What are ‘Quantum Dots’ and their applications in coatings?

When the particle size of some semiconductor crystals decreases below 10 nm, they are called nanocrystals or quantum dots. These are some of the first nano products to be available commercially. These materials display bright colors under the influence of incident light due to fluorescence and are available in various hues. These can be incorporated in various types of matrix materials depending upon the application. Apart from coatings and inks, they are widely useful in LED displays, photovoltaic, optical devices and as reagents in biotechnology.

Quantum dots are nanoparticles of semiconductor inorganic materials like PbS, CdSe and ZnS. Their particle size is of the order of 2 ~ 10 nanometers which corresponds to ten to twenty atoms. The particle size is smaller than their Bohr exciton radius which leads to quantum confinement in all of the three dimensions. This causes widening of the band gap and discretisation of energy levels in the valence and conduction bands.

Absorption pattern of quantum dots is blue-shifted with respect to the bulk material and consists of series of overlapping peaks. The absorption of the radiation at lower wavelength causes a transition of an electron into the conduction band. The return of this electron to the valence band is accompanied by the emission of light at a longer wavelength in the visible or infrared range. The emission band possesses Gaussian distribution and is relatively narrow which is responsible for bright colors. The wavelength of emission band is independent of the absorption band. However it depends on temperature, particle size and its distribution. The emission wavelength and hence the color is tunable to the requirement depending upon their particle size as shown in the Figure.

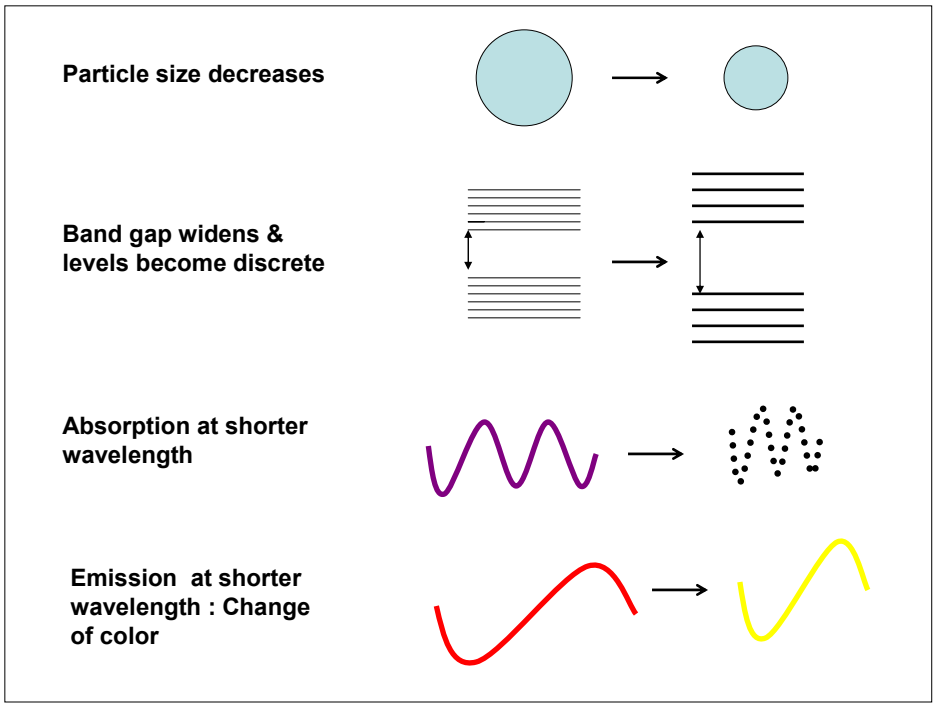

Figure: Change of color with particle size in quantum dots

The quantum dots are produced by bottom-up method via colloidal precipitation. The particle size can be controlled by temperature, surfactants and organic solvents. The temperature control is very important to achieve the right particle size and anneal out the defects in the crystals. To facilitate their incorporation in the end use matrix like polymer, the quantum dots can be coupled with organic molecules like alkane thiols, amines, phosphines carboxylic acids and proteins. The functional groups on these molecules form a co-ordinate bond with the surface of the quantum dot. The other end of the organic molecule helps in dispersion in a matrix such as a polymer.

The quantum dots are also fabricated in core-shell configuration to improve their emission performance. Due to their small size, the quantum dots possess electrons and some crystals defects on the surface. These act as ‘traps’ and cause non-radiative relaxation of the absorbed photons in the form of heat. To prevent this, the quantum dots are coated with a shell of another semiconductor material with a wider band gap. This improves quantum yield, stability and intensity of the emission bands.

Since quantum dots absorb in the UV-visible region and emit at visible-IR region, they have found use in many applications as follows:

- Opto-electronics, displays, LEDs
- Photovoltaic and solar cells
- Security inks: Inks made with quantum dots will have a signature emission color which makes counterfeiting very difficult.
- Bright color paints: Due to their narrow emission bands, paints pigmented with quantum dots exhibit bright fluorescent colors. These can be used in selective highlight areas of structures, vehicles, path markings and escape-ways. These will also facilitate sighting of the distant objects like tractors in the field and highway markings.
- Night vision paints: Quantum dots can be tailored to emit in the infrared region and hence can be used as infrared emissive paints. Such coatings can be used to aid night time vision for patrol and search operations to combat criminal and terrorist activities. Such IR fluorescent paint applied on the doors, road patches, railings and the walls captures feeble available light from the stars, sky, moon and the distant town-lights. The paint intensifies and re-emits the absorbed light as a narrow IR band which is invisible to the human eyes. Patrol persons aided by night vision goggles (NVG) can easily see any disturbance of the painted surface or movement across the painted background without the criminals being aware of it. If flashlights are used along with this IR paint, the markings and the disturbances are readily visible from a distance upto 100 meters. Such paints can last upto six months.

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