PhD Proposal: Coupled quantum dots for integrated quantum photonics

Self-assembled quantum dots (QD) – clusters of hundreds of atoms that form spontaneously under certain thin film growth conditions – are ideal for quantum information applications due to their discrete, atom-like density of states and ease of integration into conventional semiconductor devices.

Emission of single and indistinguishable photons has already been demonstrated with QDs and also the possibility to realize quantum logic gates. We propose to explore coupled quantum dots, or so-called quantum dot molecules, where two dots are close enough that carriers can tunnel coherently between them. This system has even greater potential as the quantum gate needed for quantum computation. By controlling the number of charge carriers in the molecule, a spin qubit with a large coherence time can be created, about two orders of magnitude longer than the coherence time of a single spin in a QD.

We propose to investigate such structures and realize a device for an efficient spin-photon interface. This challenging project combines advanced epitaxial growth, nanofabrication and quantum optics experiments. Molecules will be embedded in a diode structure to permit an electric field to be applied across the dots, in order to bring the energy levels of the two dots into resonance, creating new electron states which are delocalised across the two dots. The spin states will be addressed and controlled with optical pulses under magnetic field. Original experiments can then be setup, for instance tuning a sequence of radio-frequency magnetic field pulses to the singlet-triplet spin resonance allowing driving the optically initialized qubit.

The coupled QD have to be inserted in specifically designed photonic structures to enhance light-matter interaction and achieve Purcell enhanced spontaneous rate. Since the QD are randomly distributed on the surface, photoluminescence mapping for QD positioning on the sample is necessary, to spatially match the QD and the photonic structure. Such structures with single quantum dots embedded in photonic crystal cavities coupled to waveguides for light extraction are currently being studied at INSP. The process is now well mastered but other potential photonic structures will be considered. Current developments will hopefully improve the photon extraction efficiency.

The student will have the opportunity to participate in all the stages of development of a new quantum device: from thin film growth, device design and fabrication, to the final low temperature photoluminescence measurements of quantum confinement effects and quantum optics experiments.

Techniques/methods used: molecular beam epitaxy, atomic force microscopy, clean-room device fabrication, photoluminescence microscopy; FDTD modelling of photonic structures.

Applicant skills: Background knowledge of semiconductor devices, photonics and quantum mechanics; interest in crystal growth and device fabrication, experience in optical measurements will be appreciated.

PhD supervisor(s) at INSP: Valia VOLIOTIS, and Benoit Eble will supervise the optical experiments and Paola Atkinson, the growth and device fabrication.

Unité mixte de recherche 7588 – CNRS / Sorbonne université UPMC Campus
Jussieu – Tours 22 et 23 – Case courrier 840
4 place Jussieu – 75252 Paris Cedex 5 – France
Tél. : +33 (0)1 44 27 63 72 – Fax : +33 (0)1 44 27 28 78 – www.insp.upmc.fr