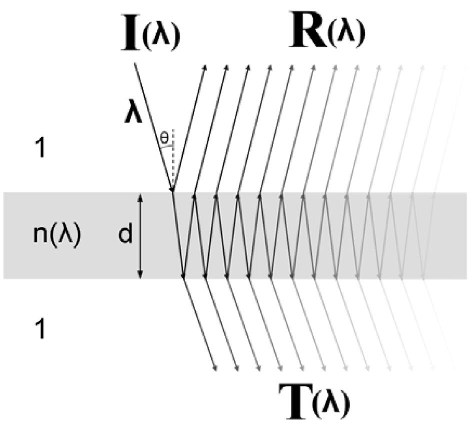

Optical Spectroscopy

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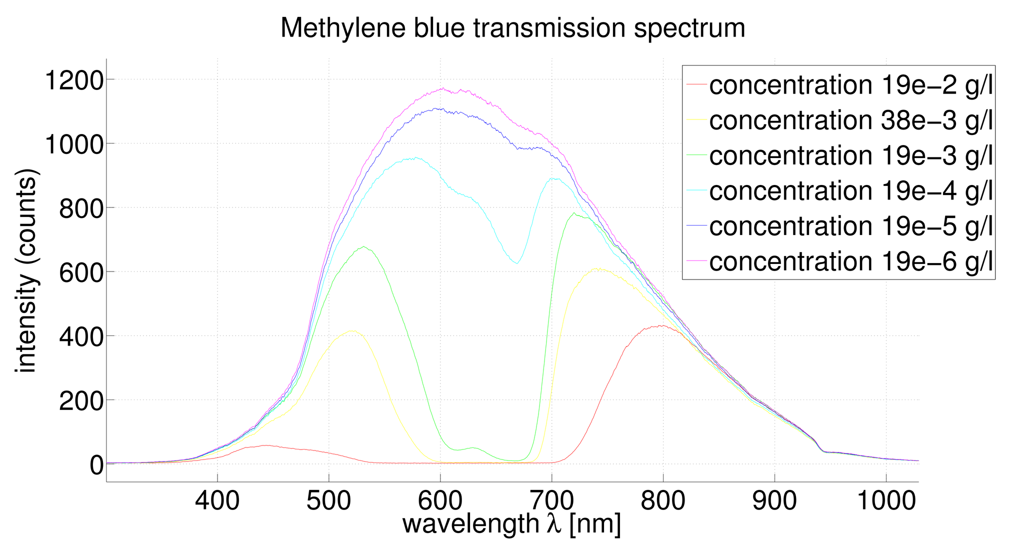
Introduction

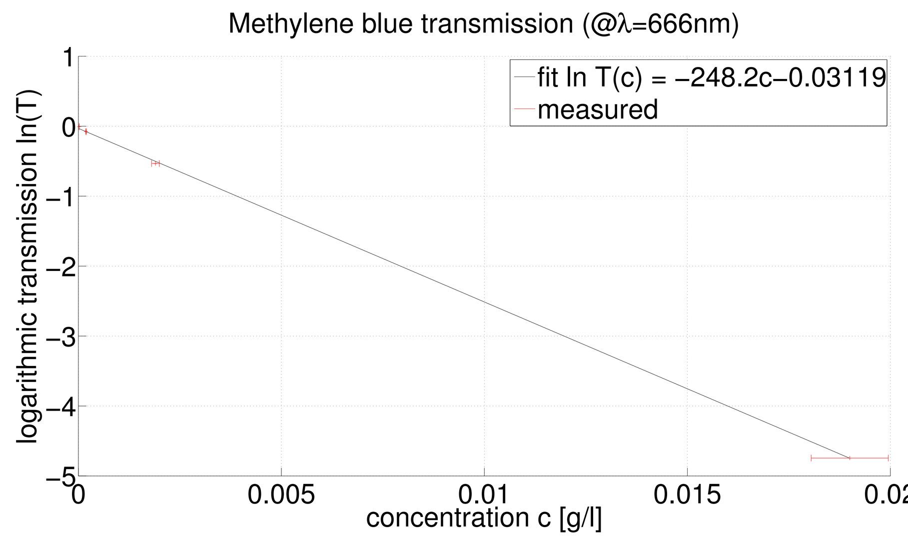
Spectroscopy is the study of interaction between matter and light. By analyzing the modification of a spectrum, which is the plot of the response of a material as a function of wavelength, one can study the properties of a sample.
Spectroscopy can be done using all possible wavelengths of light, but some wavelengths are better adapted to certain situations than other. To study crystals, one generally uses X-rays where as to study certain properties of our universe, one can use microwaves. This experiment is restricted to optical spectroscopy, i.e. the wavelengths studied are between 300 nm and 900 nm.

Absorption of methylene blue

Goal: determine the absorption coefficient of a solution.

This experiment studies the absorption of a halogen-deuterium source by a methylene blue solution. Already this simple form of spectroscopy has a basic application: after having determined the extinction coefficient, the concentration of a methylene blue solution of unknown concentration can be determined using the below formulas.





The figure clearly shows that the transmission coefficient follows an exponential law:

$$T = \frac{I}{I_0} = \exp(-\kappa c)$$

where $\kappa = \frac{\alpha L}{c}$ and $\alpha = a \cdot c \cdot \ln 10$ where a is the extinction coefficient

$$\Rightarrow a = \frac{\kappa}{L \ln 10} \approx \frac{248.2}{0.9 \ln 10} \approx 119 \frac{\text{g}}{\text{l} \cdot \text{cm}}$$

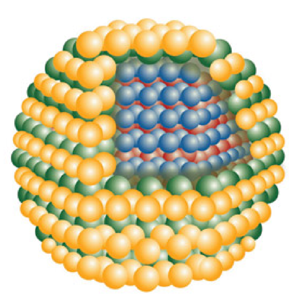
Quantum dots

Goal: determine the size of a quantum dot.

Quantum dots are semiconductors where the electron-hole pairs are confined in all three spatial dimensions. In a first approximation, quantum dots emulate very well the simple model of a particle in a box. The discrete energy levels are directly related to the size of the box. The remitted photon, has exactly the energy of the energy level separation. Knowing the emission energy of the quantum dot, it is possible to calculate its size. Using the effective mass model, one can obtain an approximative expression:

$$E_{em} = E_{gap} + \frac{h^2}{8 m_e R^2}\left(\frac{1}{m_e^*} + \frac{1}{m_h^*}\right) - \frac{1.8 e^2}{4\pi\varepsilon_0 \varepsilon R}$$

The quantum dots studied in this experiment are basically a small region of one material, enveloped by another material with a larger bandgap, used to preserve the integrity of the quantum dot. They are called core-shell structures. In this experiment, the quantum dots are a Cadmium selenide core with a Zinc sulfide shell.



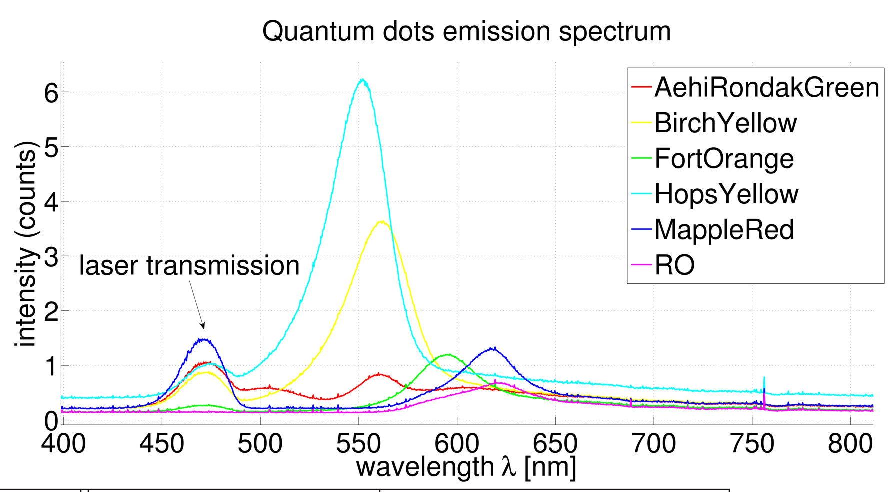
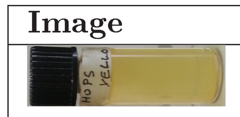
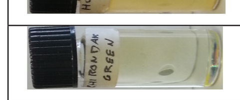
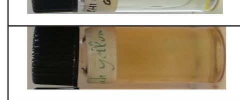
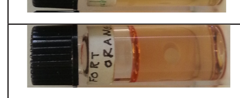


Image	Sample name	Q-dot size ± 0.015nm
	Hops yellow	2.50
	Aehi rondak green	2.58
	Birch yellow	2.60
	Fort orange	3.01
	Mapple red	3.39

References

[1] Eric Feltin, *Spectroscopie Optique*. EPFL, 2008.

[2] "Image of quantum dot." http://www.photonics.com/Article.aspx?AID=29421, May 2013.

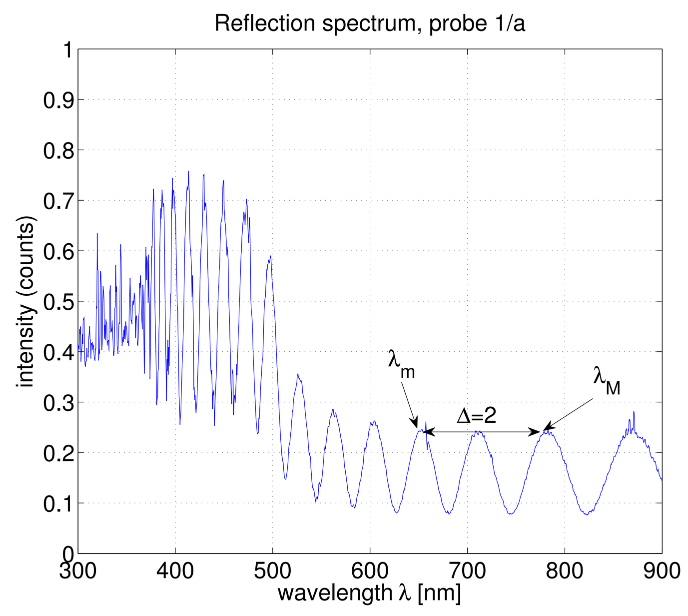
Optics of semiconductors in thin layers

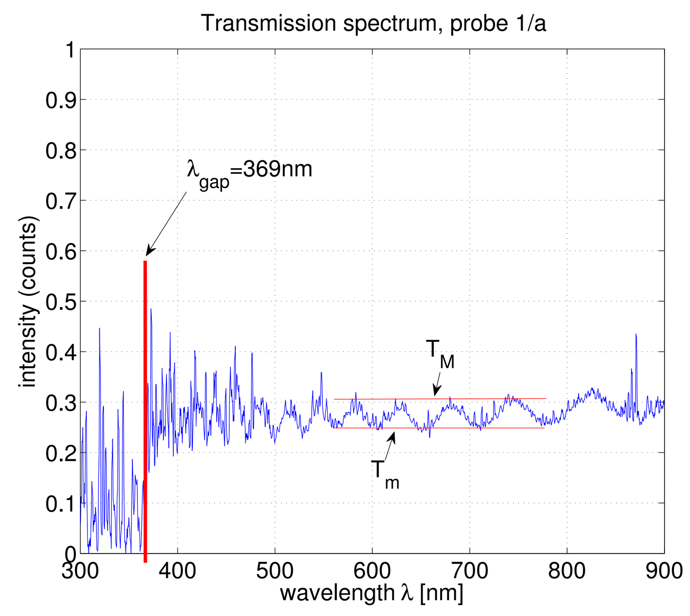
Goal: identify a semiconductor and determine its refractive index and thickness.

The properties of semiconductors come from their electronic structure. The crystalline environment adds a periodic potential energy which creates a gap energy between the valence band and the electron, making the material a conductor at high temperature.
The transmission of light through a thin layer is a result of the interference between the multiple reflections at the two sides of the material. Whether the interference is destructive or constructive depends on the wavelength of the light, the refractive index of the material and the thickness of the thin layer.
To determine the refractive index n_1 of a thin layer on a substrate with refractive index n_2, the transmission spectrum is analyzed using:

$$(n_1^2)^2 - n_1^2\left(1 + n_2^2 + \left(\frac{1}{T_m} - \frac{1}{T_M}\right) 4n_2\right) + n_2^2 = 0$$

where T_m and T_M are points on the envelopes for a given wavelength.





To determine the thickness, the following formula is used:

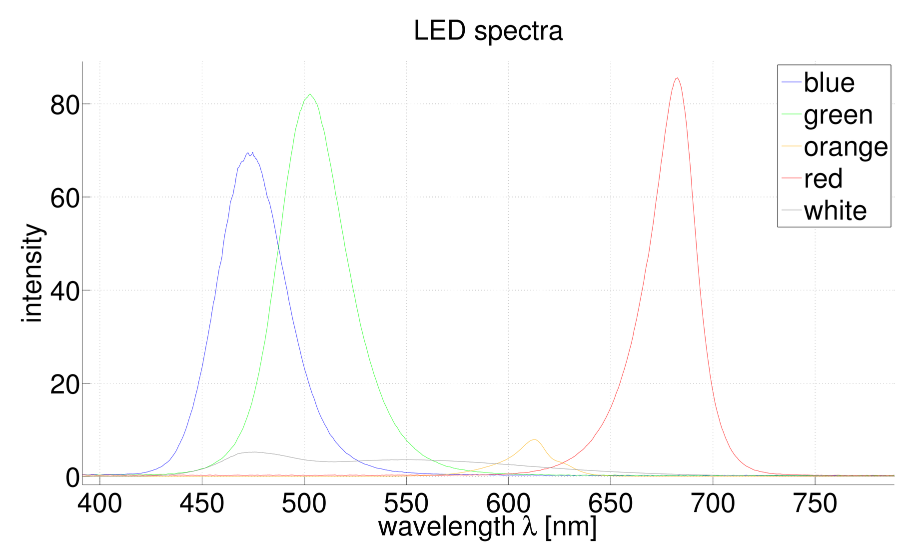
$$d = \frac{\lambda_m m}{2 n_1}$$

where m is the refraction order.

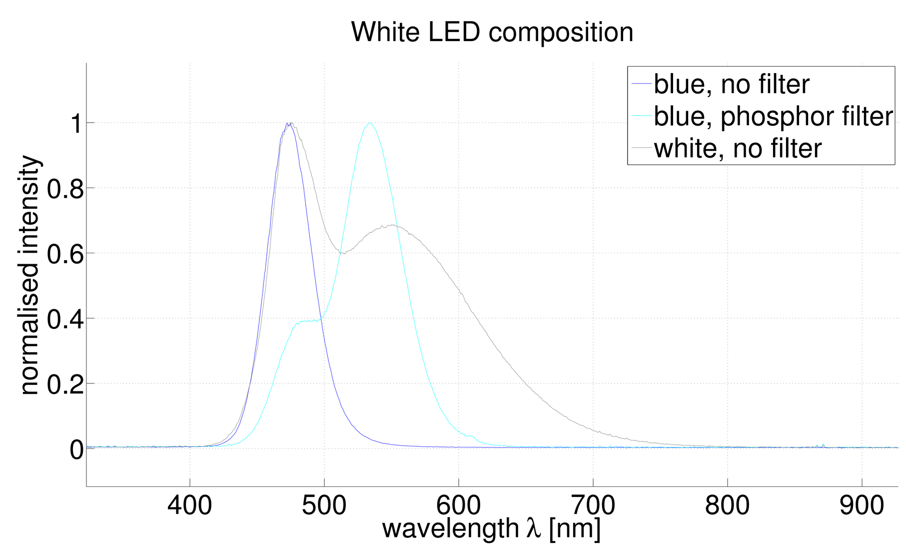
Probe	Thickness d [μm]	σ	Refractive index ($@\lambda = 700$nm)	σ	Reference value
GaN (a)	1.48	0.01	2.65	0.1	2.36
GaN (c)	1.46	0.04			
GaN (d)	1.57	0.02			
GaN (e)	1.59	0.02			
GaN (f)	1.57	0.01			
GaN (g)	2.29	0.02			
ZnSe	2.532	0.2	2.87	0.3	2.55

LED spectra

Goal: study spectrum composition of LEDs, specifically that of a white LED.



The second figure shows the spectrum of a blue LED modified by a phosphor filter. With a correct normalization, this yields a white LED.



Conclusion

Optical spectroscopy is a powerful tool to identify a substance and determine a wide range of its properties, such as refractive indices, absorption coefficients and layer thickness. Due to the restriction to visible wavelengths, optical spectroscopy is limited to "macroscopic" properties. However, to determine properties of a material on a smaller scale, such as the lattice structure of a crystal, smaller wavelengths may be used such as X-Rays.