Micromixer assisted continuous flow synthesis of nanoparticles of binary compounds and their application

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Abstract

In this work, continuous synthesis routes for binary nanoparticles using advantages of microchannel mixing (low diffusion distances and higher mass transfer) and fast heating rates provided by ultrasound induced heating are investigated. In addition, the application of silica nanoparticles in anti-reflective coatings on glass and understanding the structure-property-performance correlation in these coatings is investigated.

Batch synthesis of nanoparticles often results in wide variation of particle size, less control over particle shape and involves long processing times along with creation of large volume of chemical waste. By carrying out mixing in a microchannel mixer for nanoparticle synthesis the above issues can be resolved. Engulfment flow in T-micromixers has been reported to be a good mixing condition at Reynolds no above 250 for water. Typical T-mixer based continuous synthesis chemistries use low flow rates with low throughputs and use flow regimes less than Re 250. At these regimes there is no mixing enhancement as the flow is still stratified and diffusion occurs only at the symmetry line where two fluid streams come in contact. While engulfment flow in T-shaped microchannel mixers has been shown to provide better mixing characteristics, very little work has been reported to date on exploiting these findings for nanoparticle synthesis. In this work, engulfment flow – mixing condition is used to drive ceria nanoparticle synthesis and control over particle size, shape and crystallinity is exhibited using this approach.

Processing becomes harder to control in batch synthesis especially when higher than room temperature reactions are involved in nanoparticle synthesis. The objective is to investigate the fast heating rates provided by cavitation in a liquid subjected to ultrasound exposure in a low volume continuous flow reactor for synthesis of cadmium sulfide nanoparticles. Batch synthesis of cadmium sulfide typically takes two hours for completion. Again, by employing an upstream mixing stage using a T-micromixer and subjecting the mixed reactants in small control volumes to high intensity ultrasound the processing time is reduced to less than a minute. Under comparison, continuous synthesis yields an average size of 22 nm with a coefficient of variation of 25% suggesting better process control. High aspect ratio nanoparticles in the shape of hexagonal platelets with uncommon cubic crystal structure for CdS were synthesized using this approach. Typically, temperatures above 800°C are used to produce high aspect ratio CdS nanoparticles and yields hexagonal crystal structure. This approach appears to stabilize the metastable cubic CdS.

While exhibiting better control over nanoparticle characteristics, to use these nanoparticles in an application requires investigating the fundamental correlation between structure-properties-processing. Synthesized silica nanoparticles used to develop gradient structure based anti-reflection coatings on glass substrates are evaluated. The term Biomimetics refers to replicating applications from nature. Motheyes have subwavelength structures that reduce reflection of light and ensure higher percentage of light transmitted for better vision. In this work, silica nanoparticle based anti-reflection coatings that have a gradient structure similar to motheye that are tuned towards solar cover glass applications are produced and studied. Since solar panels are exposed to elements of nature, optical performance has to be complemented by mechanical durability. Optical and abrasion performance are evaluated in light of the mechanical properties and physical structure of the films using mechanistic and statistical models. The results suggest that the mechanical performance of these gradient coatings can be modified without adversely affecting optical performance in the design of these coatings.

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