Silicon and Germanium Nanocrystal Electronic Devices

Zachary Holman, Chin-Yi Liu, and Uwe Kortshagen
Mechanical Engineering Department, University of Minnesota
* *holma069@umn.edu*

Presentation

Abstract: Semiconductor nanocrystals have received significant attention for their potential as low-cost materials in electronic devices. Nanocrystals may be processed with many of the inexpensive techniques that make organic materials attractive, yet they are expected to have superior mobilities and resistance to degradation. In addition, new opportunities arise at the nanoscale—such as tunable absorption and emission via quantum confinement, and multiple exciton generation—that may allow for entirely new device architectures. However, in order to be integrated into devices, *films* of nanocrystals must be developed and the films would ideally have the same properties as their constituent crystals. Significant headway has been made with II-VI and VI-IV solution-synthesized nanocrystals such as CdSe and PbSe, but progress with the popular group IV materials Si and Ge has lagged behind because of a lack of a satisfactory synthesis route. We present on plasma-synthesized Si and Ge nanocrystals, thin films of these crystals, and electronic devices based on the films.

Nanocrystals are synthesized using a nonthermal plasma approach in which precursor gases are dissociated in a radiofrequency discharge and atomic clustering leads to nanoparticle nucleation [1]. The plasma environment is uniquely suited to synthesizing nanocrystals since a unipolar negative charge is dispensed on the particles, suppressing agglomeration, and the particles are selectively heated, allowing for crystallization of high-melting point materials. Silicon and Ge nanocrystals are produced with respectable mass yields, yet retain a narrow size distribution as is necessary to avoid diluting the tunability of their optical properties. Additionally, the nanocrystals are synthesized as a powder with hydrogen-terminated surfaces, which makes this process particularly clean and allows for flexibility in subsequent processing.

Several methods have been developed for depositing thin films of nanocrystals. In one technique, Si or Ge nanocrystalline powder is transferred into solution and films are spun onto substrates. The nanocrystals are not solubilized by most solvents, leading to flocculation and poor film morphology. However, solvents with similar dielectric constants as Si and Ge suppress the van der Waals attraction between nanocrystals, resulting in a stable colloid. Films cast from these solutions are particularly smooth and have been used for thin-film field-effect transistors. Germanium nanocrystal transistors exhibit *n*-type behavior with electron mobilities as large as 7×10^{-3} cm^2/Vs and on-off ratios of 10^4.

We have also investigated inorganic-organic hybrid devices based on Si nanocrystals and poly-3(hexylthiophene) (P3HT). P3HT was added to Si nanocrystal solutions and blend films were spun as the active layer in photovoltaic devices. These devices, in which the Si nanocrystals act as the electron conductor and the P3HT acts as the hole conductor, have achieved open-circuit voltages of 0.8 V, short-circuit currents of 3.9 mA/cm^2, and power conversion efficiencies of 1.5 % under solar irradiation [2].

References

[1] L. Mangolini, E. Thimsen, and U. Kortshagen, *Nano Lett.* **5,** 655 (2005).
[2] C.Y. Liu, Z.C. Holman, and U.R. Kortshagen, *Nano Lett.* **9**, 449 (2009).