4cl Microfluidic Systems for Colloidal Materials Processing

Saif A. Khan and Klavs F. Jensen

My doctoral work explores microfluidic approaches for synthesis and surface-engineering of colloidal particles with size and structure-based tuning of optical and chemical properties.

Colloidal particles of silica, titania, and related materials have many applications in diverse fields ranging from optical coatings and photonic band-gap materials to health care products. Engineering the optical properties of materials by manipulating composition and structure on length scales smaller than the wavelength of light is one of the key focus areas of the rapidly growing field of ‘nanophotonics'.

Producing well-defined and controllable nanoscale structures requires precise concentration and temperature control over very small length and time scales, as well as tailored (and often complex) modes of contacting the reactants. Conventional batch processing techniques have several limitations: rapid mixing usually involves mechanical agitation such as stirring, and thus very high liquid shear rates. This can be deleterious to the product in several ways. It can cause undesirable spatial and temporal distribution of nucleation events during nanoparticle synthesis. Shear-induced agglomeration of colloidal particles is well documented, and leads to irregular shapes and sizes of growing nanoparticles.

Microfluidic systems have been used to demonstrate a variety of chemical and biological processes that require rapid temperature and composition control. Microfluidic reactors for continuous nanoparticle synthesis have been recently demonstrated. Nanoparticle surface-engineering involves post-synthesis addition and mixing of reagents to the synthesized particles. Photolithography-based microfabrication allows complex multi-step reactant addition schemes. Segmented gas-liquid microflows enable rapid mixing of nanoparticles with the added reagents, which is difficult to accomplish using more conventional diffusive micromixing techniques. Hence microfabrication, in conjunction with segmented flow, opens the door to the continuous synthesis of tailor-made nanostructures.

We have developed microfluidic chemical reactors for the continuous synthesis of colloidal silica and titania particles. It is possible to synthesize particles having narrow size distributions with results comparable to or better than conventional batch synthesis techniques. We have also developed microfluidic reactors for the coating of sub-micron colloidal silica (or titania) particles with thin layers nanocoatings of titania (or silica) that impart unique optical properties. We have carried out extensive experimental characterization of transport and reaction in microfluidic segmented gas-liquid flow. The segmentation of the flow ensures rapid mixing of added reactants with the suspended particles, and also narrows residence time distributions. We have also developed continuous electrophoretic separation units for online particle separation. The key advantage of moving to the microscale is the ability to continuously synthesize multi-level nanostructures with precise control over the morphology, state of aggregation and surface functionalization.

My doctoral work has exposed me to a broad range of experimental tools such as silicon microfabrication, soft lithography, SEM, TEM, X-Ray Photoelectron Spectroscopy, dynamic light scattering, Particle-Image-Velocimetry, and fluorescence microscopy. My research interests include multi-phase chemical reaction engineering, microfluidics, and modeling nanomaterials using computational quantum mechanics.

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