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Strong light-matter coupling in organic crystals

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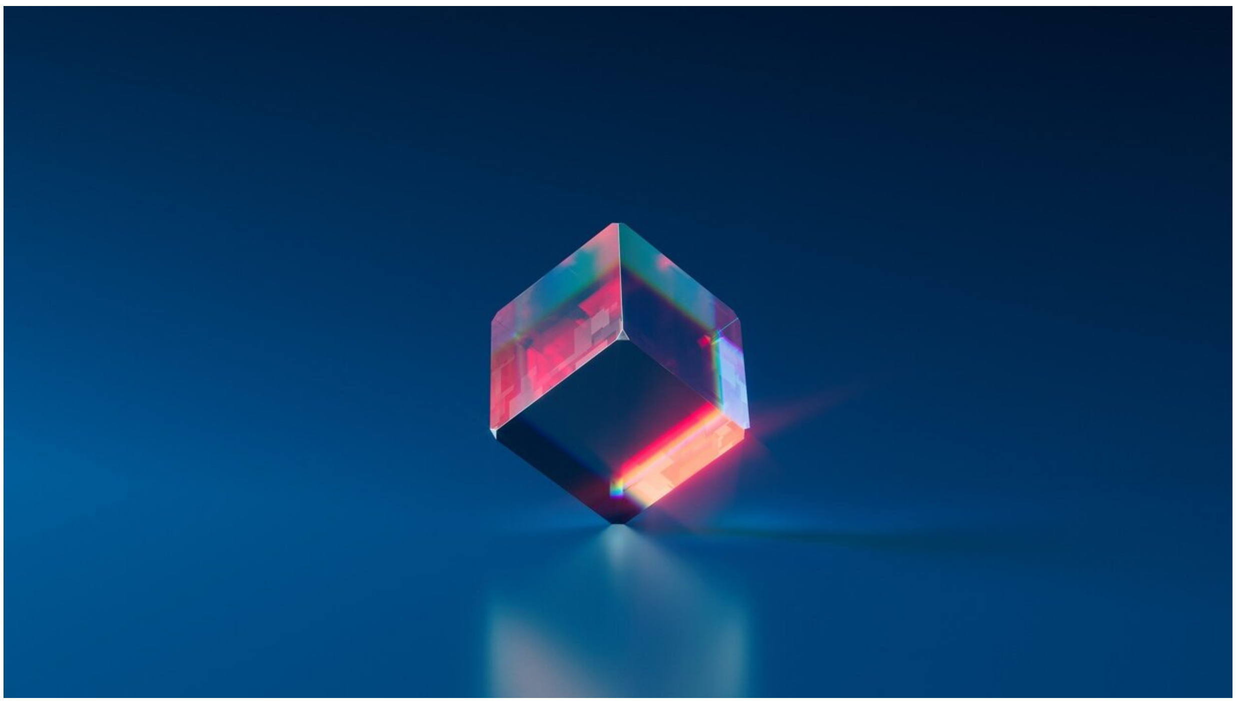

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Organic semiconductors are an emerging class of materials for opto-electronic devices such as solar cells and organic light emitting diodes. As a result, it's important to tune materials properties for specific requirements like efficient light absorption and emission, long excited state lifetimes, or more exotic properties (such as singlet fission). One of the advantages of these organic semiconductors over conventional inorganic semiconductors is that by changing the design of the molecules many different properties can be generated. For his Ph.D. research, Anton Berghuis explored changing materials properties using light.

Advancements in nanofabrication techniques enabled the structuring of matter on the scale of the wavelength of light. By doing so, the interaction of light and matter may be enhanced, leading to interesting new properties.

In his Ph.D. research, Anton Berghuis and his collaborators designed a nanostructure consisting of silver nanoparticles placed in a rectangular lattice such that the cavity supports resonances in the optical regime. When tuning the optical resonance to the exciton energy in an organic semiconductor, the light in the cavity and the exciton may interact when the semiconductor is placed on top of the cavity.

When this interaction is stronger than the average of the losses of the exciton and the cavity, the interaction results in a hybridization of the exciton and cavity mode and we speak of the strong coupling regime. The hybridization is described by the introduction of a quasi-particle called exciton-polariton, with properties of the both the exciton and the photons in the cavity.

Three discoveries

Berghuis have made three discoveries related to this light-matter interaction. First, he showed that it is possible to tune the interaction strength between the cavity and the molecules by choosing the orientation of the molecules in the cavity. This allowed for the modification of the absorption and emission spectra of the coupled system.

Second, Berghuis observed that tetracene molecules in the cavity were emitting more light and emitted the light over a longer period of time. Even though the signal was a factor of 4 higher than outside the cavity, the total emission was still very low. The phenomenon however is very interesting and should be investigated further. If the emission efficiency can be further improved, this design could be applied in organic light emitting diodes (OLEDs).

Last, he investigated the transport length of the coupled exciton-polaritons, which is a very important property for materials used in organic solar cells. The research showed that the exciton polaritons in the cavity traveled up to 100 times further when compared to uncoupled excitons. This is a very promising result, but future research should explore whether these propagated exciton polaritons (which partially have a photonic character) can be transferred to other molecules. If the transfer of the exciton polaritons to other molecules is indeed efficient, this opens up the possibility to improve the design of organic photovoltaics which may result in a longer lifetime of the solar cells without losing efficiency.

Title of Ph.D. thesis: "Strong Light-Matter Coupling in Organic Crystals." Supervisors: Jaime Gómez Rivas and Alberti González Curto.

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