Master thesis proposal

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Cooperative light emission from self-assembled semiconductor nano-objects

Keywords: fluorescent quantum dots (semiconductor nanoparticles), microscopy, exciton interactions, quantum optics

Scientific description:

Context : the group *Nanophotonics and Quantum Optics* at INSP studies light emission and propagation at the nanoscale : fluorescent nano-sources, emission control by photonic crystals or nano-antennas, chirality of fluorophores and antennas, application to photovoltaics etc. Among our interests, semi-conductor quantum dots are very bright, stable and versatile light sources with more and more applications in bio-imaging, lighting and TV displays. When a *single* nanoparticle is examined by fluorescence microscopy, its emission often displays purely quantum-optical properties such as single photon emission (photons are emitted one by one) which can be used for quantum information. Because of quantum confinement, its energy levels make it similar to an “artificial atom”.

While fluorescence from isolated emitters is now well understood (as illustrated by the recent Nobel prize on quantum dots), most opto-electronic applications (LEDs, solar cells…) involve nanoparticles packed in a dense layer. Then they are expected to behave very differently because of interactions, charge transport and energy diffusion between neighboring particles. This is more difficult to understand as disordered dense samples present an unknown structure and often irreproducible properties.

Internship topic : by using adequate solvent and ligands, the group of B. Abécassis in ENS Lyon has managed to assemble chains of hundreds of semiconductor nanoplatelets (fig. 1(a-c)). They constitute a good model system to explore nanoparticles interactions as they offer strong interactions (large dipole moment, good spectral overlap between absorption and emission, well-known controlled order). For instance, we have shown that, due to near-field dipole-dipole Förster-type interactions (FRET), energy migrates between platelets over record distances of 500 nm (fig. 1(d)) corresponding to around 100 platelets.

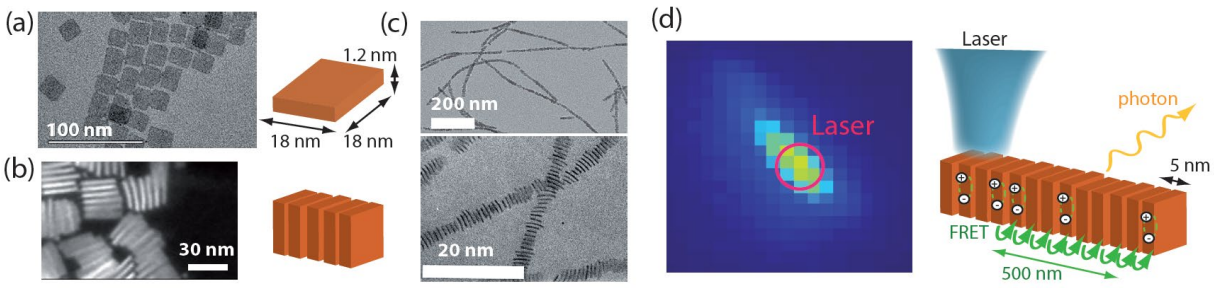

Figure 1 : TEM images of (a) CdSe nanoplatelets, (b) aggregated platelets and (c) self-assembled stacked nanoplatelets [S. Jana et al., Science Advances 2017]. (d) Previous result (Liu et al., 2020) : a laser excites a spot on the chain and energy propagates by FRET between around 100 platelets so that a 1-µm portion radiates light.

The aim of the internship is to examine whether this ensemble of light emitters can also exhibit superfluorescence, a mechanism by which incoherently excited dipoles, because of their coupling to the electromagnetic field, spontaneously develop a coherence and interfere constructively, leading to accelerated emission and original properties for emission correlations and directionality. We will probe the luminescence of chains of CdSe nanoplatelets at cryogenic temperature under various excitation powers and analyze how, for many excited platelets, the emission properties (dynamics, photon correlations) are modified.

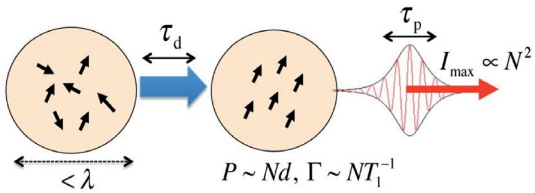

Figure 2 : Superfluorescence mechanism (Kankan Cong et al, 2016) : initially incoherent dipoles develop a coherence and a macroscopic dipole, then after this build-up time they all interfere constructively and radiate very intensity and, thus, very fast.

References (some previous work in the group) :

Jiawen Liu et al., Nano Lett. 20, 3465 (2020)
Jiawen Liu et al., ACS Photonics 7, 2825 (2020)
Jiawen Liu et al., J. Phys. Chem A 125, 7582 (2021)
Zakarya Ouzit et al., ACS Photonics 10, 421 (2023)
Zakarya Ouzit et al., J. Phys. Chem. Lett. 14, 6209 (2023)

Techniques/methods in use: Photoluminescence microscopy, spectroscopy, single-photon detection

Applicant skills: Motivation for experimental work, organization, careful treatment of results, basic knowledge in optics

Internship supervisor : Laurent COOLEN, laurent.coolen@insp.jussieu.fr
http://www.insp.jussieu.fr/-Themes-de-recherche,104-.html

Internship location: Campus Pierre et Marie Curie (4 place Jussieu), couloir 22-32, 5e étage

Possibility for a Doctoral thesis: Y (application to Ecole doctorale funding)