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# Light emitting diodes with semiconductor nanocrystals

#### 1. Quantum confinement

In the nanorange, one observes a size-dependence of the emission of semiconductor nanoparticles [1]. This is due to the confinement (*quantum confinement*) of the electrons and holes in either one, two or three dimensions where *quantum mechanics predicts discrete energy levels dependent on the size of the particle* [1, 2]. One finds that the *emission wavelength is proportional to the square of the size* of the particle:  $\lambda_{em} \sim d^2$ . Nanoparticles are also called *quantum dots*.

Typical semiconductors used as quantum dots are II-VI semiconductors like CdSe, CdTe, ZnS etc.

### 2. Synthesis of nanoparticles

There are two strategies to synthesize nanoparticles:

- a) <u>Top down</u>: Bulk  $\rightarrow$  Thin films  $\rightarrow$  nanowires  $\rightarrow$  quantum dots
- b) <u>Bottom up</u>: Atoms  $\rightarrow$  Molecules & proteins  $\rightarrow$  molecular wires  $\rightarrow$  nanoparticles

Out of these, the "bottom up" technique is by far more often used. A typical example for this is the synthesis of Cd chalcogenide nanocrystals [1, 3]:

*Cd alkyls*  $R_2Cd$  and *organophosphine chalcogenides*  $R_3PX$  (X=Se, Te) are precursors and given to a *hot coordinating solvent* (typically trioctylphosphine oxide, TOPO) very fast. This leads to a supersaturation and nucleation. The coordinating solvent *passivates* the forming CdX nanoparticles to give a *better protection and higher quantum yields*. The consumption of the nanoparticles is faster than the addition of the precursors  $\rightarrow$  *monodisperse size distribution* of the quantum dots.



**Fig. 1.** Typical apparatus for the synthesis of CdX QDs [3].

Further protection and better quantum efficiencies can be achieved by coating the quantum dots with semiconductors of a wider band gap (*core-shell technique*) [1, 4]. The nanocrystals are characterized with different (surface-sensitive) techniques: SAXS, WAXS, XRF, EXAFS, TEM, AFM etc. [3]

# 3. Semiconductor nanoparticles in OLEDs

Semiconductor nanocrystals can be used as luminescent material in OLEDs [1, 5]. An OLED consists of several layers (from the bottom to the top) [6], which can be fixed by *epitaxy* or *spincoating*:

- 1. Indium tin oxide (ITO) anode: coated on a glass substrate, provides the holes.
- <u>Hole-transporting layer (HTL)</u>: Typically conducting organic polymers like PEDOT: PSS [1].
- 3. Luminescent layer (LL): This is a monolayer of quantum dots.
- 4. <u>Electron-transporting layer (ETL)</u>: Typically, Aluminiumtris(8-hydroxyquinolate), Alq<sub>3</sub>, is used here.
- 5. <u>Cathode</u>: Metals with low work function like Mg, Ca or Sr are used here, it provides the electrons. For better protection, it is coated with a layer of Ag.

*Mechanism of the luminescence*: The electrons and holes, provided by the cathode and anode, respectively, attract each other and pass through the HTL and ETL to meet in the luminescent layer. There, they form an *exciton* (bound state between electron and hole). There exist several proposed mechanisms; however, the most probable one discussed in literature includes a *Förster energy transfer*. The electron and the hole recombine and the released energy is transferred to the quantum dots which are excited and finally show luminescence [5].

## 4. Literature

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