a constant temperature. Vapour is generated at the heat source level and it condensates at the heat sink level. Liquid returns from the condenser to the evaporator through a capillary structure made of grooves, meshes or sintered powder wicks. Using a FPHP reduces the temperature difference between the electronic components and the cold source and as a result improves the efficiency of the electronic components and increases their lifetime.

Flat plate heat pipes (FPHP) have been widely studied in the last fifteen years, especially for their application to electronic cooling (Lallemand et al., 2004; Vasiliev et al., 2008). Although the literature on FPHP is abundant, experimental papers are relatively rare and do not provide measurements inside these systems, but only surface temperature measurements. Besides, theoretical works generally focus on capillary-driven flows and thermal models in ideal conditions, i.e. the system being optimally filled with liquid (Khrustalev et al., 1995; Kim et al., 2003; Lefèvre et al., 2008).

Since a few years, we have developed experimental benches to visualize the flow in the capillary structure of FPHPs closed with transparent plates. Different capillary structures have been studied (grooves with constant or variable widths, crossed grooves, figure 1) for FPHPs made of copper or silicon. Depending on the applications, we have tested FPHPs with different sizes and different evaporator, condenser and adiabatic areas. The behavior of those systems filled with various working fluids has been studied for different filling ratios and a wide range of applied heat fluxes.

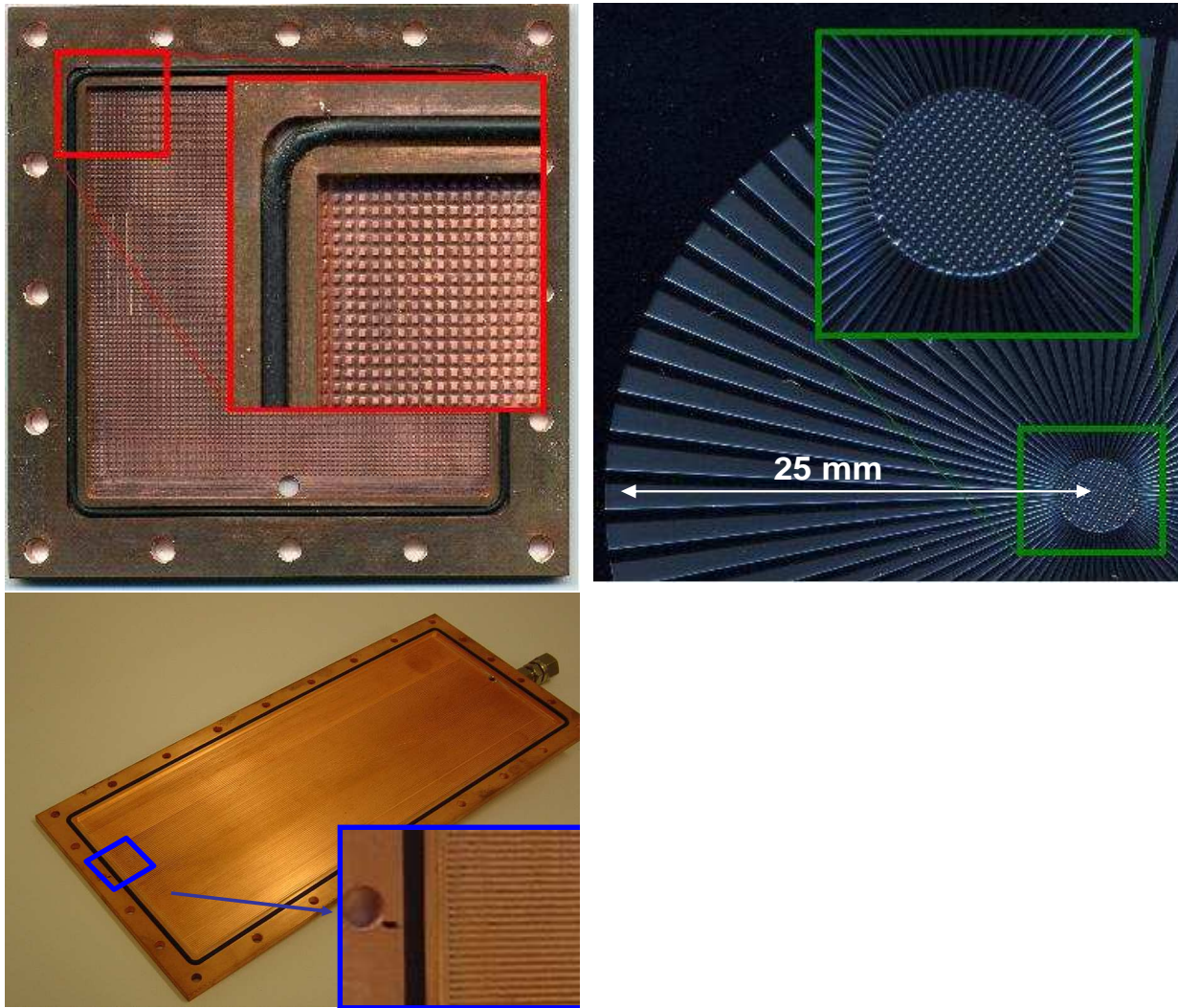


Figure 1 : FPHP made of different capillary structures

Confocal microscopy has been used more or less successfully (depending on various parameters such as the size of the capillary structure, the heat flux applied at the evaporator, ...) to characterize the liquid-vapor interface in the capillary structure (Rullière et al., 2007) and thin films of condensation on the groove fins (Lefèvre et al., 2010). This non intrusive technique allows measuring liquid films of very small thickness (down to 2 μm). Such measurements have never been provided before although they are necessary to validate most of the theoretical works published on FPHP (Lefèvre et al., 2008; Revellin et al., 2009). Temperature measurements are indeed not sufficient to validate hydrodynamic models that depend mostly on the meniscus curvature radius variation from the condenser to the evaporator. Furthermore, the temperature field in flat heat pipes depends on the thickness of thin films in both the condensing and evaporating areas. Thus, the curvature radius of the menisci is a key parameter in both hydrodynamic and thermal models of heat pipes. We have shown that the vapour space thickness has a huge influence on the liquid distribution inside the system and thus the thermal performances of FPHPs (Lips et al., 2010). We have also shown that nucleate boiling does not constitute a limit as it is generally stated in the literature (Lips et al., 2009).

If a grooved capillary structure provides very high thermal performance in horizontal location or in a zero gravity field, it is not appropriated in vertical location. Indeed, groove

characteristic length is generally too high to generate a capillary pressure higher than the hydrostatic pressure. However, in numerous applications, electronic systems can be used in different orientations. Thus, other capillary structures have to be tested such as meshes, sintered powder wick or a combination of different capillary structures. The main objectives of this thesis are to model, develop and test innovative capillary structures for the cooling of multiple electronic components. Physical mechanisms involved in those systems will be studied using confocal microscopy. These experimental results coupled with temperature measurements will be used to validate thermohydraulic models of those systems.

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