Defocused Imaging of Single Emitters in Photonic Crystals

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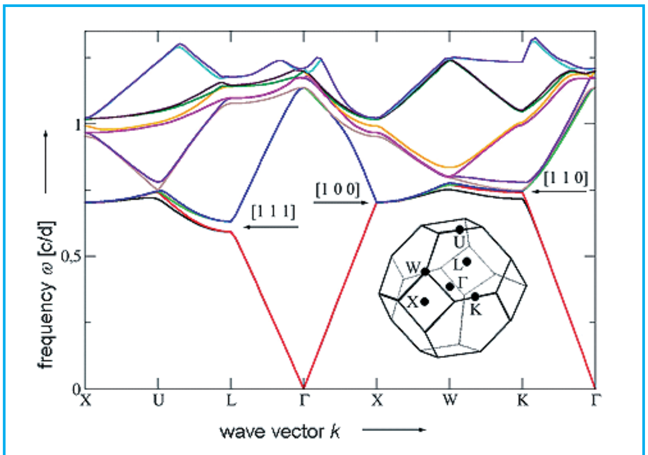
Application Note

Theory

Photonic Crystals (PCs) are materials with a periodically varying dielectric constant, which leads to a photonic band structure, similar to the electronic band structure in semiconductor physics. In recent years, these materials have attracted a lot of attention, since they give the possibility to tailor the emission properties of internal light sources. As in semiconductor physics one can calculate an optical density of states. However, since the dielectric constant is a local property, the density of states is a local density of states, too. Thus all the optical properties of PCs are local properties. For this reason, there is a need for local measurements.

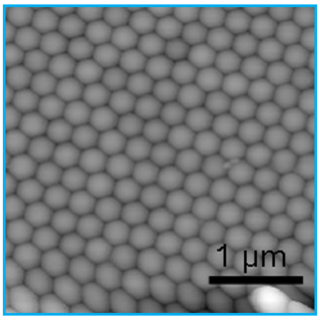
Because the dielectric contrast of our colloidal polystyrene-PCs is small, a complete band gap does not exist, but only a so-called stop band. This means that band gaps only exist for certain directions in the PC. To take this into account, a new value, the FLDoS (Fractional Local Density of States), is introduced [1]. It describes the angular dependence of the density of states at a certain wavelength. Our idea is to use single emitters, incorporated into the PC, as local probes and detect how their emission is influenced by this FLDoS.



Band structure for an fcc-crystal made of polystyrene beads (ε_{air}=1, ε_{bead}=2.53) simulated with 'MIT Photonic Bands' [2]. The positions of band gaps for certain directions are marked with arrows. In the included picture of an fcc brillouin zone some symmetry points are labelled.

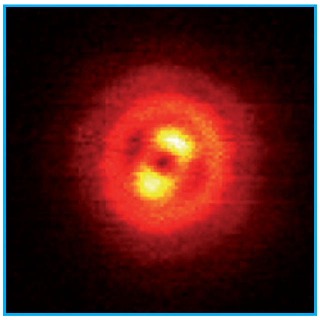
Experiment

We produce PCs made of polystyrene beads by a vertical deposition method (self-organisation) [3]. The beads form an fcc lattice with the (111) plane parallel to the substrate. The PCs are doped with dyed beads during the crystal growth or afterwards with quantum dots.



AFM image of PC made of 260 nm polystyrene beads

The fluorescence of single internal emitters is detected with a home built wide field microscope. However, if we focus on a single emitter we will only see the point spread function from which we do not obtain any information about the angular dependence of its emission. To gain this information, we use a technique called defocused imaging. Using this technique it is possible to observe the anisotropy of emission which is inherent to emitters like molecules or quantum dots. It is often used to determine the orientation of single emitters on a substrate [4]. Our idea is that, if it is possible to observe the anisotropic emission inherent to single emitters, it will also be possible to observe an anisotropy which is induced by a photonic crystal [5].



Quantum dot on a glass substrate defocused by -2 µm. The anisotropic emission leads to the asymmetric diffraction pattern.

To observe all the small details of the diffraction patterns we need a CCD with small pixels. At the same time, we want to observe large areas, so we need many pixels, too. This was one of the reasons why we decided for the iXon EMCCD detector DV885 LC-VP (Andor Technology, Belfast) with 1004 x 1002 pixels of 8 µm x 8 µm about one year ago. This EMCCD has other advantages, too. It can be cooled down to -70°C to achieve a high signal to noise ratio and it offers electron multiplying, which is both important for the detection of single emitters.

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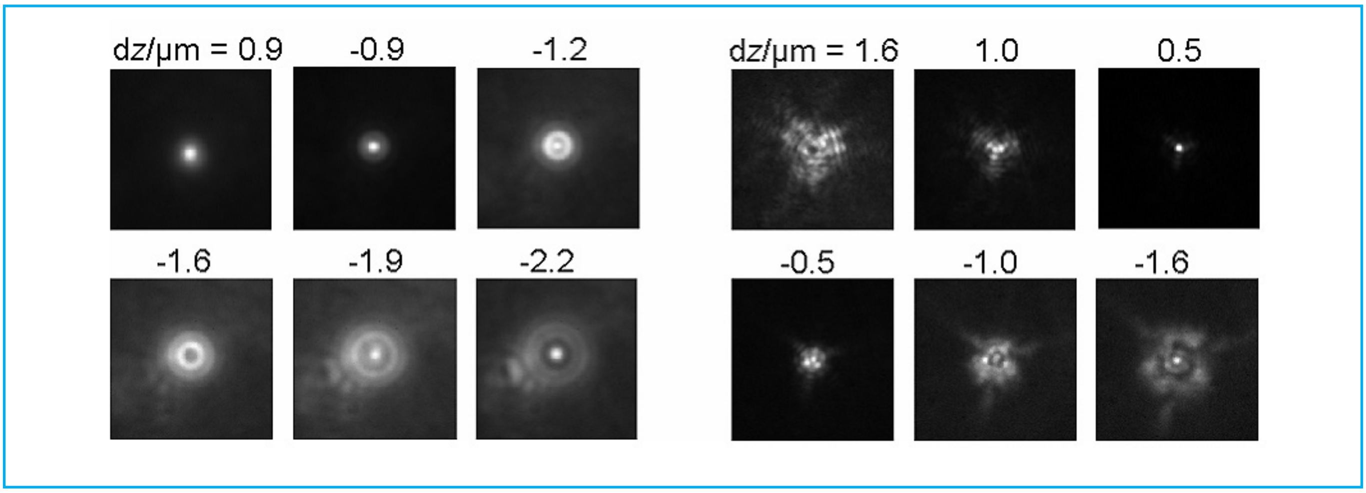
Using the Basic programming language included in the Andor Solis software, it is easily possible to write a program that controls a piezo scanner and the EMCCD. Series with different defocusing values can be recorded automatically.

Comparison of defocused images for dyed beads at the interface between glass substrate and PC and inside the PC clearly shows an influence of the PC on the emission.

At the moment we are working on simulations that will hopefully explain the observed three fold symmetry of the diffraction patterns.



Series of different defocusing values dz for polystyrene beads dyed with nile red. The influence of the PC can be seen clearly.
left: Bead at interface between substrate and PC right: Bead 3.5 μm inside PC.

Literature

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