Porous coating protects ceramics from surface thermal fatigue

Ceramics are typically used for applications demanding mechanical and chemical protection. However, the insulating properties of ceramics usually make them unsuitable for applications in which resistance to thermal shock is required. When a cold liquid touches a hot surface—as occurs on many occasions such as in wind turbines, steam engines, or even in the bakery when making a crispy crust on bread—convective heat transfer generates thermal stresses at the surface of the material. When a ceramic is involved, it usually cracks.

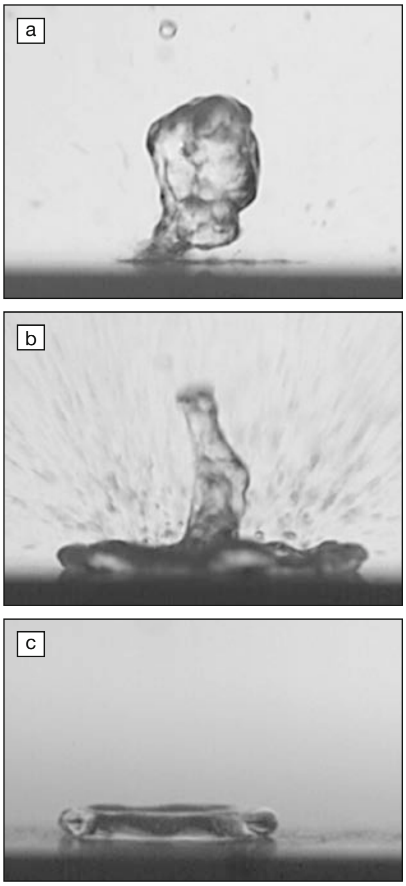
In a recent study published in *AIP Advances* (doi:10.1063/1.5041809), Divya Prakash and Youho Lee from The University of New Mexico, Albuquerque, explore surface heat-transfer of an aluminum oxide (alumina) ceramic—one of the most widely used ceramics—and propose a simple strategy to protect it from thermal fatigue-induced failure.

The researchers impacted a heated alumina surface with a cold water drop and recorded its heat-transfer modes at the surface, including a "tornado lift-off" (see Fig. a) and a water jet (Fig. b).

Since cracks are the hallmark of thermal shock, measurement of the residual strength of the material provides information about its ability to withstand sharp variations in temperature. The alumina coupons used in the study could withstand a sudden temperature gradient from 25°C to 325°C, but the strength decreased above 200°C. By relating these measurements to the surface heat flux, the researchers suggested that a hydrophobic surface containing air pockets would protect the ceramic. Upon implementing this approach by coating the alumina substrate with a porous silica layer to give rise to a contact angle of 145°, typical of hydrophobicity, the incoming cold water was found to form a planar film at the surface (see Fig. c) and the residual strength remained high up to 350°C.

These results suggest a new coating-based approach to afford thermal-shock protection to ceramics, which Lee plans to develop in the future "to enhance our current mechanistic understanding and increase the temperature range." He also emphasizes that "the surface nanostructure plays a dominant role in the rate of boiling surface heat transfer, so a hydrophobic polymer can work in similar ways." Indeed, the calculated predictions take into account the contact area between the incoming water and the surface, which is drastically reduced on hydrophobic surfaces. This strategy therefore opens up new avenues for resistance to thermal shocks in a wide range of applications.

Carolina Tallon, assistant professor at Virginia Tech, who is unaffiliated with the study, finds this work very exciting. Her group develops ultrahigh-temperature ceramics components for extreme applications such as hypersonic vehicles. "The idea of controlling the nanostructure at the surface of the material to increase the thermal-shock resistance—but also to be able to correlate the surface heat transfer experienced by the material to detect the actual thermal stress it was submitted to—will have a significant impact in the high-temperature materials community. For example, it can be used to test, evaluate, and predict the response of the ceramics in stringent conditions, where direct experimental measurements are not always feasible." Tallon cautions, though, that "in the case of extreme thermal loads as the ones experienced in hypersonic conditions, the challenge of developing a substrate that has a suitable temperature resistance, thermal expansion coefficient, and thermal conductivity still remains."



(a) Tornado lift-off of cold water impacting a ceramic heated to 175°C and (b) water jet occurring on the same surface heated to 300°C. (c) Appearance of the droplet after applying the hydrophobic coating to the alumina ceramic. Credit: *AIP Advances*.

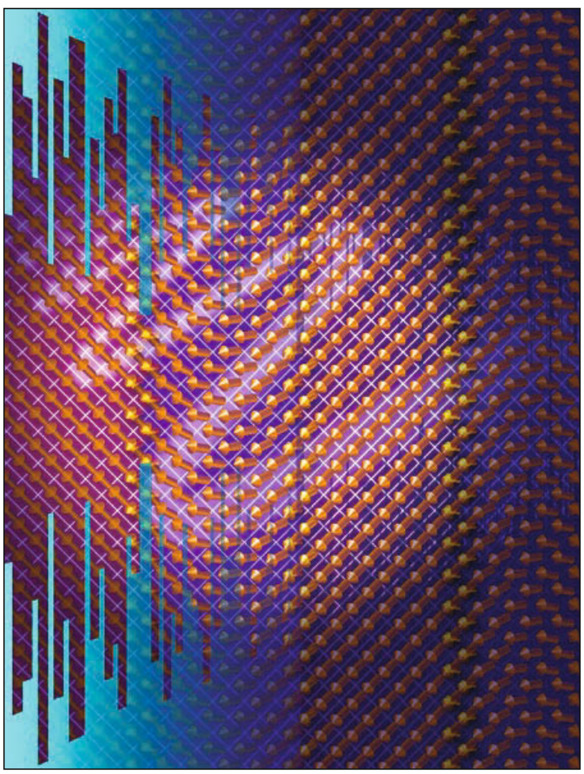
Hortense Le Ferrand

Dynamic domain walls enable ferroelectrics with GHz microwave tunability, ultralow loss

Currently, mobile devices rely on the ability to tune or switch device radiofrequency. The rising demands for device miniaturization and high data transmission rates, however, necessitate more efficient use of the microwave spectrum. An ideal thin-film dielectric would embody both high dielectric properties and wide-range frequency tunability. However, ferroelectric domain walls have been thought to lead to an unavoidable tradeoff between the dielectric loss and tunability, limiting the performance of thin-film dielectrics.

In a recent publication in *Nature* (doi:10.1038/s41586-018-0434-2), it was reported that these naturally occurring ferroelectric domain walls can also lead to extremely low dielectric loss. Researchers from Drexel University, Bar-Ilan University, the University of California, Berkeley, and the University of California, Santa Barbara, demonstrated that domain walls can oscillate under very weak driving electric fields in $Ba_xSr_{1-x}TiO_3$ (BST) films. With careful design and engineering, the domain-wall-rich films permit reduction in values of dielectric loss to those that are orders of magnitude lower than the bulk domain-wall-free counterpart, and covers gigahertz microwave-frequency range.

"Normally a domain wall is static, or it can move in one direction in the presence of a sufficiently large bias electric field. But the energy landscape of a domain wall can be engineered and tuned so that under certain conditions the barrier to its motion is small enough to permit the domain wall to move back and forth, in resonance with even a weak incident microwave field," says Jonathan E. Spanier, the leader of the research group from Drexel University.



Artist's rendering of the oscillating domain walls. Credit: Felice Macera.

Essential to the large capacitance and frequency tunability are the abundance of different thermodynamic phases and a high density of domain walls. Engineering a film material to have many and more easily available phases allows the material to attain much higher capacitance tuning with the same voltage.

"We first carried out theoretical simulations to predict the energy landscapes of domain-rich films, and then optimized the substrate materials and their thickness to achieve the desired phases and density of domain walls," says Zongquan Gu, a postdoctoral fellow from Spanier's group and the lead author of the study. "Thus far we have identified how the abundance of different thermodynamic domain-wall-variant phases can be realized to produce the desired extrinsically driven properties," he says.

The domain-wall-enhanced ferroelectrics demonstrated a microwave tunability (1~8 GHz) of the loss minimum that is 100 times greater than the previous best intrinsically tunable material. The new approaches, including design of new engineered materials that have microwave-frequency solid-state ionic oscillators, may enable more facile access to the increasingly congested radio-frequency spectrum used in current telecommunications devices, as well as other novel applications.

"This work nicely demonstrates that certain configurations of ferroelectric domain walls can really significantly enhance materials performance," says Jiri Hlinka from the Institute of Physics of the Czech Academy of Sciences. It would be great news for the development of the next generation of tunable antennas and similar microwave devices if further work can investigate whether the field-induced variation of microwave quality factor is a reproducible intrinsic property of the BST thin films, Hlinka adds.

Next, the researchers plan to expand their modeling efforts to explore other orientations of domain walls. They also plan to further probe and clarify the mechanism, and capacity for prediction of properties, in order to better design and engineer the dielectric materials.

Xiwen Gong

Energy Focus

Continuous roll-to-roll system facilitates mass production of organic photovoltaic cells

To promote the practical applications of organic photovoltaic (OPV) cells, manufacturing techniques allowing rapid and high-throughput production of highly uniform organic thin films are needed. Stephen R. Forrest of the University of Michigan and co-workers have now developed a continuous roll-to-roll vapor-phase growth system for OPV cells. This work was published in a recent issue of *Applied Physics Letters* (doi: 10.1063/1.5039701).

According to Forrest, the motivation of this work was to "test whether vacuum deposition could be combined with organic vapor-phase deposition (OVPD) in a single integrated system to produce high-performance organic photovoltaics." The core components of their apparatus include a low-pressure OVPD chamber upstream, and a high-vacuum vapor thermal evaporation (VTE) chamber downstream. Both chambers deposit active thin films from gas-phase precursors but under very different pressure conditions. Flexible indium tin oxide-coated poly(ethylene terephthalate) sheets as conveyor belts serve as the device substrate.

OPV cells were fabricated in a sequential deposition manner. First, a thin molybdenum oxide bottom layer was deposited on the substrate in the VTE chamber. An 80-nm-thick film composed of C_{70} fullerene-blended 2-((7-(4-(diptolylamino)phenyl)benzo[c][1,2,5]thiadiazol-4-yl)methylene)malononitrile (DTDCPB) was then deposited on top of the oxide in the same