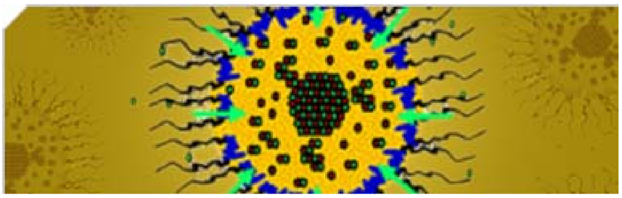
Synthesis and Functionalization of Nanostructured Photonic Materials

The advent of Nanotechnology has created the need for developing efficient processes for manufacturing nanostructured materials with precise control on their size, shape, atomic structure and composition. Our current research efforts focus on developing new synthetic routes and designing scalable, environmentally-friendly processes for producing II-VI semiconductor nanocrystals (quantum dots). Quantum dots are materials that exhibit size-dependent luminescence and have applications in biological imaging, quantum computing, high-density information storage, high-definition displays, and solar energy conversion. We employ liquid-phase synthesis techniques to grow Zn-based nanocrystals (e.g., ZnSe, ZnS and ZnTe), core-shell structures (e.g., ZnSe/ZnS) and doped nanocrystals (e.g., ZnSe:Mn and ZnSe:Cu). Our group has developed patented techniques for growing semiconductor nanocrystals using microemulsions and liquid crystals as templates. These techniques allow for precise control of particle size, shape and size distribution. Surface modification techniques are being developed to enhance the stability of the nanocrystals and introduce functional units that enable applications in biological sensors and clinical diagnostics. Transport and kinetic processes are studied using a combination of experiments, modeling and computer simulations to elucidate the underlying mechanisms, develop new reactor designs and identify optimal operating conditions.



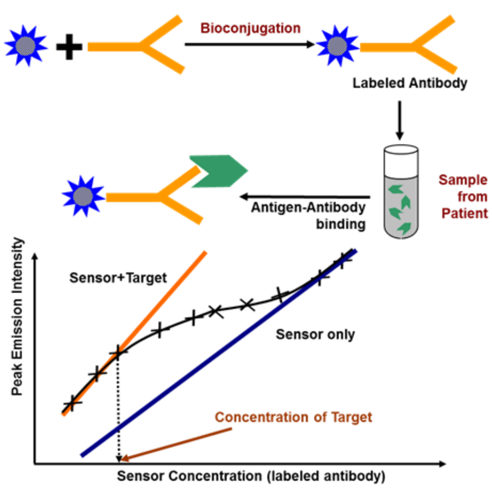
Patents

P. Alexandridis, G.N. Karanikolos and T.J. Mountziaris, "Synthesis of Nanostructured Materials Using Liquid Crystalline Templates", ***United States Patent 7,608,237***; issued October 27, 2009.

T.J. Mountziaris and P. Alexandridis, "Synthesis of nanoparticles by an emulsion-gas contacting process", ***United States Patent 8,859,000***; issued October 14, 2014. (Licensed to the Quantum Technology Group).

Novel Optical Biosensors based on ZnSe Nanocrystals

Our research aims to develop a new class of optical biosensors for rapid detection and quantitative analysis of biomolecules and biological materials based on ZnSe quantum dots. The quantum dots are conjugated with biomolecular probes, such as antibodies, and are being used to detect the presence of specific targets by measuring the changes in the fluorescence emission spectrum of the quantum dots upon binding of the probe to the target. Homogeneous (separation-free) assays are being developed for rapid detection and quantitative analysis of proteins for biomedical research and clinical applications. Multiplexed detection schemes and arrays for high-throughput screening of targets are developed using nanocrystals that emit at different wavelengths. The performance of the biosensors is being studied using models of the underlying transport phenomena and binding kinetics with the purpose of designing miniaturized instruments that can be used for point-of-care diagnostics. The ultimate objective of this work is the development of novel optical biosensors with high sensitivity, short response time, high probe stability, and broad dynamic range.

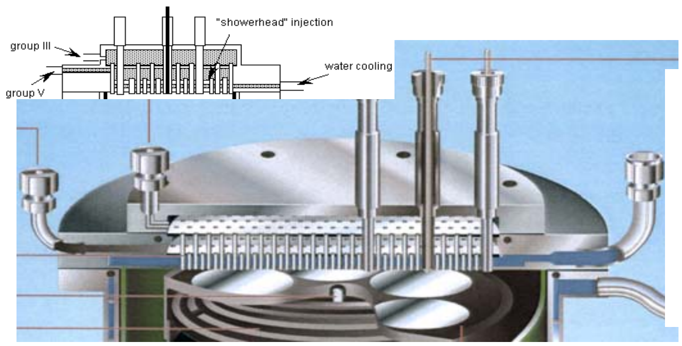


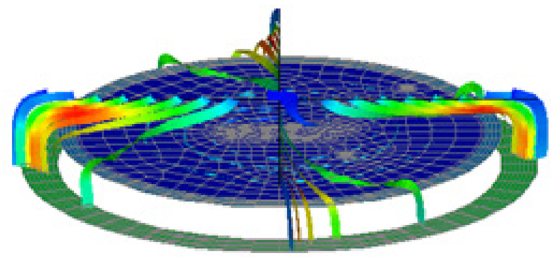
Patent

T.J. Mountziaris and J. Wang, "Quantum dot-based optical sensors for rapid detection and quantitative analysis of biomolecules and biological materials", ***United States Patent Application 20130115713 and World Patent Application WO2011127001A2.*** (notice of allowance received from USPTO 09/2018; patent pending).

Metalorganic Vapor-Phase Epitaxy of Compound Semiconductors

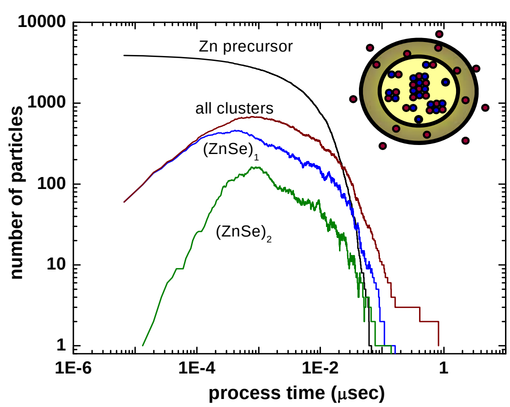
We study the kinetics and transport phenomena during metalorganic vapor-phase epitaxy of thin films of compound semiconductors, such as III-V arsenides, phosphides and nitrides, using experiments and fundamental process models. The objective of this work is the design of thin-film chemical vapor deposition systems providing optimal growth conditions for multi-layer structures of compound semiconductors used in advanced optoelectronic devices. Typical reactor design objectives include uniformity of film thickness and composition over large-area substrates, ability to grow atomically-abrupt heterostructures, and maximization of reactant conversion into film.





Multi-scale Models of Reaction and Transport Processes

We study the transport and kinetic processes during the synthesis of nanostructured materials by liquid- and vapor-phase routes using stochastic mesoscopic simulations (e.g., lattice Monte Carlo) and macroscopic simulations (e.g., finite element descriptions of conservation equations). Ab initio quantum mechanical models have been used to understand doping mechanisms in semiconductor nanocrystals and to investigate the thermodynamic stability of core-shell structures, in collaboration with the group of Prof. Dimitrios Maroudas (UMass). We have employed "equation-free" techniques to simulate the behavior of reacting systems in time and space using microscopic atomistic simulators, in collaboration with the group of Prof. Ioannis Kevrekidis (Johns Hopkins University). The objective of this work is the development of robust multi-scale modeling approaches that can reveal the fundamental links between reactor-level operating conditions (temperature, pressure, flow rates, inlet concentrations of reactants) and particle-level properties (size, shape, and crystallinity) to allow precise control of the latter.



Fluidization and Fluid-Particle Systems

Transport processes involving granular materials are very common in industry. These materials can exhibit both fluid-like and solid-like behavior and the underlying physics is complex and fascinating. We study gas-particle flows that are related to fluidization, pneumatic transport, and gravity flow in standpipes that are vital to many important industrial processes, e.g. in fluid catalytic cracking units. Standpipes are known to be pathogenic due to flow instabilities that lead to abrupt changes in the particle flow rate. We are interested in understanding the flow regimes and stability of granular flows in such systems to identify procedures for precisely controlling particle flow rates and catalytic reactions. The optimal design of fluidized-bed reactors for catalytic fast pyrolysis of biomass to fuels and chemicals has been recently studied using a combination of experiments, modeling and computer simulations, in collaboration with the groups of Professors W. Curtis Conner, Jeffrey Davis, Stephen de Bruyn Kops, and Wei Fan (UMass), and Prof. George Huber (University of Wisconsin-Madison). The design of fluidized-bed reactors for coal combustion using re-engineered feedstocks for optimal emissions control has been recently studied in collaboration with the group of Prof. Paul Dauenhauer (University of Minnesota).