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Colloidal photonic crystals: Beyond optics, beyond spheres

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Monodisperse and symmetrically shaped colloidal particles tend to form ordered aggregates. When the particle size is in the hundreds of nanometres, such highly ordered structures exhibit fascinating optical properties, hence their name and fame as colloidal "photonic crystals" or as "photonic bandgap material", because they exhibit a forbidden energy band for photons, very much like semiconductor crystals are characterized by a bandgap for electrons. Photonic bandgap engineering is possible by a proper choice of the size and nature of the "photonic atom", and by a proper combination of different kinds of particles. The fame of monodisperse colloidal spheres as photonic atoms is largely based on the self-assembling capabilities into inherently three-dimensional photonic crystals. Colloidal photonic crystals can hence be used as an easy photonic crystal platform to demonstrate proof-of-principle for effects such as reduced local density of states for photons on their emission probability. We have induced spectral narrowing for emission from dye molecules and enhanced energy transfer between light-absorbing molecules in colloidal photonic crystals. By inserting superparamagnetic particles in the tens of nanometres range, it is possible to additionally impart magnetic properties to the photonic crystal. Tuning and enhancing Faraday rotation was possible by careful nanoscale bandgap engineering at two different nanoscales. One disadvantage of colloidal spheres for photonic crystals is the incomplete bandgap that is typical for the highly symmetrical crystal structures that are commensurable with dense packing of spheres. A number of approaches allow deviating from this paradigm towards a complete bandgap in the visible. Etching of material allows a less dense crystal, while non-spherical colloidal particles provide alternate crystal structures. Orientational ordering of such anisotropic particles in an anisotropic photonic crystal requires an additional handle on the particles, the colloidal assembly providing the positional order. Magnetism again provides this handle. Post-formation processing of crystals of positionally ordered spheres into orientationally anisotropic crystals represents another approach.