Z44 - Quantum Dots

Physics Laboratory II – academic year 2017/2018
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Rapid miniaturization of electronic devices results in nanoscale dimensions of fabricated objects. In such regime classical laws governing the electron dynamics are no longer valid and the role of quantum effects is manifested. Objects with all dimensions in the nanoscale range – quantum dots – as regarded as one of the most promising. They are often called "artificial atoms" due to the discrete fluorescence spectrum comprised of narrow lines characterized by a specific wavelengths accurately related to the quantum dot spatial dimensions. In the experiment, by application of the CCD spectrometer, we record both fluorescence and absorption spectrum. The analysis allows us to determine the band gap of the CdTe crystal.

Preparatory questions

1. Density of states in one-, two- and three-dimensional systems. Density of states distribution.
2. Low dimensionality in nanoscale systems: density of states in quasi one- and two-dimensional objects. Quantum dots density of states. [1, 2, 3]
3. Electronic structure of crystals. Fermi energy, Fermi sphere. Fermi-Dirac distribution. Pauli exclusion principle. [1, 2, 3]
4. Particle in a box: enegies, eigenfunctions. [1, 2, 3]
5. Bloch's theorem. Dispersion relation for electrons in crystals. Effective mass. [1, 2, 3]
6. Fluorescence and absorption spectrum of quantum dots [1, 2, 3]
7. What is a CCD detector and spectrometer? Detector dark current and reference spectrum. What do we have to record in order to draw the absorbance spectrum? How do we excite quantum dots?
8. Methods of quantum dots fabrication.
9. Experimental setup and measurement idea.

Computational assignments

1. Starting from the simple free electron model calculate the energy levels for electrons and holes in CdTe quantum dots. Assume that the dots could be described as cubes with 2, 3, 4 and 5 nm long edges. Effective mass for electron and hole equals 0.11 and 0.4 of electron mass, respectively.
2. Starting from the numerical results obtained in the previous exercise and assuming that CdTe band gap equals $1.56eV$ calculate the luminescence photon energies and wavelengths for differently sized quantum dots. What is the color of the emitted light for given dots (see figure)?

Apparatus and materials

The experimental setup contains:

- CCD spectrometer
- Blue laser diode
- Halogen lamp
- Set of optical fibers
- Quantum dots solutions

Experiment

1. Assemble the setup for luminescence detection. Identify appropriate optical fibers.
2. Determine the measurement parameters, i.e. time of acquisition, number of repetitions, etc.
3. Register luminescence spectra for different quantum dots.
4. Measure dark current and reference spectrum.
5. Register absorption spectra for different quantum dots.

Data analysis

1. Analyze registered fluorescence spectra. Prepare the diagram showing dependence of emitted photons energy on the inversed square size of the dot. On the basis of linear regression determine the band gap of CdTe and compare with literature.
2. Analyze registered absorption spectra. Determine the absorption edge for different quantum dots.

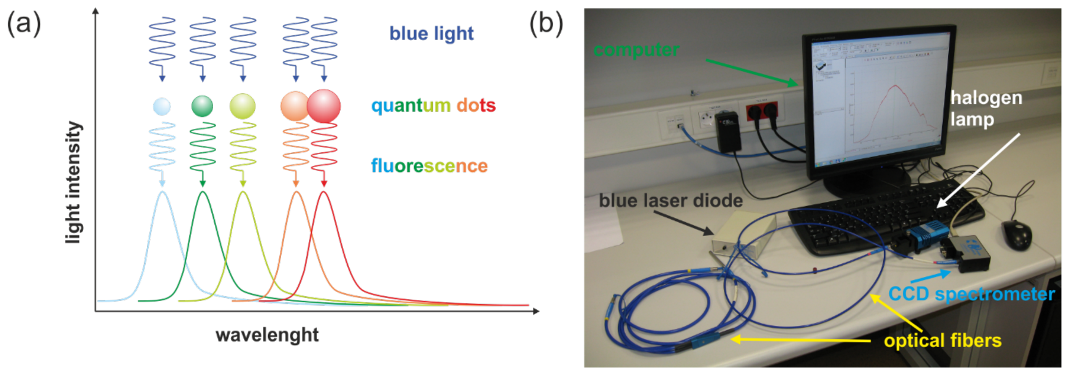

Figure 1: (a) Fluorescence spectrum obtained for differently sized quantum dots, (b) experimental setup.

References

[1] N.W. Ashcroft, N.D. Mermin, *Solid State Physics*.

[2] C. Kittel, , *Introduction to solid State Physics*.

[3] Rainer Waser (Ed.), *Nanoelectronics and Information Technology*, 2003, WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim.