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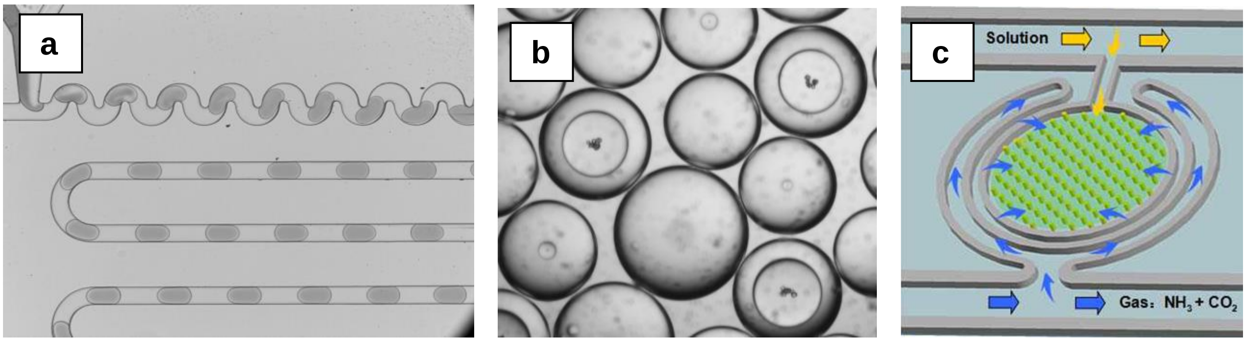
Microfluidic Systems as Nanoscale Reactors for Crystallization Studies

Control over crystallization to yield particles with defined sizes, shapes, polymorphs, and orientations is a subject that attracts huge interest, finding applications in the production of pharmaceuticals, biomaterials, ceramics and nanomaterials. The formation of biominerals such as bones, teeth and seashells, provides a unique inspiration for the control of crystallization processes, where these exhibit complex morphologies, hierarchical structures and superior mechanical properties that go far beyond those of their synthetic counterparts. All this is achieved in aqueous solution at room temperature. Identification of the strategies that nature uses to create biominerals therefore promises the ability to translate these to synthetic systems (1, 2).

A key feature of biological systems is that they are dynamic and typically operate under non-equilibrium conditions. They also occur within confined volumes rather than in bulk solution. These conditions have seldom been investigated experimentally. This project will profit from advances in microfabrication techniques to use microfluidic devices to investigate how organisms control crystallization processes. Our ultimate goal is then to apply these biogenic strategies to the synthesis of functional materials. Microfluidics is a multidisciplinary field that focuses on the control and manipulation of fluids within channels on the sub-millimeter scale, and has been widely used in analytical science and chemical synthesis when only small volumes of reagents are available ("lab-on-a-chip technology"). Microfluidic systems therefore provide a unique and straightforward way of studying dynamic processes – and their ability to offer control over confinement, flow and spatial organisation – makes them excellent mimics of biological systems.



(a) Droplets created in a microfluidic system and (b) crystals in double emulsions and (c) the crystal hotel

We will investigate crystallization within a wide range of microfluidic devices, including single (Fig a) and double emulsion droplets (Fig b) and a "crystal hotel" (Fig c). Droplets provide very well-defined reaction environments, where we can perform multi-step reactions and control the reaction conditions (3, 4). Their excellent time resolution also allows us to study crystallization mechanisms. Our "crystal hotel", in contrast, is designed to provide a series of confined reaction volumes of well-defined shape, size and internal patterning, into which a controlled flow of reactant ions and additives can be achieved (5). This will be used to generate single crystals with pre-defined macroscopic shapes, patterned microstructures and crystallographic orientations and will be explored to create complex 3D structures with nanometer-scale features of technologically-important single crystals for applications in areas such as optical devices. This project will give experience in microfluidic systems, crystal growth techniques and a wide range of analytical methods including scanning and transmission electron microscopy, X-ray diffraction, Raman microscopy, atomic force microscopy and IR spectroscopy.

References

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