EXTENDED ABSTRACT

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Title of the contribution: A coupled model of heat spreading and flow boiling for two phase cooling in microchannels.

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Advanced cooling technologies are needed to reach the increasing heat flux density of chips, of which two phase cooling in microchannels is a promising method [1]. Single phase cooling methods require a high flow rate to absorb the high heat loads. This results in a high pressure drop over the cooling structure. Two phase cooling, on the other hand, requires much lower flow rates as it uses the latent heat to absorb the heat of the chip. In this way, cooling capacities in the order of ~250W/cm^2 can be achieved with a relatively low pressure drop [2]. Proper microfluidic flow boiling models are essential to design a high performance two phase cooling device.

In a typical two phase cooling device, the heat of the chip is first spread by a heat spreader before it is absorbed by the cooling fluid in an array of microchannels. In literature [2, 4], models to predict the maximum junction temperature of the chip treat the heat spreading and the physics of boiling separately (see Figure 1a). This assumption is inaccurate as the heat flux is a function of both the temperature of the heat spreader and the local physical state of the fluid. In order to take both effects into account, a novel model is developed, by coupling a 2D temperature model to a flow boiling model (see Figure 1b).

The two-dimensional temperature field in the heat spreader can be described by a Fourier series [5]:

$$T(x,y) = \sum_{n=0}^{n=\infty} \left(C_1 \sinh\left(\frac{n\pi}{L_x} y\right) + C_2 \cosh\left(\frac{n\pi}{L_x} y\right) \right) \cos\left(\frac{n\pi}{L_x} x\right)$$

Where, L_x is the width of the heat spreader, the coefficients C_1 and C_2 are found by the heat flux profiles at the top and the bottom of the heat spreader. The heat transfer at the bottom depends on whether the fluid is boiling or not. If not, a single phase Nusselt relation is used. If it is boiling, annular flow is assumed, and the heat transfer is calculated by the heat conduction through the liquid film. The annular film thickness is calculated using a dynamic force balance.

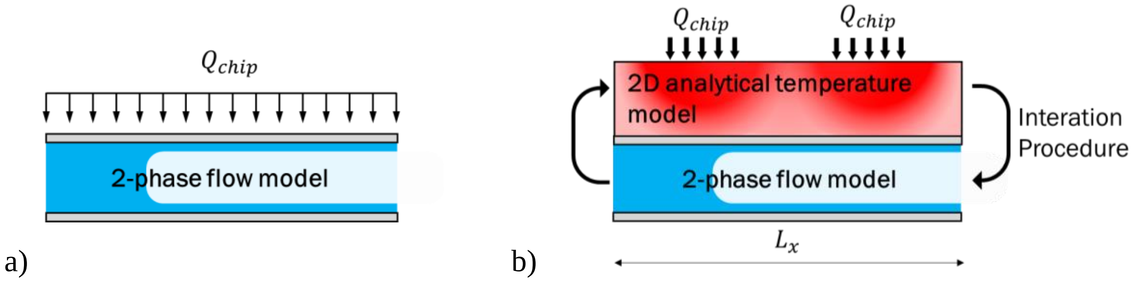

Figure 1. Schematics of different flow boiling models. **a)** Typical way of modeling: a fixed uniform heatflux cooled by a two phase flow. **b)** The coupled model for heat spreading and flow boiling.

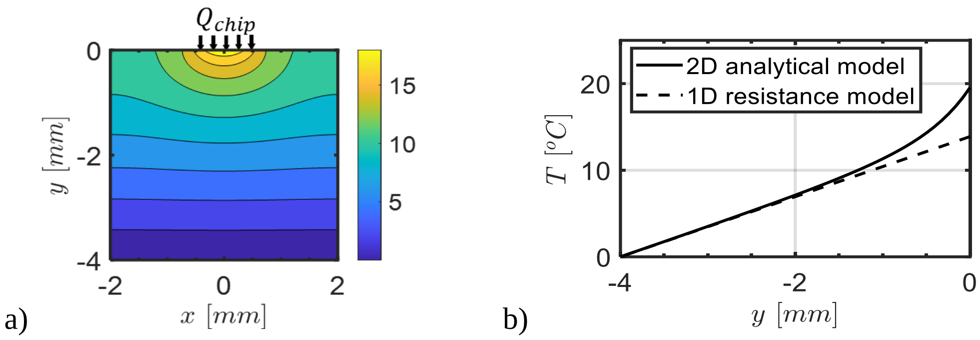

Figure 2. a) The 2D temperature field of a 1mm wide chip on a 4mm wide block, calculated using equation 1. **b)** The 2D analytical model at x = 0mm compared to a 1 dimensionsal resistance model.

To illustrate the importance of a 2D approach of the heat spreader, the temperature field inside a 4mm wide block is calculated and compared a 1D thermal resistance. A heat source of 1mm wide with a heat flux density of 250W/cm^2 is used. It is clear from the resulting temperature profile at the centreline of the domain that the 1D model significantly underestimates the temperature near the chip.

As an example of the coupled 2D temperature and flow boiling model, two chips of 3mm wide are placed on top of a 15mm heat spreader with a heat output of 250W/cm^2. The thickness of the heat spreader is first set at 1mm and is cooled by boiling water flowing through 0.3mm wide channels with a depth of 1.0mm. The resulting temperatures are plotted in Figure 3a. The peak temperatures at the top of the heat spreader are 140°C and 130°C respectively and are located at the chip interface. The temperature of the left chip is significantly higher as the heat transfer is lower at the beginning of the channel as the fluid is single phase.

To further illustrate the applicability of the model, the temperature of the top of the heat spreader is plotted for various heat spreader thicknesses in Figure 3b. If the heat spreader is too thin (0.4mm) the heat cannot spread well enough, leading to high peak temperatures (~145°C). Similarly, a too high thickness (2.0mm) will also lead to a higher temperature jump (~145°C). The optimal thickness for this chip configuration is found around 1.0mm.

The present paper demonstrates the importance of coupling a non-uniform heat flux model of the heat spreader to the cooling fluid. Both the flow boiling and the maximum temperature at the chip interface is influenced by this. As such, the coupled model presented in this paper, warrants the opportunity to design an efficient cooling device, which can achieve an as low as possible junction temperature.

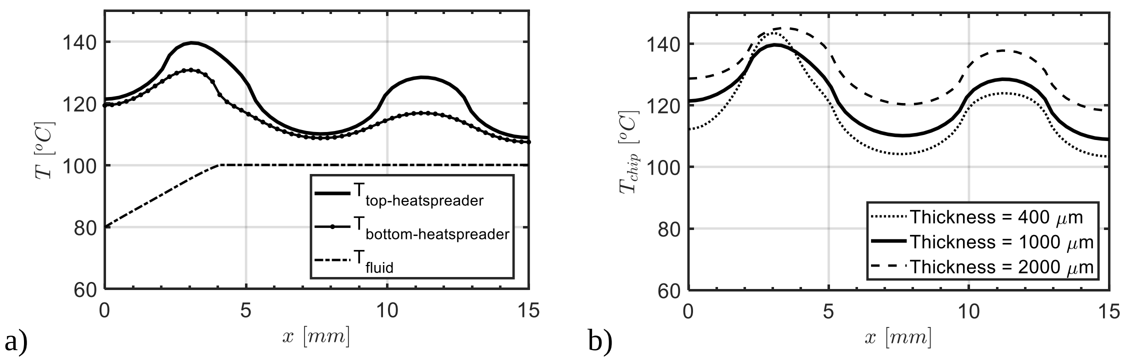

Figure 3. a) The top bottom and fluid temperature of a 1000μm heat spreader **b)** The temperature at the heat spreader-chip interface for different heat spreader thicknesses.

References

[1] Thome, J. R. (2006). State-of-the-Art Overview of Boiling and Two-Phase Flows in Microchannels. Heat Transfer Engineering. 27(9). 4–19. doi:10.1080/01457630600845481

[2] T.G. Karayiannis, M.M. Mahmoud. (2017). Flow boiling in microchannels: Fundamentals and applications. Applied Thermal Engineering. 115. 1372-1397.

[3] Sung-Min Kim, Issam Mudawar.(2012) .Theoretical model for annular flow condensation in rectangular micro-channels. International Journal of Heat and Mass Transfer. 55. 4. 958-970. ISSN 0017-9310.

[4] Thome, J.R. & Dupont, Vincent & Jacobi, A.M.. (2004). Heat Transfer Model for Evaporation in Microchannels, Part I: Presentation of the Model. International Journal of Heat and Mass Transfer. 47. 3375-3385. 10.1016/j.ijheatmasstransfer.2004.01.006.

[5] P. V. O'Neil. (1999) Beginning partial differential equations. John Wiley and Sons, INC. ISBN: 978-1-118-62994-9.