layer, following the release of the twist. The intriguing transfer of chirality from the macroscale to the nanoscale occurs through the non-uniform compressive stress field that develops as the twist is released. As the nanocomposite undergoes compression during un-twisting, the non-uniform compressive stress field induces buckling of the nanocomposite layer and converts the isotropic random arrangement of metal nanoparticles into non-planar S-like chiral nanochains. The dimensions of these buckles, as well as those of the S-shaped nanochains, are comparable to the wavelength of visible light, making these structures ideal for inducing polarization rotation. The chirality of the nanochains can be increased substantially by simply applying uniaxial tensile stress to the PDMS, which accentuates the out-of-plane displacement of the S-shaped chains. Kotov and colleagues also show that non-plasmonic materials such as carbon nanotubes can also be used to create reconfigurable chiroptical materials, thus demonstrating the generality of the approach. The dynamic control of nanostructures by macroscopic stretching would be extremely useful in the optical switching of solid-state devices, as this cannot be easily achieved through static structures or by using solutions with optically active molecules.

Beyond chiroptical materials, the method of converting two-dimensional materials into three-dimensional structures by inducing buckling of rigid materials in pre-stressed soft matter could be further generalized for other nano-optical applications, including negative refraction, lensing, spectral filtering, optical nanocircuitry, photolithography and absorption control. For example, three-dimensional buckling could be used to fabricate high-inductance structures that selectively suppress absorption loss in metals within metal/non-metal composite nanostructures, enabling high-efficiency optoelectronics[8,9]. Still, to fully realize the potential of this approach and to obtain desired structures and optical properties, it will be critical to further deepen our understanding of the mechanical instabilities that take place in structures made of soft and hard materials. ❐

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WETTING

Bumps lead the way

Surfaces with slippery asymmetric bumps significantly increase water droplet condensation and shedding.

Manu Prakash

As is evident from early morning dew, grass blades can pull water out of the air. In fact, the geometry of any given surface determines the efficiency of water condensation. But what shapes lead to maximum water harvesting? Inspired by the surfaces of water-harvesting beetles and plants, Joanna Aizenberg and colleagues[1] describe in *Nature* the design and fabrication of surfaces, featuring asymmetric millimetric bumps coated with a slippery lubricant, that lead to the highest water collection efficiency reported so far for passive vapour condensation.

Water is a scarce resource[2] and such scarcity is far more pronounced in dry regions with high population densities, many of them being megacities in developing countries, such as India. Almost two-thirds of the world population, or roughly four billion people, face severe water shortage one month every year[3]. Efficient methods to capture water vapour from the air may offer alleviating solutions to this issue. Indeed, mesh net prototypes[4] have been used in the field and mathematically optimized[5] for water-vapour harvesting, but the technology needs further improvements before water-vapour capture can be deployed on a large scale.

Most water-harvesting methods require a two-step process: dropwise condensation and water transport away from the capture surface. At first glance, achieving these two requirements seems paradoxical; if a surface is designed to trigger increases in water condensation, the surface will also tend to hold onto the condensed water. Also, contact-line dynamics keeps droplets stuck in place. And droplets that remain stuck on a water-harvesting surface reduce the

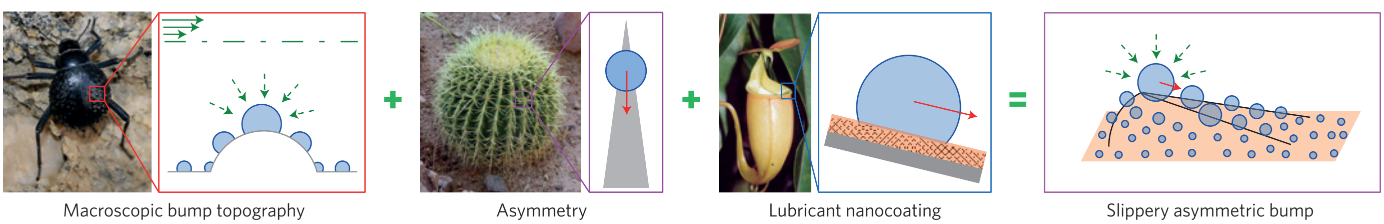

Figure 1 | Efficient passive water capture on surfaces with slippery asymmetric bumps[1]. The surfaces combine the physical principles of (i) enhanced condensation via focused diffusion flux on bumpy surfaces, (ii) the simple surface-energy minimization principle on asymmetric substrates (such as the conical shape of cactus spines) for water transport, and (iii) the reduction of contact-line pinning on lubricant-nanocoated surfaces (such as those of pitcher plants). Green arrows indicate diffusion flux and red arrows indicate droplet flow. Figure reproduced from ref. 1, NPG.

total water capture efficiency. By drawing inspiration from droplet capture and transport mechanisms in the bumpy surface of Namib desert beetles, the conical shape of cactus spines and the slippery surface of ant-capturing pitcher plants, Aizenberg and co-authors designed an integrated solution that solves this conundrum (Fig. 1). First, they show that Namib-beetle-inspired rounded and flat top bumps moulded on a flat surface significantly enhance the growth rate of water droplets at the top of the bump (when compared to featureless surfaces). As expected, shape plays a crucial role in the rate of condensation[6,7], with surface edges — such as those of grass blades — capturing more vapour[7]. This effect of focused diffusion flux is purely geometrical and scales favourably with the surface's radius of curvature.

Aizenberg and co-authors also took advantage of the fact that droplets tend to spontaneously climb away from pointy (high curvature) areas[8] — such as the tip of a cactus spine or a sharpened wire — in order to minimize the net surface energy (conical surfaces have high curvature and thus higher surface energy closer to the pointy end). The authors designed the bumps to include a gradually widening slope so as to guide the harvested droplets to move downwards by means of capillarity, thus taking the droplets away from the areas of the bump with higher water condensation rates. Moreover, the authors used their pitcher-plant-inspired lubricant technology[9] to coat the bumpy surface with a lubricant-impregnated nanotexture in order to further reduce the negative effects of contact-line pinning. The combined effects of the optimized geometry (millimetre-sized asymmetric bumps) and the slippery nanocoating led to optimal capturing and transport of water droplets.

Aizenberg and collaborators employed actively cooled surfaces at typical laboratory conditions to facilitate dropwise condensation. However, efficient water harvesting has to take place outdoors, and natural environments are harsh to most surface coatings. To translate the optimal water-harvesting surfaces into products that can be installed (in, for example, rooftops), one obvious challenge is related to the fact that the designed surfaces lack effective porosity. Unlike spider webs and the mesh nets traditionally employed in water harvesting, which are capable of handling high wind loads and can be added in series as they don't cast an effective shadow, the designed bumpy surfaces do not allow for air transport through them. Hence, the surface is only in contact with a small fraction of the available air mass and thus water vapour. Also, material scaffolds come with significant costs regarding infrastructure. It might then be best to incorporate the bumpy surfaces with already existing structures, such as the widely used tin rooftops.

Aizenberg and co-authors have cleverly combined seemingly disconnected ideas and knowledge from prior studies[6–9], which had described each of the individual wetting phenomena in detail, with observations from the natural world in order to attempt to solve the specific problem of efficient water harvesting in a potentially scalable and cost-effective manner. This is a reminder that, when looking at a natural phenomenon — such as a droplet hanging from the tip of a grass blade — it is certainly worth pondering 'how does it work?' for a little longer. ❐

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HYDROGEL COMPOSITES

Shaped after print

A plant-inspired approach can be used to print hydrogels that dynamically change shape on immersion in water in order to yield prescribed complex structures.

Michael D. Dickey

By exploiting local changes in swelling to generate internal pressure, plants can adjust their physical form in response to humidity, temperature, light and other stimuli[1]. The presence of stiff, oriented cellulose fibres within the plant gives the resulting movement directionality through differential elongation (thus avoiding uniform swelling). Man-made materials, however, have not yet reached a comparable level of sophistication in terms of shape adaptation to external stimuli. Having taken inspiration from the shape-morphing capabilities of plants, Jennifer Lewis and colleagues now demonstrate in *Nature Materials* that printed hydrogels containing cellulose fibrils aligned within the printed structures change shape in a predictable manner when immersed in water[2]. The aligned fibrils cause the individual printed filaments to swell anisotropically, generating stresses that transform a flat, printed mesh of filaments into predetermined, complex 3D shapes.

Stiff fillers are often added to polymers to create composites with enhanced properties. For example, embedding aligned carbon fibres in an epoxy matrix greatly enhances the strength of the resulting composite in the direction of fibre alignment. A number of methods allow for the uniform alignment of high-aspect-ratio fillers within a composite, but few techniques are able to pattern or deposit voxels of a composite material with controlled local alignment of the fillers. Lewis and colleagues aligned cellulose fibrils locally by taking advantage of the shear forces that arise when dispensing a fluid through a nozzle[3] (Fig. 1a). The nozzle dispensed the resulting fibril-containing filaments in precise locations in order to form a structured composite. Photopolymerization of the printed filaments formed a hydrogel that secured the orientation of the fibrils within the filaments.

It is possible to induce hydrogel sheets to bend by joining together two or more gels that swell differentially. Differential expansion has been applied to programme the shape of a variety of 2D polymer sheets to induce out-of-plane bending[4], and similar principles have been utilized