Capillary Boiling Heat Transfer on Hierarchical Microporous Surfaces

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Enhancing liquid-to-vapor phase-change heat transfer is fundamental to a broad range of industries including power generation, water desalination and treatment, chemical processing, and thermal management of electronics. For many of these applications, it is essential to design surfaces that enable both high heat transfer coefficient and high critical heat flux. However, the approaches based on capillary evaporation on wicking structures suffer from intrinsic tradeoffs between low thermal resistance and high wicking capability that make it difficult to optimize both heat transfer coefficient and critical heat flux simultaneously. In this work, we present a hierarchical wicking surface consisting of gradient micropores covered by nanostructures to achieve highly efficient capillary boiling heat transfer. By increasing the nucleation site density on the hierarchical surface, the nanostructures reduce the required superheat to activate nucleate boiling, thus decreasing the thermal resistance of liquid film compared to that of capillary evaporation at the liquid-vapor interface. Once the nucleate boiling is activated on the wicking surface, the micropores provide an additional surface tension gradient to drive continuous bubble removal from the wicking structures for delaying the formation of a vapor blanket at high heat flux. By coupling the dense nanostructure-enhanced bubble nucleation and gradient micropore-driven bubble removal, both high critical heat flux and high heat transfer coefficient are achieved on the hierarchical microporous surface.