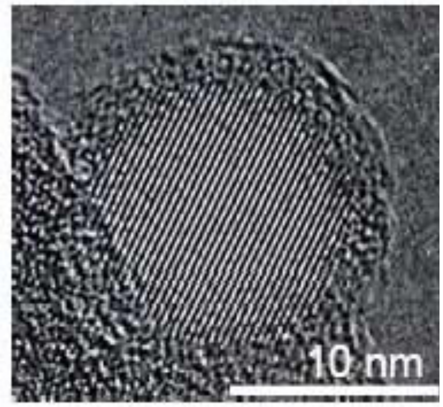
Activity 4



D. Hippo et al., IEEE Intl. Conf. Grp. IV Photonics, 114, (2005).

A researcher in your group has established a way to synthesize nano-crystalline silicon, which they call "silicon quantum dots". They claim that the dots can emit light in the visible spectrum if they are the right size. Another person in your group says that silicon is an indirect band gap semiconductor, so it won't emit light efficiently, and it emits in the infrared since its band gap is 1.10 eV.

Can the behavior of bulk silicon be modified by quantum confinement to create silicon quantum dots that emit light in the visible?

What size would such dots need to be? How does that size compare to the exciton (electron-hole pair) radius of 5 nm in bulk silicon?

It is true that the 1.10eV band gap of silicon is outside of the visible range, which extends from ~1.77eV (700nm) to 3.1eV (400nm).

If we model silicon quantum dots as infinite potential wells, then the energy levels from quantum confinement will be different from bulk silicon.

Let's assume that an electron in a Si QD transitions from an excited energy state to the ground state. The difference in electron energy can be emitted as a photon.

For an infinite quantum well $E_n = \frac{n^2h^2}{8ma^2}$

$$\Delta E = E_2 - E_1 = \frac{h^2}{8ma^2}(4-1) = \frac{3h^2}{8ma^2} \Rightarrow a = \sqrt{\frac{3h^2}{8m\Delta E}}$$

If $\Delta E = 1.77\,eV \Rightarrow a = \sqrt{\frac{1.129\,eV\,nm^2}{1.77\,eV}} = 0.799\,nm$

If $\Delta E = 3.1\,eV \Rightarrow a = 0.604\,nm$

If we consider higher energy transitions, such as $n=3$ to $n=2$, then the Si QD diameter is $a = 1.03$ nm to emit a 1.77 eV photon.

So it does seem that quantum confinement can modify the behavior of bulk silicon.

The diameters needed to emit visible photons are ~ 5x smaller than the Bohr radius of an exciton in bulk silicon. Quantum behavior is often observed when a physical dimension goes below a bulk dimension or parameter.