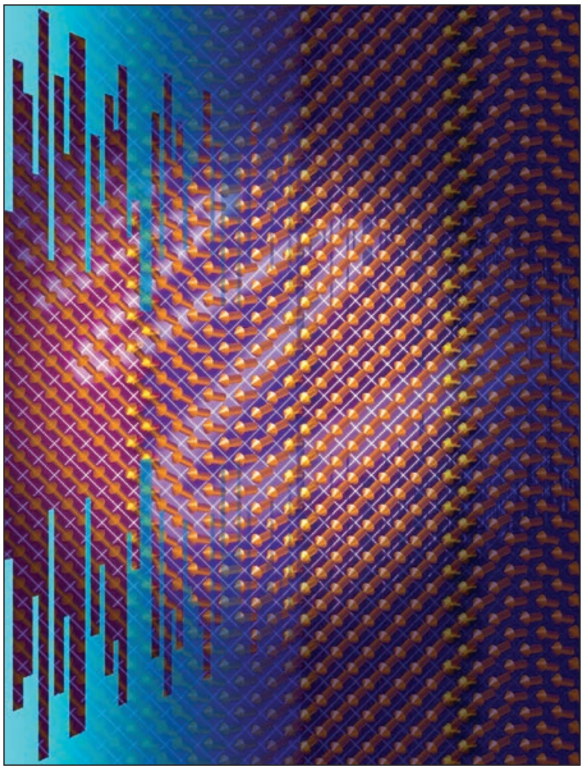
walls can oscillate under very weak driving electric fields in $Ba_xSr_{1-x}TiO_3$ (BST) films. With careful design and engineering, the domain-wall-rich films permit reduction in values of dielectric loss to those that are orders of magnitude lower than the bulk domain-wall-free counterpart, and covers 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

https://doi.org/10.1557/mrs.2018.268 Published online by Cambridge University Press

reactor. The substrate was then moved into the OVPD compartment via rollers where a buffer layer of bathophenanthroline (BPhen) with a thickness of 6 nm was deposited. The top of the multilayered film was finally capped with a 100-nm-thick Ag layer back in the VTE chamber.

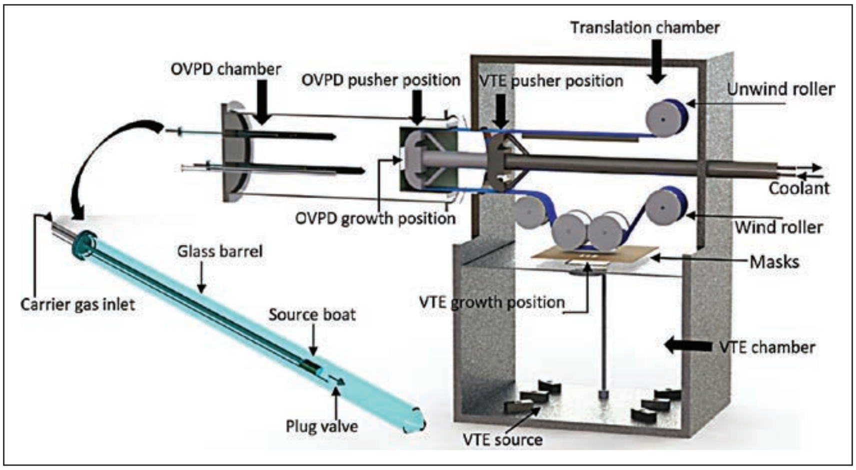
The roll-to-roll manufactured OPV cell showed excellent energy-conversion performance. It achieved a power-conversion efficiency (the ratio of output electrical energy to input optical energy) of 8.5 ± 0.2%. This value is nearly identical to those of devices produced by high-vacuum thermal evaporation, the conventional small-scale fabrication method.

Additionally, this integrated system was able to generate highly uniform films; the thickness nonuniformity of the BPhen buffer layer was <3% and the root-mean-square surface roughness was as low as 0.66 nm. This thickness-homogeneity is critical for reproducible performance and reliable long-term operation. The same setup was also demonstrated to be suitable for producing tandem photovoltaic cells with sophisticated, multilayer structures but enhanced output voltage.

Alexander Ayzner of the University of California, Santa Cruz, who was not involved in this study, says that this work "is a very encouraging demonstration that roll-to-roll processing of organic photovoltaic devices can be accomplished with nearly no loss in performance relative to conventional, small-scale fabrication methods. As the OPV field has become more mature, rapid and large-scale processing techniques are extremely important for the broad adoption of organic solar cells in industry."

The research team is interested in investigating the possibility of making other organic electronics, such as organic light-emitting diodes, with their system. "Growth dynamics under a range of manufacturing conditions [e.g., throughput, materials dependence on film properties] are all the parameters that need to be better understood in growing controlled films," Forrest says.

Tianyu Liu



The structure of the roll-to-roll manufacturing system. It integrates organic vapor-phase deposition (OVPD) with vapor thermal evaporation (VTE) techniques. Credit: American Institute of Physics.

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