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From molecular morphogenesis – towards autonomous material robotics

Autonomous material robotics would combine sensing, actuation, memory in a material and enable interactions with its environment. Our work on combinatorially inter-penetrating functional phases in materials has brought this conceptually to an achievable level.[1] We achieve predictability in multifunctional synthesis and show just 3 phases of 20 already optimized functions would lead to over 8000 trifunctional materials. We demonstrate such interpenetrating networks with the separate individual functions, as well as emerging effects.[2] In addition to internally structuring bulk materials only, we also report on methods for bottom-up scalable manufacturing (growing) of complex macroscopic particles and active structures. Growing by nano-assembly could replace the current planar lithographic processing and its relatively low throughput and expensive infrastructure. Bottom-up methods we have developed are scalable with high energy and material efficiency, and additional opportunities to shape objects in 3D, not available in top-down lithographic methods. In collaborations with the University of Sofia, we have reported novel molecular-to-macroscopic ordering mechanisms to direct growth, shape change, and induce spontaneous symmetry breaking that address fundamental questions in materials science, chemistry and physics. By coupling molecular phase transitions in liquid droplets[3], without any external applied fields, are able to generate a number of regular geometric shapes, including octahedra, hexagons, rhomboids, triangles and fibers. This rich behaviour is the result of an oil plastic crystal phase with a special curvature forming at the oil/water interface, which counteracts surface tension, but at the same time is modulated by the surface tension. The competition of forces of similar magnitudes gives rise to such rich shape behaviour even from a single phase transition. We have described over 70 systems of oils and surfactants exhibiting this shape change (including triglyceride oils), making this a general phenomenon with good thermodynamic underpinnings.[4] We explain this general behaviour, the transitions between these shapes, and methods to control them in both the liquid and solid state. We have since classified a number of functional classes of oils that can be shaped in this manner, and produced a theoretical model which explains the sequence of multiple symmetry shapes as a competition between the frustrated formation of a plastic crystal phase at the surface of the droplets opposed by increasing interfacial energy.[5] Most recently we have also discovered we can drive an emulsion system to smaller and smaller droplet sizes (and higher and higher energies) by harnessed thermal fluctuations in the environment.[6] I will outline a number of implications for further fundamental discoveries and for potential applied explorations we are pursuing in symmetry breaking, manufacturing and nanoscience.

Biography

Stoyan Smoukov is Senior Lecturer at Queen Mary University of London and led the Active & Intelligent Materials lab since 2012 at the University of Cambridge. He has published more than 70 journal papers, cited over 2100 times, with H-index of 22, co-founded a startup company for producing nanofibers, and is leading the work on a number of European projects and industrial collaborations. His current research interests are focused on the fundamentals of confinement, multi-responsive materials, as well as geometry and processing technologies for achieving responsiveness. The longer term goal is to create autonomous material robotics, where the materials themselves are the robots.

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