Background

Silicon nanoparticles (SiNCs) are notable for optical and electrical properties that arising from quantum mechanical effects. Their size dependant tunable wavelength emission makes SiNCs promising for renewable resources such as solar cells, optoelectronics, and light-emitting devices (LEDs).

A promising method for SiNC synthesis and surface modification is the use of a low-pressure nonthermal plasma. Although easy to translate into manufacturing and cleaner for the environment, this method has thus far produced SiNCs with low quantum yield (QY), where

\[
QY = \frac{\text{photons emitted}}{\text{photons absorbed}}
\]

QY is decreased by dangling bonds and surface defects on the nanoparticle.

Silicon Nanocrystal Synthesis

SiNCs are synthesized in a low pressure nonthermal plasma comprised of argon, hydrogen, and silane (SiH₄) as pictured in figure 1. A radiofrequency power is supplied to the gases through a dual ring electrode around. SiNCs are collected on steel mesh, shown figure 2.

The nanoparticles are passivated with an organic ligand injected through the sidearm of the reactor, as shown in figure 1. The amount of organic ligand allowed into the reactor is controlled using a needle valve.

An accepted hypothesis of how SiNCs are formed is depicted in figure 3. Electrons in the plasma dissociate silane. The silicon atoms form small clusters and nucleate, creating particles. In turn, the particles become SiNCs. Organic ligands are injected into the reactor, and radicals are created. These radicals react with the SiNCs, passivating their surfaces. [1].

Increasing Quantum Yield

To increase QY we exposed SiNCs to ultraviolet (UV) light post-synthesis. We also varied plasma parameters, including power and gas flow rates, and the passivating ligand.

Exposure to UV light increased the QY, as shown in figure 4. A higher valve number corresponds to a higher amount of organic ligand allowed into the reactor. We believe UV light aids in the attachment of ligands to the nanoparticle surface thus increasing the QY.

Figure 5 shows the QY of SiNCs passivated using organic ligands hexene and pentene for various power sent to the plasma. We believe that at high powers there is too much energy in the plasma to allow for complete bonding.

We also varied the argon flow rate for SiNCs passivated with hexene and exposed the samples to UV light, figure 6. Lower flow rates correspond to larger SiNCs, which demonstrate higher QY.

Future Work

We plan to further increase the QY by exposing the SiNCs to UV light in flight, while still in the reactor. In this way more individual SiNCs should be exposed to UV light.

SiNCs produced with the nonthermal plasma will be used to make LEDs such as the one depicted in figure 7. The SiNCs are part of the tunnel junction comprised of zinc tin oxide, copper aluminum sulfide, and zinc sulfide.

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References