Subwavelength Confinement with J-aggregates: A Novel Quantum Material for Nanophotonics

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Mass production of on-chip quantum photonic technologies requires low-cost integration of devices at the nanometer scale. Presently photonic components are made of 'passive' structures such as optical fibres and are limited in how small components can be made (several microns). More recently gold and silver photonic components have been proposed as building blocks for nano-scale on-chip integration. However, some applications require crossing the visible range and obtaining plasmon-like response at infrared or ultraviolet wavelengths. A variety of alternative materials have been explored, including doped semiconductors, graphene or transparent conducting oxides. [1, 2] Here we present an exciting alternative to plasmonics: an organic quantum material which could confine the light at the nanoscale, like metals, but with more flexibility and taking the advantages of fabrication tools of supramolecular chemistry to design properties on demand. [3]

The organic quantum material under study is formed by J-aggregates randomly distributed in a polymer matrix. The J-aggregates are supramolecular structures where strong electronic interactions between closer molecules results in the delocalization of Frenkel excitons over two or more molecules. As a consequence, we can define a quantum wave function over the collective system with a particular pattern of amplitudes across the molecules, equivalent to an extended state. These extended and delocalized Frenkel excitons bring extreme dielectric permittivity values to the polymer thin films, giving rise to high reflectivity and achieving negative real electric permittivity as metals but in a narrow wavelength range. [4] This extraordinary and narrow metal-like properties could be used not just to confine light at nanoscale as in plasmonics, it also can be used as a tool in photonic design defining new types of optical modes. [5]

In this contribution I will show that these organic quantum materials can be used as building blocks at nanoscale. First, I will demonstrate that plasmon-like properties of molecular thin films can be obtained for a large variety of molecular J-aggregates with metal-like properties expanded from the VIS to the NIR. I will continue explaining how their intriguing properties such as spontaneous and reversible self-assembly can be used to master the properties of a quantum solid from the mesoscale. And, finally, I will show how colloidal chemistry approaches for nanofabrication can bring us to novel plastic quantum material platform at nanoscale.

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