Flow Boiling in Microchannels for High Heat Flux Cooling

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ABSTRACT

Cooling of microprocessors using flow boiling of low pressure refrigerants in multi-microchannel evaporator cooling elements is a promising technique for dissipation of footprint heat fluxes of over 300 W/cm^2 while maintaining the new generation of microprocessor chips safely below their maximum working temperature of about 85°C. Boiling heat transfer in so-called microchannels has been increasingly investigated is just now beginning to achieve its technological potential. The flow boiling approach has several potential advantages over competing technologies, such as providing a nearly uniform chip base temperature, cooling of hot spots and minimizing energy consumption. The present invited lecture focuses on our own recent experimental work and our efforts to model of two-phase flow and boiling in single and multi-microchannels, covering the following topics: bubble dynamics, bubble coalescence, flow pattern recognition, a diabatic flow pattern map, critical heat flux, hot spots, flow boiling heat transfer and two-phase pressure drops.

In particular, bubble dynamics of elongated bubbles and their coalescence have been found to be a very important phenomenon that influences flow pattern transitions, flow boiling heat transfer and two-phase pressure drops. Critical heat flux at the exit of the flow channels and critical heat flux under hot spots are two important design parameters that limit heat transfer capabilities of a multi-microchannel evaporator for cooling of microprocessors. We have proposed new theoretical models for analysis of these two processes. As a flow pattern based methodology appears to be the superior approach to modelling of heat transfer and pressure drops, a new diabatic, mechanistic flow pattern map have been developed. Our work has also continued to obtain new local flow boiling data in high aspect ratio, multi-microchannel cooling elements and to test the accuracy of our three-zone flow boiling model. Some progress has been made to this end. Two-phase pressure drops are also an important aspect to consider when designing an energy efficient micro-cooling system; we have compiled an extensive database for microchannels and are developing a new annular flow pressure drop model that covers the range of laminar to turbulent flows. The lecture will focus on the highlights of our very recent work on methods for the thermal design of high performance heat sinks for cooling of microprocessors, much of which is just now being published.

Figure 1, for example, illustrates the flow boiling heat transfer coefficients measured by Agostini et al. (2007) as a function of vapor quality for R-236fa flowing in silicon multi-microchannels (0.223 mm x 0.680 mm). The results are for base heat fluxes ranging from 3.6 to 221.7 W/cm^2 (the latter corresponds to *2.217 MW/m^2*, perhaps the highest ever tested for microchannel boiling in non-aqueous tests). Figure 2 shows the comparison of their test results for R-236fa and R-245fa with the three-zone flow boiling model for elongated bubble flow, utilizing the measured surface roughness as the thin film dryout parameter in the model.

Agostini, B., Thome, J.R., Fabbri, M., Calmi, D., Kloter, U. and Michel, B. (2007). High Heat Flux Flow Boiling in Silicon Multi-Microchannels: Part I – Heat Transfer Characteristics of R-236fa, *Int. J. Heat Mass Transfer*, in press.
Agostini, B., Thome, J.R., Fabbri, M., Calmi, D., Kloter, U. and Michel, B. (2007). High Heat Flux Flow Boiling in Silicon Multi-Microchannels: Part II – Heat Transfer Characteristics of R-245fa, *Int. J. Heat Mass Transfer*, in press.

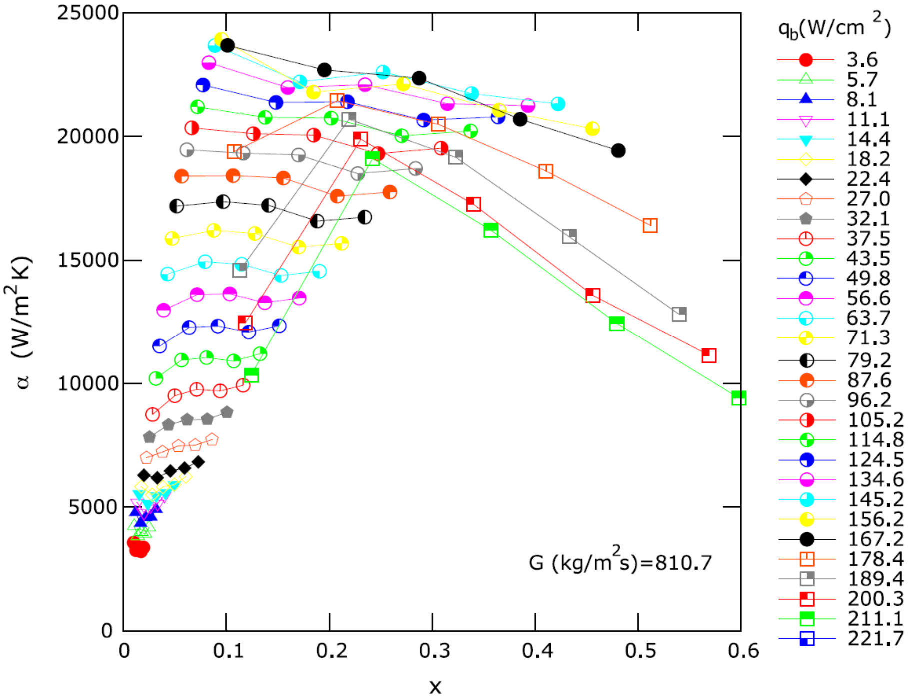

Figure 1. Flow boiling data in a multi-microchannel cooling element showing local heat transfer coefficients based on effective heat transfer area versus the local vapor quality and as a function of the based heat flux.

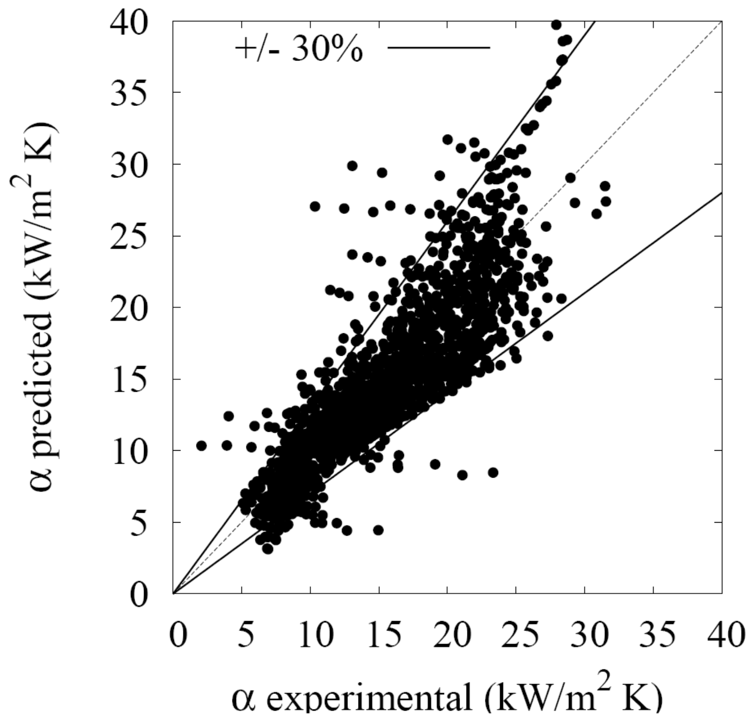

Figure 2. Flow boiling data for two refrigerants in a multi-microchannel cooling element showing their comparison to the three-zone heat transfer model.