the use of increasingly longer wavelengths. As CPA schemes have evolved and reached maturity, further progress towards shorter pulses, higher intensities, or greater pulse energies has slowed. At the same time, the optical parametric variant of CPA, termed OPCPA, which operates in the mid-infrared is rapidly developing, offering higher energies with a temporal duration of just a few cycles of the optical field.

When these mid-infrared OPCPA sources are focused to a tight spot, the resulting physics is remarkably different from similar experiments in the near infrared and much more dominated by the wave picture of light than by photons and tunnelling. In the emerging semi-classical picture, the much longer cycle duration leads to elongated trajectories that can extend tens of nanometres away from the parent atom[6].

Apart from the megafilamentation behaviour seen by Tochitsky et al., mid-infrared ultrafast nonlinear optics opens the door to the high-harmonic generation of much more energetic soft X-ray photons than is possible with conventional CPA. In particular, the generation of Cu Kα X-ray femtosecond pulses for structural dynamics investigations greatly benefits from long-wavelength drivers[7]. Again, a similar picture is invoked to explain the resulting remarkable efficiency, namely Brunel heating of a metal surface. Still, while exploiting the same physics, all these OPCPA sources are dwarfed, both in terms of wavelength and energy, by the CO_2 laser used in the current experiments. ❐

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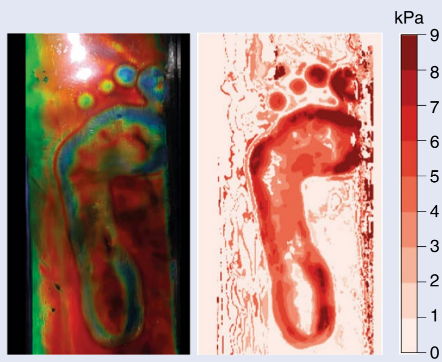
FABRICATION

Nano goes big

Roll-to-roll, metre-scale, hydroxypropyl cellulose mechanochromic laminates, using continuous coating and encapsulation, have now been demonstrated by a team at Cambridge University (*Nat. Commun.* **9**, 4632; 2018). Hydroxypropyl cellulose, a derivative of cellulose, can exhibit Bragg-based colour thanks to helical nanostructures. The periodicity of the structure (and also colour) is pressure-sensitive, opening possibilities of displays, sensors and other applications. The team quantified the pressure-induced hue change and investigated real-time pressure distributions and temporal evolution of a human footprint (see image); the pressure maps can be read out with standard cameras, such as those built into a mobile phone.



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The corresponding author, Michael De Volder, told *Nature Photonics* that exciting developments in photonics and nanotechnology often fail due to high manufacturing costs. Their main motivation was to develop advanced nanomaterial self-assembly processes directly into scalable roll-to-roll manufacturing. He explained that too often scientists ignore how to make things on the nanoscale and that with their approach they aimed to overcome the 'valley of death' between lab demonstrations and industrial development.

"With the process developed in our *Nature Communications* paper, we are able to fabricate square metres of a mechanochromic material made of a biocompatible polymer that allows for low-cost 2D pressure mapping using colour tracking," explained De Volder.

The self-assembly of materials on a continuous roll-to-roll coater, where both the material deposition and device packaging are achieved simultaneously, is a unique fabrication process according to De Volder. Additionally, that the pressure read-out of the mechanochromic films is possible with a simple mobile phone camera is another important experimental aspect.

The most challenging part of the work was controlling assembly at the nanoscale, in particular since low cost requires significant coating speeds. This means that more raw nanoparticles are required than are typically available at an 'early science' stage. Fortuitously, cellulose forms bulk nanorods that can be assembled.

A wider issue, De Volder explained, is challenging nanoscientists to move from the test tube to realistic advanced film production and that very broad interdisciplinary teams are needed.

"Besides the functional developments we show here in making colour-changing films that can watch the gait of people walking, such photonic films can find applications in monitoring of engineering structures like bridges, banknote security and even colour-changing clothes." De Volder also summarized the team's hopes more broadly: "We hope this exemplar inspires the community to look to create many more photonic nanomaterials at scale and triggers increased scientific interest in addressing the crucial manufacturing challenge."

Moving forwards the team is working on a new development, aimed at creating vast, flexible, building-scale display screens. The creation of such 'colour-changing wallpapers' may soon be feasible with new means to integrate low-cost sustainable materials via roll-to-roll into films. ❐

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