Manufacturing of Surfaces with Nanoscale and Microscale Features

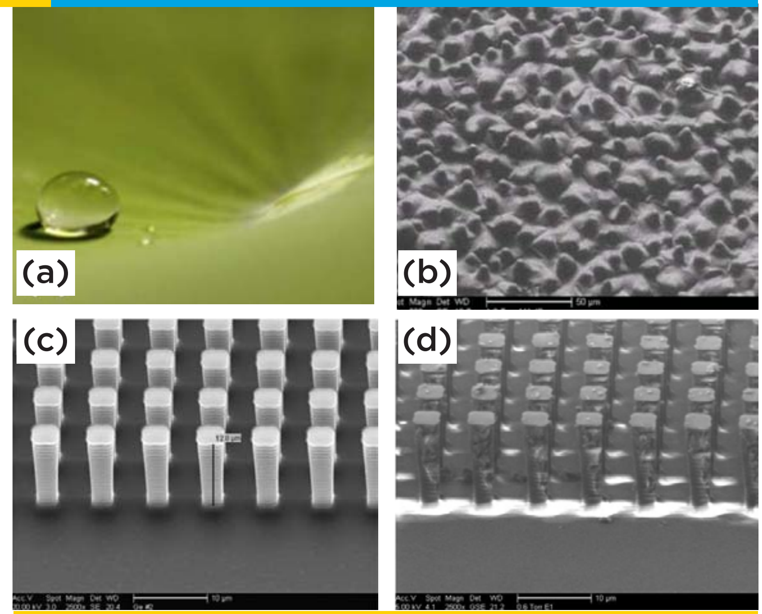
Enhanced Boiling, Condensation, and Water Repellency through the Fabrication of Structured Surfaces

In nature, extremely hydrophobic surfaces such as the lotus plant leaf are called superhydrophobic (SHP). These surfaces appear to be macroscopically smooth, but are actually composed of nano- and micro-structured surfaces, the key to their SHP properties. The industrial production of SHP surfaces, which are not yet available commercially, would enable a range of applications with far-reaching energy and environmental benefits. These applications include enhanced boiling and dropwise condensation, with potential to also reduce biofouling and other undesirable effects of water exposure.

This project is using a unique rapid tooling technique to fabricate the structured surfaces, enabling high-volume manufacturing of nanostructured surfaces with superior thermal transfer performance, enhanced water repellency, and reduced friction in fluid flow. The structured surface features that are created are as small as approximately 1µm. Air or gas gets trapped in the space between various pillars, resulting in significantly reduced contact area between the liquid droplets and the solid surface. The hydrophobicity results from the liquid forming a bridge on these rough pillars and thus, liquid touches only the peaks of these pillars. Using this approach, nanopatterned/micropatterned molds and dies are fabricated using a spray-forming process that is faster and more cost effective than conventional techniques. These molds and dies are then used to image these features onto surfaces via plastic injection molding, stamping, forging, die casting, or pressing. This approach will be extended to allow nanotextured three-dimensional shapes to be commercially manufactured at high volumes.

Benefits for Our Industry and Our Nation

The spray-forming method can result in greater productivity due to shorter manufacturing timeframes and lower costs than conventional approaches. The potential energy benefits of spray-formed tooling arise from process simplification and the elimination of energy-intensive unit operations in conventional processing such as forging, machining and heat treatment, as well as performance/productivity improvements, due to inherent rapid solidification benefits that can result in die life extension.



(a) Superhydrophobic nature of a lotus leaf surface
(b) Scanning electron microscope (SEM) image of the surface of an Idaho National Laboratory (INL) made molded polymer with surface features similar to that of the lotus leaf
(c) SEM image of silicon pillars
(d) SEM image of INL made molded polymer pillars
The image height in (b), (c), and (d) is ~175 micrometers (µm).

Images courtesy of Idaho National Laboratory.

Spray forming is also an environmentally friendly process. During spray forming, molten metal is converted to a solid deposit with a yield of about 95%. The remaining 5% of unconsolidated powder, bulk, and scrap material can be remelted and reused.

Applications in Our Nation's Industry

An appropriate structured surface that is designed for specific applications can significantly enhance boiling and condensation nucleation. As a result, this technology can be useful in a wide range of commercial and industrial applications that require boiling, condensation,water-repellent surfaces, reduced biofouling, and improved corrosion resistance. These applications include superhydrophobic dropwise condensers for the chemical, petrochemical, and power generation industries.

Project Description

This project is developing a technology to enable the imaging of nano- and micro-scale features onto surfaces. Promising applicaitons include high-volume manufacturing of boiling and condensing tubes, and water-repellent components. The technology can be demonstrated via techniques such as hot forming polymer components and stamping sheet metal. The technology can then be scaled up to transfer the nano- and micro-scale features onto complex and curved three-dimensional (3-D) surfaces.

Barriers

- Designing structured surface features on commercially viable materials, for example, copper for dropwise condensation
- Accurate imaging of 3-D tool patterns at a production-scale
- Production of 3-D tool patterns at sufficiently low cost

Pathways

This project is developing geometric designs of surfaces with superhydrophobic characteristics and low surface free energy. The designs are made specific to chosen applications, for example, enhanced boiling, condensation, or superhydrophobicity. The materials and processing conditions have been optimized to enable accurate transfer of nanoscale and microscale features onto the surface of molds and dies. Industry partners provide input on alloy choices and commercial requirements for surface fidelity. Later, R&D results from the simple mold structures will be applied to qualify the technology for more complex structures that have the added technical hurdle of 3-D component geometry.

Idaho National Laboratory (INL) has developed and commercialized Rapid Solidification Process (RSP) Tooling, a rapid tooling technology that is being used to produce molds, dies, and related tooling. The robust molds and dies can be used in a number of manufacturing processes, including stamping, forging, aluminum die casting, and plastic injection molding. INL has previously established the feasibility of this process and successfully fabricated nanotextured and microtextured molds, dies, and related tooling based on the surface structure of SHP plant species such as the lotus plant.

Milestones

This project started in October 2008.

- Design of SHP surfaces (Completed)
- Fabrication of Generation 0 (simple and planar) SHP surfaces (Completed)
- Completion of enhanced boiling surface design (Completed)
- Fabrication of Generation 1 (hierarchical) SHP samples

Commercialization

Enhanced boiling and condensation surfaces can have major impact in power and processing industries, for example boiler tubes and dropwise condensation. The INL intellectual property suite consists of five issued U.S. Patents and six foreign counterpart patents for its spray forming technology. Additional patents are contemplated from the ongoing research related to micro-structured and superhydrophobic surface fabrication technology. INL executed a field of use license with RSP Tooling, LLC (RSP) granting RSP to rights use INL's intellectual property suite to produce tools and dies for industrial applications. INL's spray-forming process greatly reduces the time and cost normally required to produce tools and dies. INL has continued its research in the area of spray-forming, which has been an integral step in fabricating micro-structured surfaces for use in other industrial applications such as boiling and condenser tube.

Project Partners

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