Title: Understanding the Fundamental Degradation Mechanisms of Hydrophobic Interfaces and Surface Structures Enables the Development of Enhanced Two-Phase Heat Transfer Processes

Abstract: Almost a century ago, the concept of 'dropwise condensation' was proposed, which states that steam condensation on hydrophobic surfaces can enhance heat transfer by up to 10 times compared to traditional 'filmwise condensation'. The heat transfer enhancement may result in a 2% enhancement in energy efficiency for steam-based power plants, which are responsible for the overwhelming majority of global electricity production. The potential of dropwise condensation has driven researchers to design thin (≈100 nm-thick) hydrophobic coating materials. However, the lack of long-term (>5 year) durability has been the main hindrance to coating utilization over the past century. In this talk, I will present our most recent progress in designing thin and durable hydrophobic coating materials for stable dropwise condensation. First, I will discuss our fundamental studies probing the origin of hydrophobic coating degradation. We show that nanoscale pinhole defects in the coating are the source of steam penetration during condensation, where the condensate forms water blisters that pressurize and delaminate the coating. The understanding of the mechanics of water blister formation and growth enables us to develop quantitative guidelines for rational coating design and selection. Next, I will present the design of self-healing vitrimer thin film (dyn-PDMS) that actively eliminate coating defects to prevent the initiation of blisters. The dyn-PDMS thin film maintains excellent hydrophobicity after scratching, cutting, and indenting due to the dynamic exchange of its network strands, which represents a paradigm shift in achieving long-term durable hydrophobicity. In addition to dyn-PDMS, I will show how alternate coating such as fluorinated-diamond like carbon (F-DLC) with polymer-like low surface energy and metal-like exceptional mechanical properties can enhance durability. We show experimentally that the high bending stiffness and coating adhesion makes F-DLC durable to 5,000 cycles of mechanical abrasion and more than 3 continual years of stable dropwise condensation without degradation in hydrophobicity. I end my talk by discussing a few key applications where our work has particular impact, including frosting/icing, additive manufacturing, and flow boiling.