Droplet contact angle behavior on a hybrid surface with hydrophobic and hydrophilic properties

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A hybrid surface consisting of an array of hydrophobic and hydrophilic sites was designed and fabricated in an effort to better understand the effects of micropillar roughness on wettability. A model based on energy minimization was developed to design and predict the wettability of hybrid surfaces. Measured advancing, receding, and equilibrium contact angles fit the proposed model well. Experiments show that a higher degree of hydrophobicity results in higher contact angles and that contact angle hysteresis increases with decreasing micropillar spacing (b/a). Moreover, measured roll-off angle as an indicator of droplet shedding, decreases with b/a. © 2012 American Institute of Physics. [http://dx.doi.org/10.1063/1.4752470]

Artificial hydrophobic or superhydrophobic surfaces have been studied recently in an effort to understand the role of microscale features and surface chemistry on wettability. In general, artificial hydrophobic surfaces require a suitable type of morphology or roughness exhibiting low surface free energy when the right materials are used. Such surfaces interact with liquids in a way that results in high contact angles and low contact angle hysteresis, and shed liquids such as water easily. These characteristics are highly desirable in condensation heat transfer. In the past few years, ways to promote drowise condensation have been attempted, because in general it manifests higher heat transfer coefficients than does filmwise condensation. Liu et al. proposed an ideal droplet growth mechanism for engineered surfaces during drowise condensation. The mechanism is based on the assumption that condensed droplets fill surface cavities first while reaching a Wenzel state. Liu et al. also assumed that as droplets continue to grow, they transition to a Cassie-Baxter state, where droplets end up sitting on top of air-filled cavities. They also assumed that Cassie droplets are able to leave the surfaces at a small rolling angle. Recent studies with artificial hydrophobic or superhydrophobic surfaces have revealed that enhanced drowise condensation takes place due to enhanced droplet shedding. However, it is well known that nucleation on hydrophobic surfaces requires a higher degree of subcooling than is required for surfaces that are wetted. Thus, in order to promote droplet shedding, a hydrophobic surface is desired, whereas promoting nucleation calls for a hydrophilic surface which may result in the liquid initially wetting the surface as predicted by Wenzel theory. Fabrication and characterization of hybrid surfaces have already been carried out by Drellich et al. and Morita et al. who determined the effects of alternating hydrophobic and hydrophilic strips on droplet contact angle. Varanasi et al. investigated the effects of using hydrophobic-hydrophilic surfaces on heterogeneous nucleation. Saha and Mitra theoretically analyzed a microchannel consisting of hydrophilic and hydrophobic layers. However, few studies have been able to demonstrate the relationship between hybrid surface morphology and contact angle from the context of the Cassie-Baxter and Wenzel theories. In the current work, hybrid surfaces have been designed, fabricated, and tested under controlled laboratory conditions. The hybrid surface consists of hydrophilic tops and hydrophobic valleys or troughs to promote Cassie-Baxter type droplets to enhance drowise condensation. A model based on energy minimization has been developed to estimate contact angle on hybrid surfaces. The wetting behavior of hybrid surfaces is discussed by comparing experimental data to predictions from the model.

In order to develop hybrid surfaces which promote Cassie-Baxter type droplets, a surface-energy-based model has been developed to predict the equilibrium contact angle, accounting for surface material (i.e., hydrophobic or hydrophilic), micropillar width, micropillar height, and gap size. The model takes into account the unique topography of a designed hybrid surface as shown in Figs. 1(a) and 1(b).

The model was developed by accounting for the surface energy of a unit cell before a droplet contacts the hybrid surfaces

\[ E = \gamma_{SV1} \times \frac{a^2}{(a+b)^2} \times (a+b)^2 \]
\[ + \gamma_{SV2} \times \left( 1 - \frac{a^2}{(a+b)^2} \right) \times (a+b)^2 + 4ah \]  

(1)