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MICROSCALE GAS FLOWS IN HIGH HEAT FLUX ELECTRONICS COOLING APPLICATIONS

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KEY WORDS

Thermal management, phase-change, vapor, rarefied flow.

ABSTRACT

Electronic device cooling is tending towards heat dissipation requirements that are ~10kW/cm^2. This thermal management challenge arises in a number of applications. Sub-millimetre local hotspots on CMOS processors have been demonstrated to be >100W/cm^2 [1]. These local hotspots result in temperature-limited chips, and reliability problems, even with reasonably low total processor powers of order 10W. Power Amplifiers are also restricted due to thermal issues. A limited amount of power can be transmitted through the device, as heat fluxes can be an order of magnitude greater than microprocessor levels (i.e. ~1kW/m^2) [2]. In order to remove these limitations and provide more functionality from these devices in smaller spaces, advanced thermal solutions are necessary across many lengthscales. Single-phase microchannels are a promising method that have been used for direct interlayer cooling of 3D component architectures [3]. As laminar single-phase pressure drop increases at a faster rate with miniaturisation than heat transfer coefficient (D^{-4} vs D^{-1}), heat transfer enhancements and pressure drop reductions are necessary to ensure successful developments [4].

Utilising the latent heat of vaporisation is a valuable method to enhance heat transport with lower work input. Phase-change microscale heat transfer has received significant interest in recent years for cooling electronic devices with high heat flux demands. Flow boiling in microchannel arrays [5] is an ongoing area of research. The predominant challenge with this approach remains the occurrence of flow instability modes that must be suppressed without adding increased pressure drop to the cooling system [4]. An alternative phase-change approach utilises evaporation from nanoporous membranes and capillary confinement [6-8]. Narayanan et al. [6] demonstrated the potential to dissipate heat fluxes over 600W/cm^2, and hotspot temperatures approaching 95^{o}C, using an ultra-thin membrane and confined liquid film with thicknesses of ~1µm and ~15µm respectively. A similar arrangement is illustrated in Fig. 1. Evaporation was enhanced through gas-assisted advection above the membrane using dry air impingement, while liquid was actively pumped.

In an effort to develop a passively pumped system, Hanks et al. [7] presented a nanoporous evaporative device which draws liquid through microchannels beneath the membrane using capillarity, similar to that shown in Fig. 1. The microchannels create a mechanical support, reduce the thermal resistance from the heat

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source to the membrane, and also provide an even supply of liquid across the membrane pores. The thickness of the porous membrane, and diameter of individual pores, ensure that the viscous pressure drop is below the capillary pressure generated. The initial numerical simulations of this concept suggest heat fluxes of up to $5kW/cm^2$ can be achieved. However, the gas transport characteristics at the vapor side were neglected. In order to create a fully functional ultra-thin device, the vapor must be transported or manifolded towards a condenser. Lu et al. [8] modelled the non-equilibrium aspects of the pore scale evaporation to maximise performance at the local level. The impact of pore spatial distribution on net flux was considered, assuming evaporation to a far field. Knowledge regarding the interaction of adjacent pores is currently lacking, as the impact of a manifolded microscale gas flow on performance has previously been neglected.

The objective of this work is to fundamentally assess the microscale gas flows that occur in these types of high heat flux devices (Fig. 1). A combined experimental and numerical investigation will consider many lengthscales and rarefaction levels from continuum to high *Kn*, where kinetic theory approaches must be considered. The effect of pulsatile gas flow will also be included to understand the heat transport phenomena when used as a means to enhance advection. This research will provide a new insight that can be used to advance the design of high heat flux microscale evaporators for practical implementation.

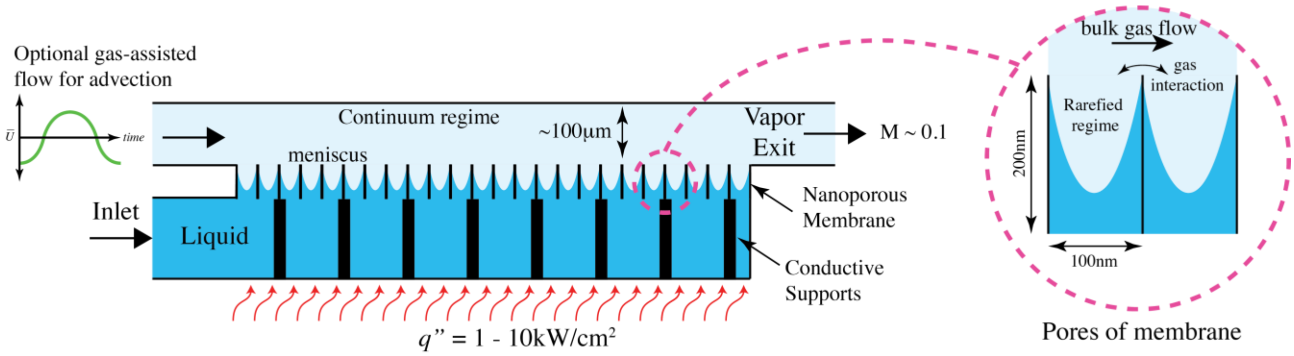

Figure 1. Microscale gas flows within a nanoporous membrane evaporator.

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