CdTe/PbTe periodic structures as photonic crystals

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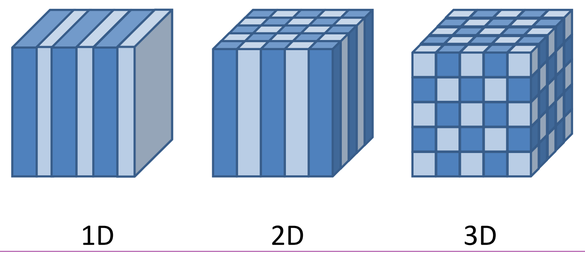
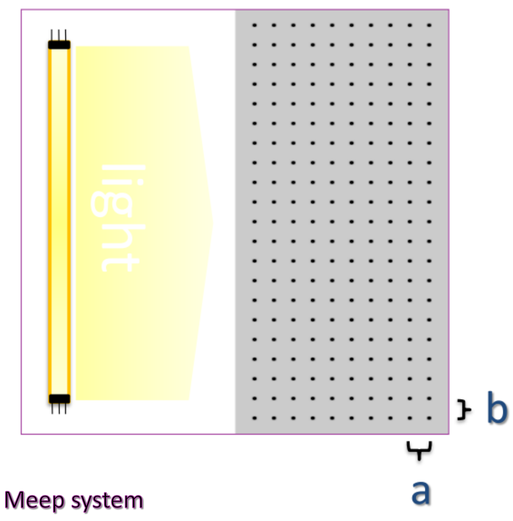
Photonic crystals

Photonic crystal is a structure with periodic distribution of refractive index. Changes in the refractive index induce reflection and deflection of electromagnetic waves falling on such structure. The interference of waves propagating in photonic crystal causes, that only part of the light spectrum is transmitted. The range of light wavelength, which can not propagate via the crystal is called ***photonic band gap***. Due to the number of directions, in which the refractive index can change in crystal, we distinguish 1D, 2D and 3D photonic crystals.



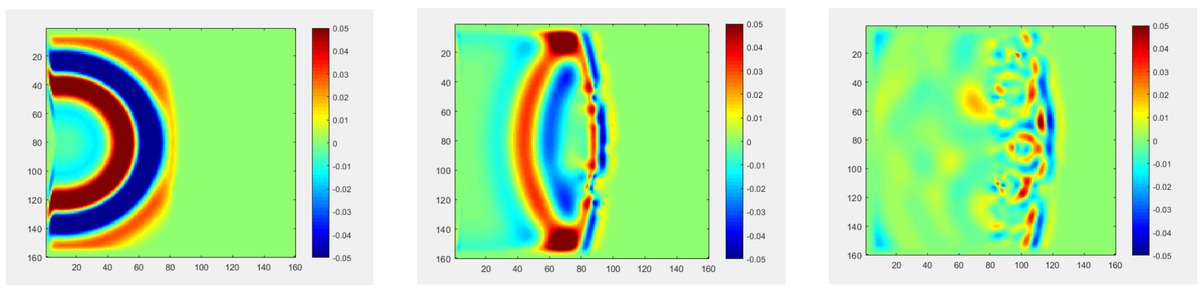
Meep simulations

Photonic behaviour of composite crystal containing PbTe(CdTe) dots in CdTe(PbTe) matrix was investigated using an open-source software *Meep* (MIT Electromagnetic Equation Propagation) [3]. *Meep* exploits the *finite – difference time – domain* (FDTD) method for simulation of light propagation in any electromagnetic system. The simulation process consist of several steps. It requires creating the photonic structure by specifying spatial dimensions and distribution of refractive index. The next step is to determine properties of light source and position of the detector.

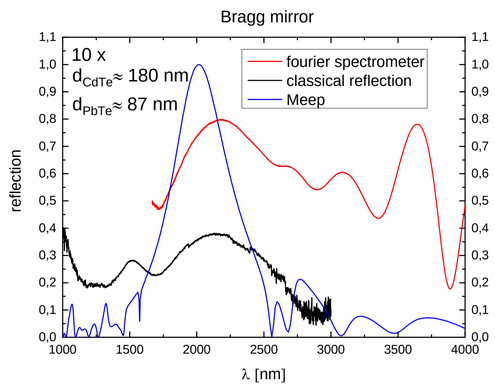


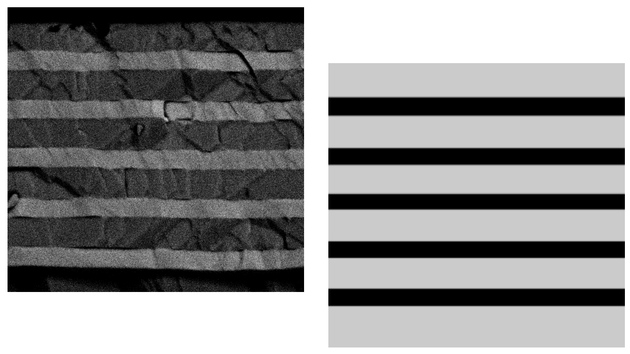
Effects of simulations in Meep system

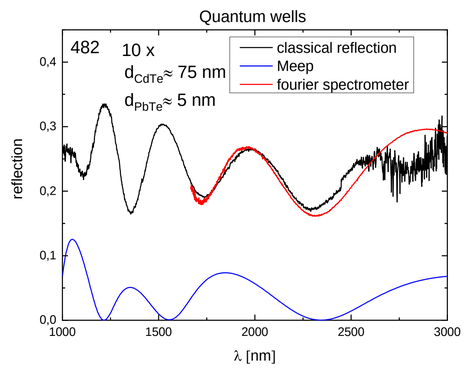
The *Meep* package returns informations, which allow tracking the propagation of an electromagnetic wave in photonic structure.

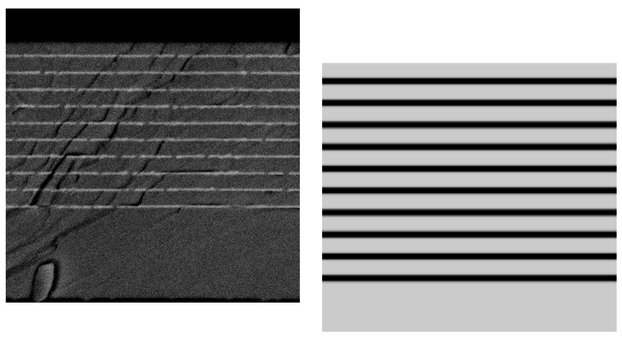


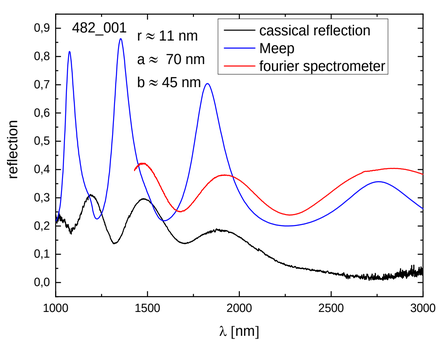
Simulations vs measurements

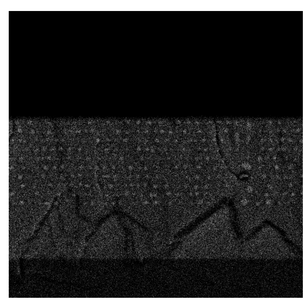


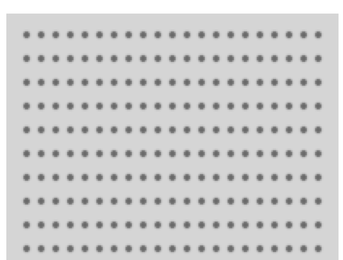






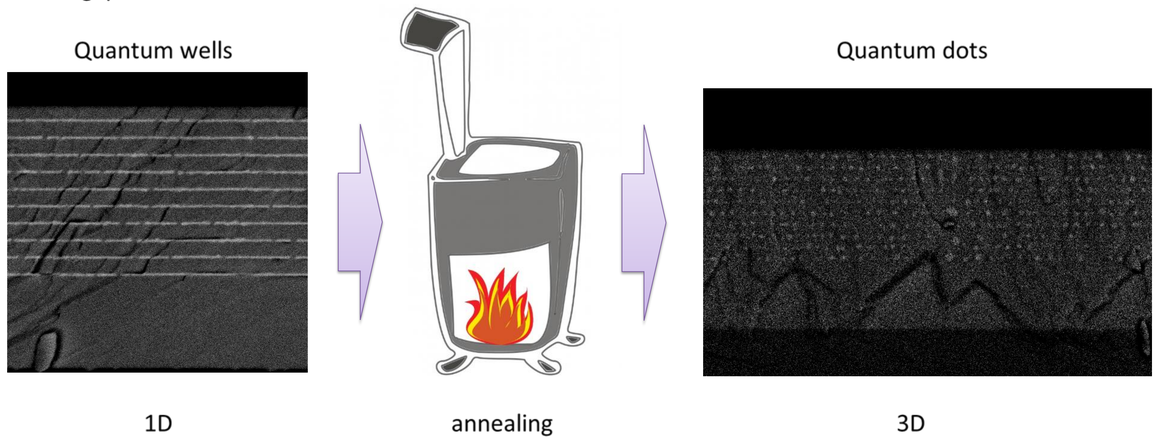






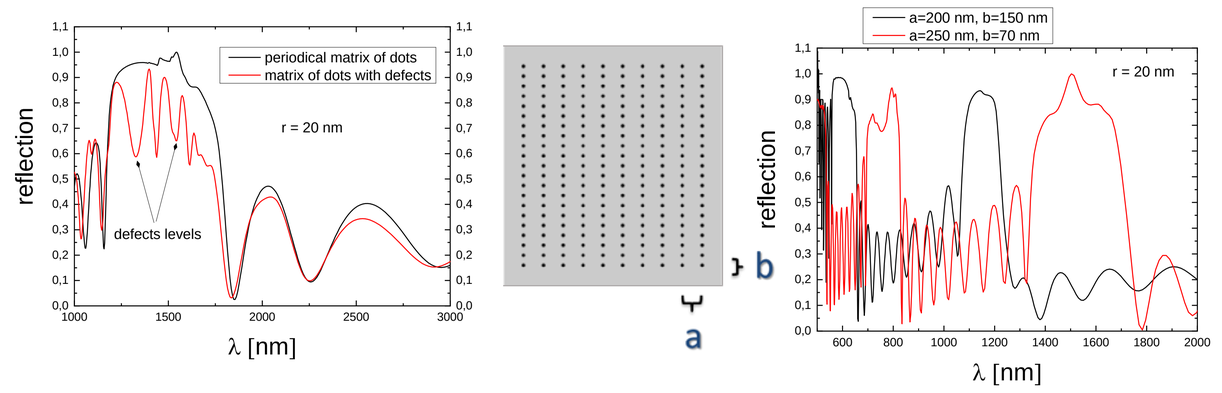
CdTe/PbTe heterostructures as a photonic crystals

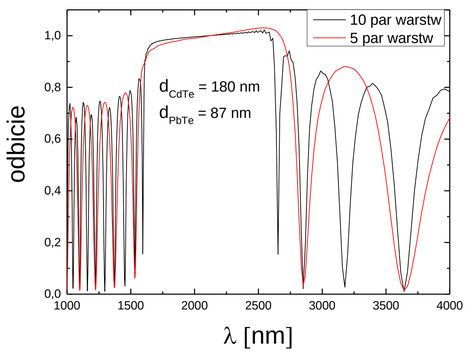
Low-dimensional CdTe/PbTe heterostructures are widely known for their potentially applicable optical and thermoelectric properties [1,2]. Use of molecular beam epitaxy method in combination with appropriate temperature and time of annealing of CdTe/PbTe multilayer structures allows to easily obtain samples containing PbTe(CdTe) quantum dots or nano – pilars. Their well controllable spatial dimensions and periodic distribution together with over two times higher refractive index of PbTe ($n_{PbTe} = 5.75$) in comparison to CdTe ($n_{CdTe} = 2.75$) makes light see CdTe/PbTe heterostructures as a new meta-material, which creates potential for obtaining composite crystal with photonic band gap.



Simulations of transmission and reflection spectra for photonic crystals with PbTe dots and layers

Meep package was also used to calculate the experimentally useful transmission and reflection spectra for CdTe/PbTe periodic crystals with different sizes and spatial distribution of dots. Due to large contrast of refraction indexes, photonic behavior was already observed for virtual crystals containing relatively low number of about 100 dots or 10 pairs of layers.

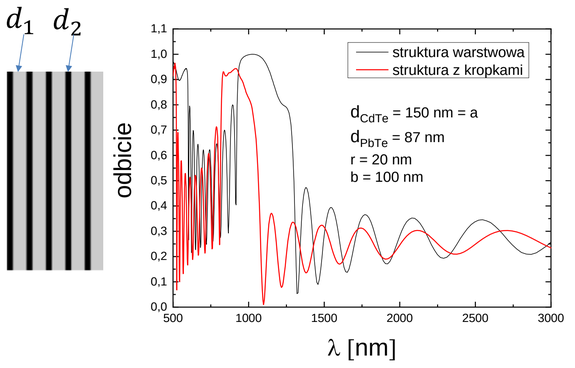




Bragg mirror

$$d_1 = \frac{\lambda}{4n_1}$$

$$d_2 = \frac{\lambda}{4n_2}$$



Luminescence

Measurements of luminescence as a function of temperature showed the optical activity of the structure containing the PbTe dots.

Homogenity measurements

The homogeneity of the layered structures was confirmed by reflection measurements of many points (left picture). The homogeneity of the annealed structure containing PbTe dots was confirmed by the same method (right picture).

Reference

[1] Karczewski G. et al. Nanotechnology **26**, 135601 (2015)

[2] Szot M. et al. Cryst. Growth Des. **11**, 4794 (2011)

[3] A.F. Oskooi, et al., Computer Physics Communications, **181**, 687-702 (2010)

Summary

- The position and number of photonic gaps strongly depend on distances between the dots along the axis parallel to the direction of light propagation. The most common trend is red shift of the gap for increasing *a*.
- The position of the gap very week depends on distances between the dots in axis perpendicular to the direction of light propagation. However, *b* strongly affect the width of the gap – with decreasing *b* the width of the gap increases.
- Experimental results vary from simulations due to the presence of defects but the general character of oscillations is preserved.
- The structures containing PbTe dots show optical activity.