Nonthermal Plasma Synthesis of Nanocrystals: Fundamental Principles, Materials, and Applications

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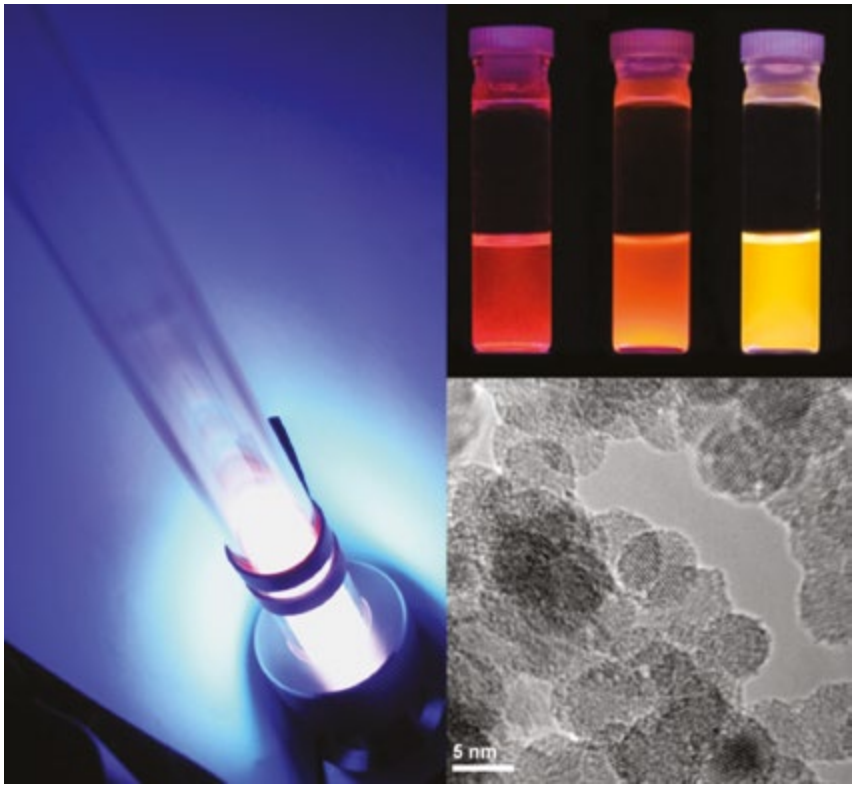
Ever since the discovery of size-dependent electronic properties in nanometer-sized crystals of semiconductors, their synthesis, characterization, and applications have intrigued the scientific community. Nanocrystals have led to advances in the fields of solar cells, light emitting devices, and bioimaging, to name just a few. The majority of nanocrystal research is based on materials that are synthesized in the liquid phase, most prominently, group II–VI and IV–VI semiconductors. The temperatures of liquid phase synthesis approaches, however, are limited by the boiling points of available solvents. Thus, the liquid phase synthesis of some materials is inherently difficult as they usually require higher temperatures to produce in crystalline form. This is where gas phase approaches excel, as they do not require organic solvents and are thus inherently capable of high process temperatures. Gas-phase processes can operate under conditions that are close to thermal equilibrium or very far from it. Approaches in the former category include flame synthesis, thermal pyrolysis in furnaces, laser pyrolysis, and thermal plasmas.



Nonthermal plasmas are at the opposite end of the spectrum of gas-phase synthesis approaches as they feature very different temperatures of their constituents: the heavy gas species are at temperatures close to room temperature, while free plasma electrons can achieve temperatures above ~10 000. Collisions between these hot electrons and molecules very effectively dissociate and ionize gaseous nanoparticle precursors, producing highly reactive radicals and ions. These radicals and ions react exothermically on the nanoparticle surfaces, heating the nanoparticles to hundreds of Kelvin above the neutral gas temperature, which is essential for forming nanocrystals. The plasma electrons also charge nanoparticles in the plasma negatively, reducing or eliminating agglomeration, in contrast to other gas-phase processes where agglomeration is difficult to avoid. In an article published in Chemical Reviews, we reviewed the state of the art in nonthermal plasma synthesis of nanocrystals. We discuss the fundamentals of nanocrystal formation in plasmas, review practical implementations of plasma reactors, survey the materials that have been produced with nonthermal plasmas and surface chemistries that have been developed, and provide an overview of applications of plasma-synthesized nanocrystals.