CdTe/PbTe periodic structures as photonic crystals

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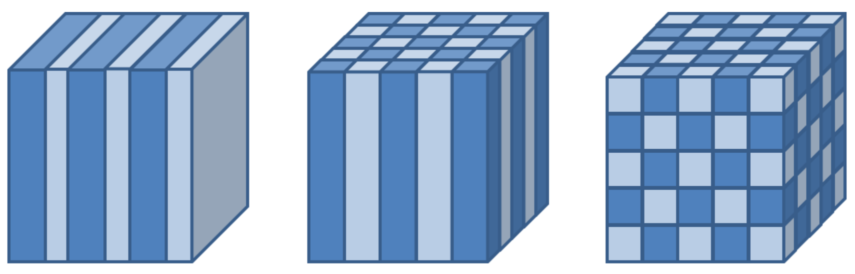
Photonic crystals

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



1D 2D 3D

Fig.1 Different types of photonic crystals.

CdTe/PbTe as photonic crystals

Low-dimensional CdTe/PbTe heterostructures are widely known for their potentially applicable optical and thermoelectrical 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 od 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.

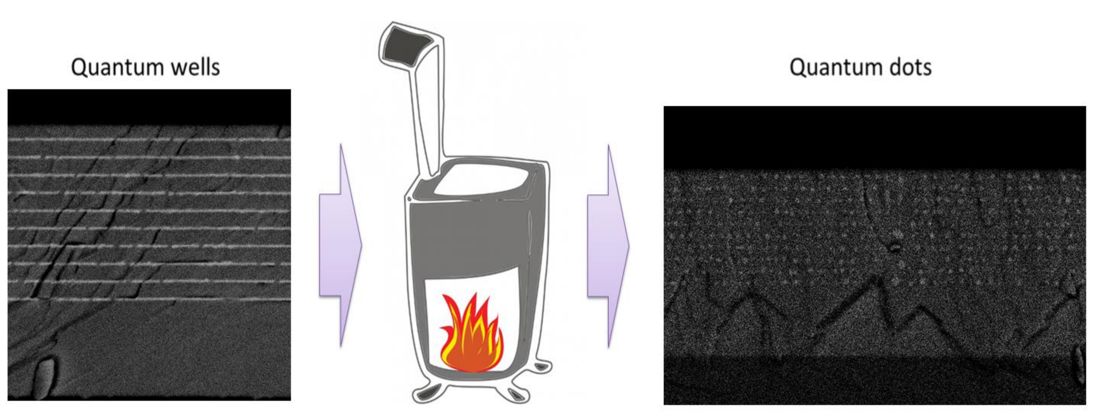
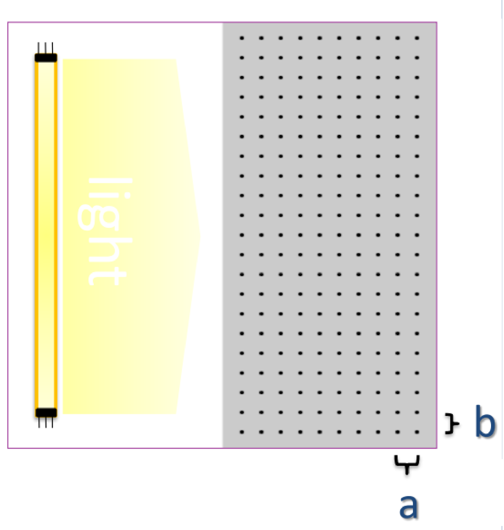


Fig.2 Transformation of layered structure into dot structure (1D → 3D)

Meep simulations

The photonic behavior of the composite crystal containing PbTe(CdTe) dots (or layers) in CdTe(PbTe) matrix was investigated with open-source software *Meep* (MIT Electromagnetic Equation Propagation) [3]. *Meep* uses the *finite – difference time – domain* (FDTD) method to simulate the propagation of light in any electromagnetic system. The simulation process consist of several stages. It requires the creation of a photonic structure by specifying the spatial dimensions and the refractive index distribution. The next step is to determine the properties of the light source and the location of the detector.



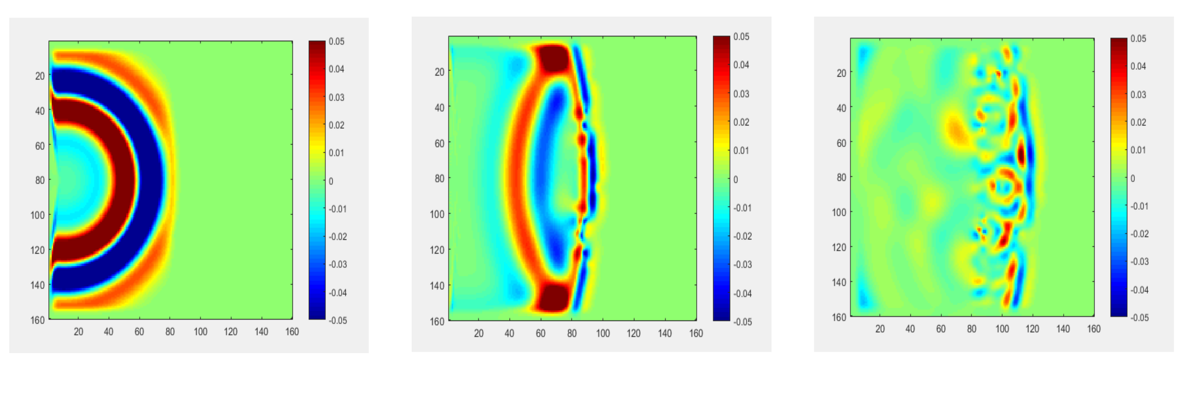
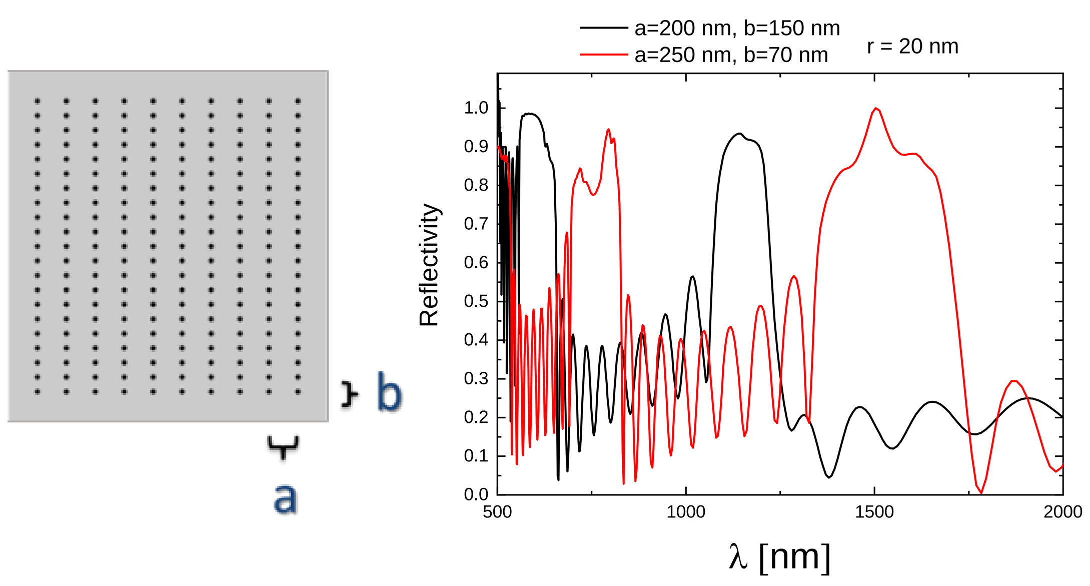


Fig.3 Simulations with the *Meep* package allow tracking the propagation of an electromagnetic wave in photonic structure.

Meep simulations

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

Photonic crystals with PbTe dots



Photonic crystals with PbTe/CdTe layers

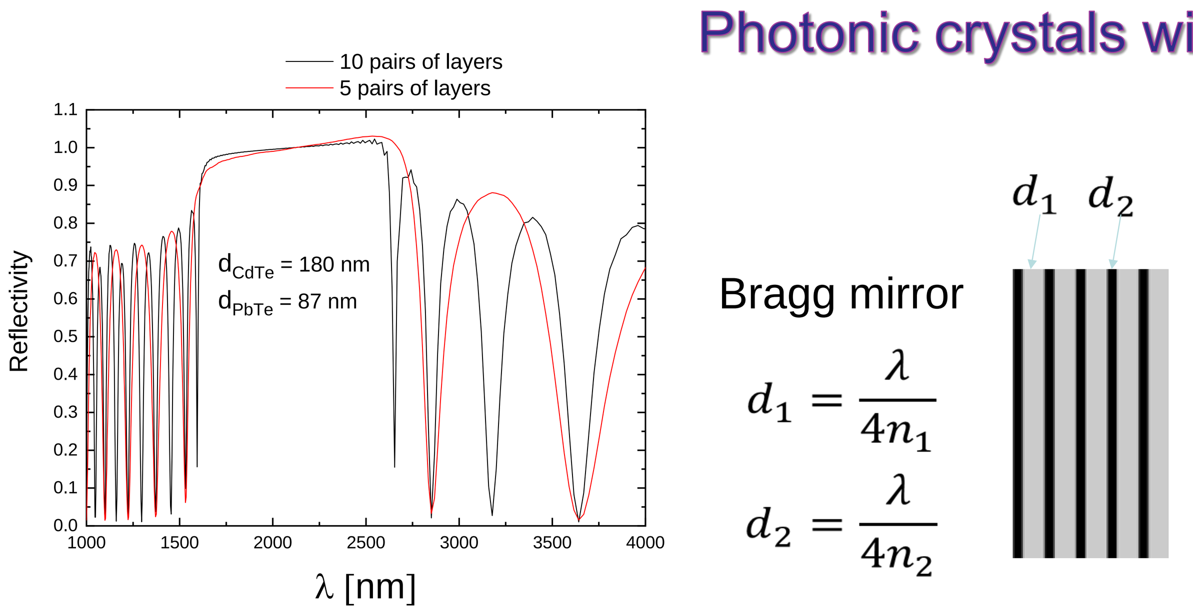
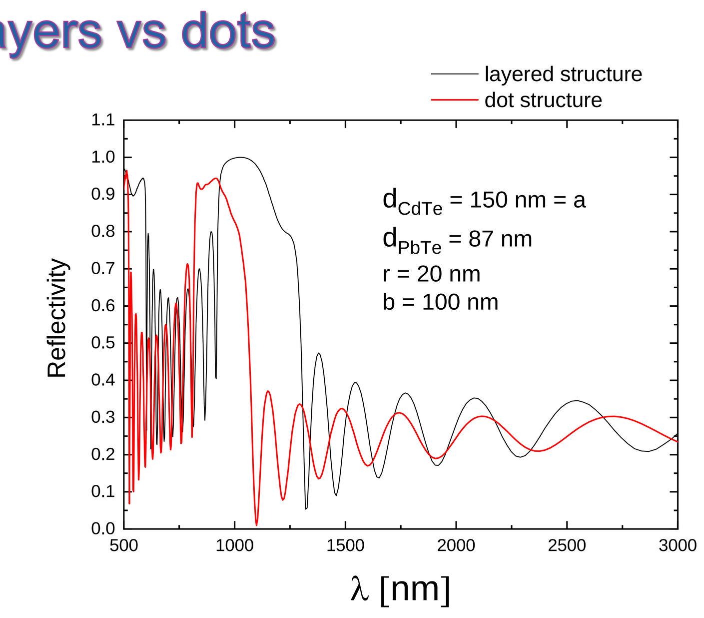


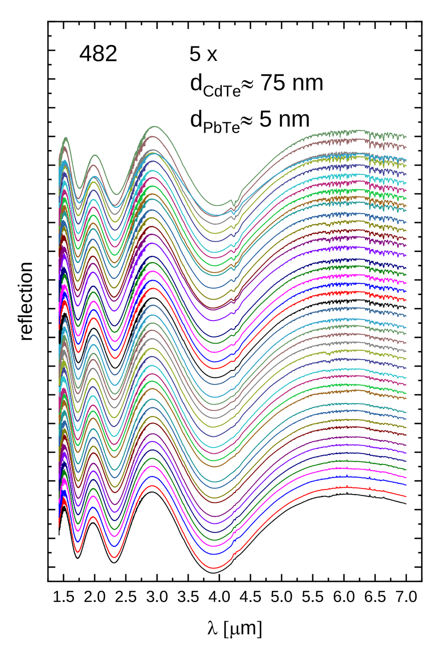
Fig.4 The results of the reflectivity spectra simulations for the CdTe/PbTe structures performed with the Meep package - dots (top panel) and layers (bottom panel).

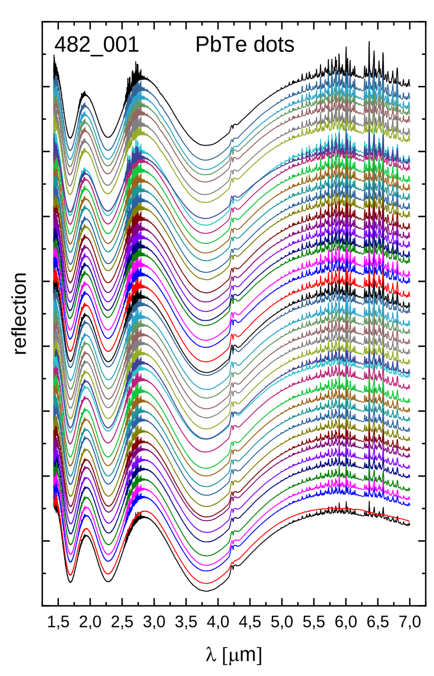
Layers vs dots



Homogeneity measurements

The homogeneity of the examined structures was confirmed by micro-reflectivity measurements using the Fourier spectrometry method at many points of the sample.





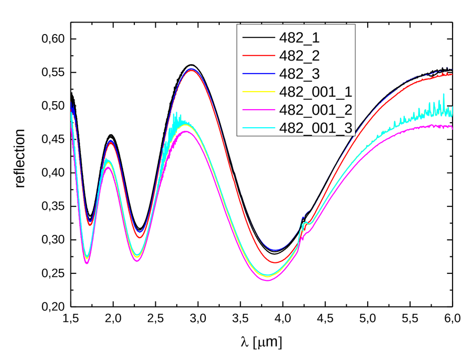
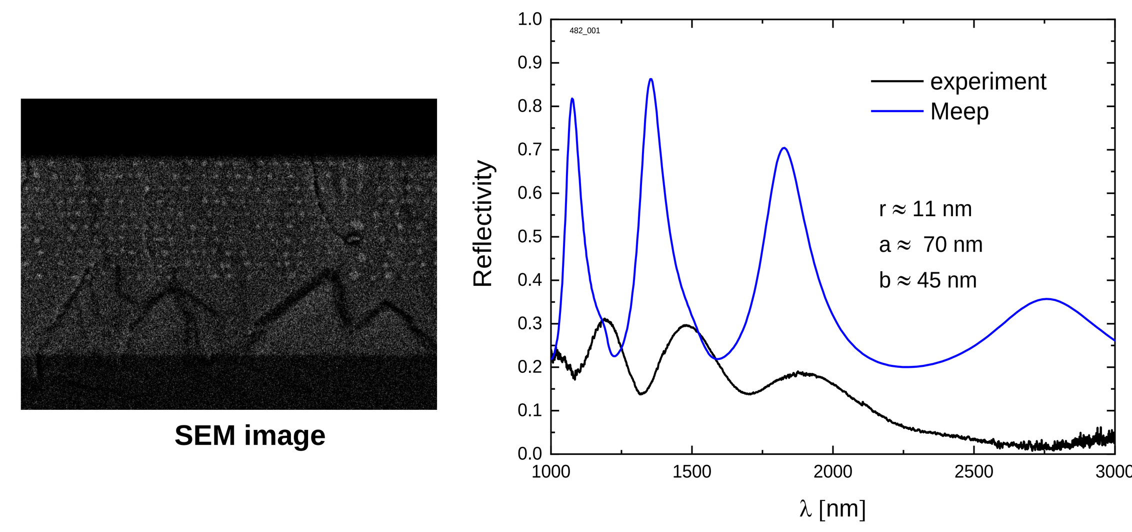


Fig.5 Comparison of micro-reflectivity measurements (bottom right panel) for the CdTe/PbTe structures before (top panel) and after annealing (bottom left panel).

Simulations vs experiment

The comparison of measurements and simulations shows the differences that are caused by the imperfect representation of the real structures in the calculations. An additional limitation is the use of a static dielectric constant in simulations instead of a dynamic dielectric function.



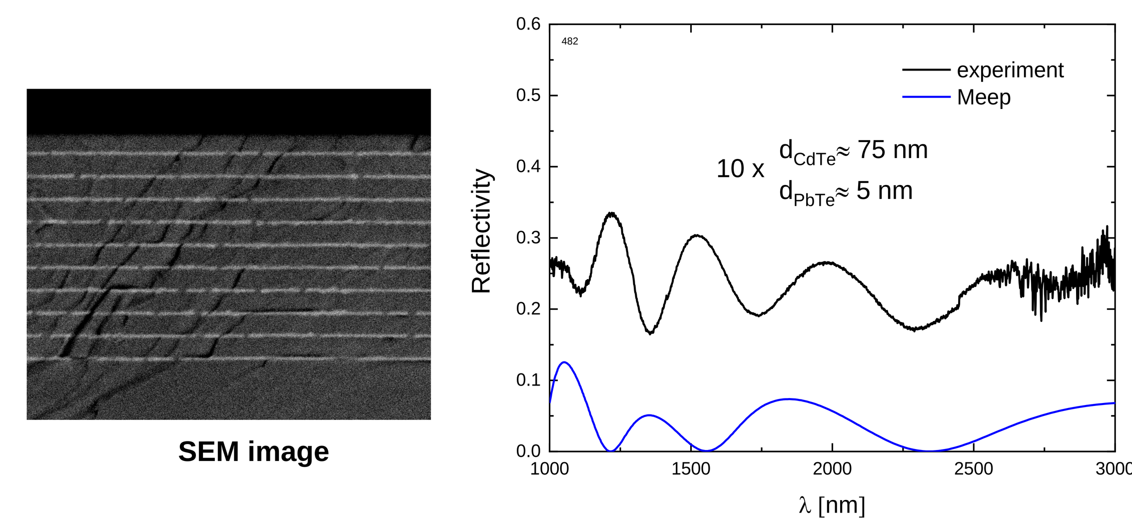


Fig.6 Comparison of simulations and measurements results for real CdTe/PbTe structures with: dots (top panel) and layers (bottom panel).

CdTe/PbTe Bragg mirror

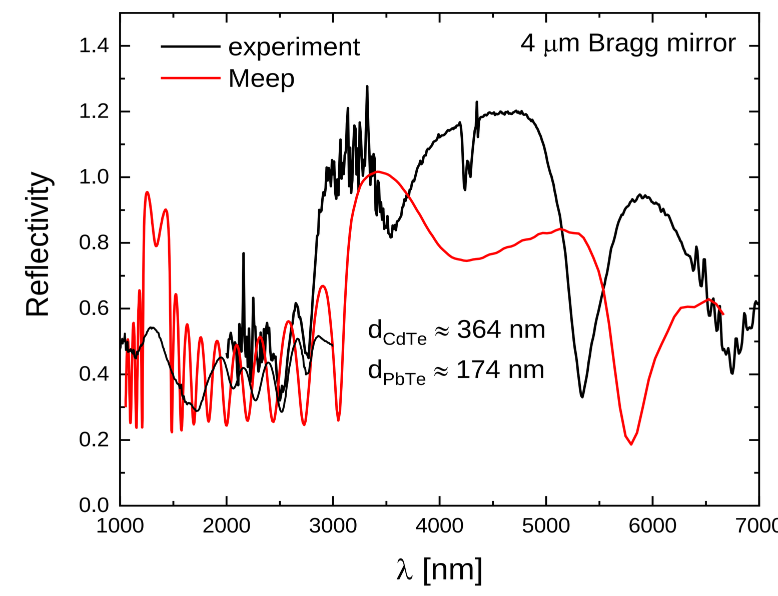


Fig.7 Reflectivity spectra of CdTe/PbTe Bragg mirror type structure designed for 4 μm.

Summary

- Experimental results differ from the simulations due to the presence of structural defects, but the general character of reflectivity spectra is maintained.
- The CdTe/PbTe structures are characterized by high homogeneity both before and after annealing.
- Good quality CdTe/PbTe Bragg mirror structure for mid-infrared spectral range was obtained .

References

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