

CONTROLLED QUANTUM DOT SYNTHESIS WITHIN MICROFLUIDIC CIRCUITS

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Abstract

Nanocrystalline semiconductors are of considerable scientific and commercial interest owing to their tuneable optical and electronic properties, and potential applications in a wide range of electronic devices. We show that the use of microfluidic synthesis procedures offers distinct advantages over bulk scale fabrication procedures for the production of nanoparticles. The small size of the microreactor ensures that thermal and chemical homogeneity pertain throughout the entire reaction volume, leading to well controlled reaction conditions.

Keywords: semiconductor, nanoparticle, microreactor, quantum dots

1. Introduction

In the last decade semiconductor quantum dots (QD) have become the subject of one of the most rapidly growing branches of chemistry and physics. QD's or nanoparticles (NPs) are in the transition regime between molecules and the bulk material. Due to quantum confinement effects NPs show unique physical and chemical properties such as size-dependent band gap shifts and size dependent photoluminescence. Currently there is considerable interest in synthesizing nanoparticles of well-defined sizes [1]. One of the primary challenges associated with the synthesis of NP's is the ability to limit the size of growing clusters and to prevent them from interacting with each other. To date, techniques for producing highly monodisperse nanoparticles have been relatively complex and involve multiple processing steps. Herein we show that by using a continuous flow microreactor [2], operating within Low Reynold's number regimes, we are able to synthesise and control the size and monodispersity of certain nanoparticles.

2. Experimental

To generate CdS nanoparticles stock solutions of $\text{Cd}(\text{NO}_3)_2 \cdot 4\text{H}_2\text{O}$ and Na_2S were prepared at concentrations of 4×10^{-4} M and hydrodynamically delivered into a microfluidic channel network at various flow rates (1-600 $\mu\text{L}/\text{min}$). The outlet flow from a microfluidic reactor chip was coupled to a quartz flow cell and absorption spectra were taken. The microfluidic chip used is a two-layer device made up of a glass/silicon/glass sandwich and has an internal volume of 600 nL. Two inlet flows are split into a series of separate multichannel streams (16 partial flows). This is achieved

by repeated splitting of the channels in such a way that an array of symmetrical elements results. Wafer-through nozzles connecting the two fluidic layers allow the two liquid streams to converge and mix. Channels are then sequentially combined in a reverse network until all partial flows are united in one broad outlet channel.

3. Results and discussion

Absorption spectra of CdS colloids obtained at flow rates ranging from 0.025 – 0.30 ml/min are shown in **Figure 1**. The maximum gradient of absorption profiles increases as a function of volumetric flow rate, indicating a reduction the dispersy of the produced NPs [3].

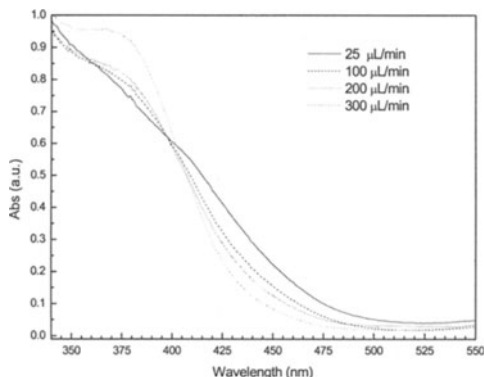


Figure 1. Absorption spectra of fluid stream containing quantum dots exiting the micromixer chip

Figure 2 shows absorption spectra of CdS using various initial cadmium concentrations at two different flow rates. Two key observations can be made. First, as the cadmium concentration is decreased absorption spectra shift to higher energies. Second, at higher flow rates the polydispersity of the produced NP populations is reduced.

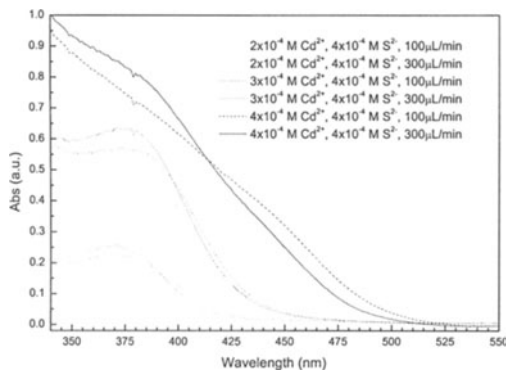


Figure 2 Absorption spectra of CdS colloids using various cadmium ion concentrations

An interesting feature of the data presented in Figure 1 is the existence of an approximate isosbestic point at 3.12 eV. This may be rationalized theoretically to be directly related to the polydispersity of the solution [3]. Let $N(E)$ be defined as the relative occurrence of particles with bandgap E , and $A(E, E_G)$ being defined as an absorption spectrum of a given set of monodisperse nanoparticles with a given bandgap E_G . The average absorption spectrum of the population $\langle A(E) \rangle$ may then be approximated by $\langle A(E) \rangle = A(E, E_G) \otimes N(E)$ (\otimes denotes a convolution). It should be noted that various absorption spectra will yield an isosbestic point only in special circumstances: *underlying population distributions must be of similar form – with the same modal energy gap & skewness – but different variances.*

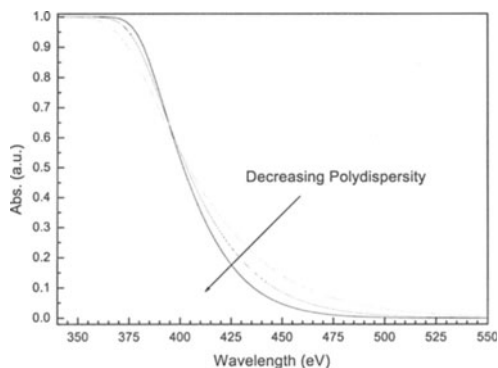


Figure3. Theoretical absorption spectra for samples of nanoparticles obtained by convolving an arbitrary single-particle absorption spectrum with three crystallite distributions of similar shape.

4. Conclusions

By adjusting experimental parameters such as concentration and flow rate both monodispersity and particle size of synthesised nanoparticles can be controlled.

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References

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