Microwave investigations of photo-transport and exciton fission in organic conductors

Research project in the Optoelectronics-group at the Cavendish Laboratory

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Early development in photovoltaic cells relied on inorganic semiconducting materials to realize the active layer where electron-hole pairs are created due the absorption of photons. After absorption, the electron hole pair usually forms a bound pair that is termed an exciton. In order to provide energy to an external circuit, the positive and negative charges forming the exciton must be separated. This can be achieved by applying an external electric field that causes positive and negative charges to drift in opposite directions or by establishing a gradient in carrier concentration that creates a diffusive flow to compensate the gradient of the electrochemical potential. These two routes to efficient carrier separation are now well understood for inorganic semiconductors cells, however these suffer from some practical limitations for broad practical application. For example silicon solar cells require relatively thick silicon films to obtain full optical absorption. These inorganic layers can only be processed at very high temperatures, and are therefore relatively expensive.

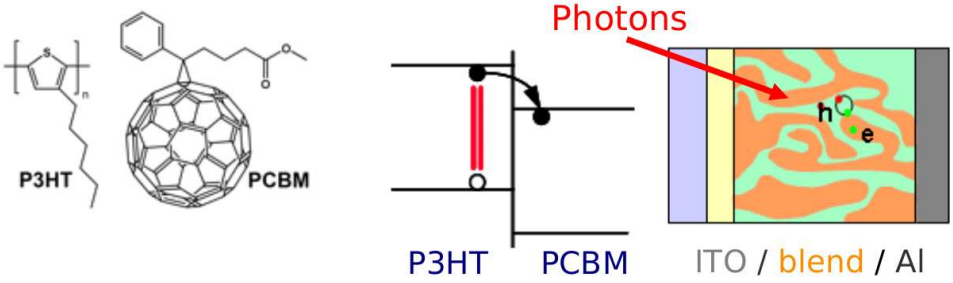

Figure 1: The blend of regio-regular poly(3-hexylthiophene) and [6,6]-penyl C_{61}-butyric acid methylester (P3HT:PCBM, their chemical structure is represented on the left) forms a reference organic solar cell with power conversion efficiencies as high as 5%. It is energetically favorable for an excited P3HT molecule to transfer an electron to a PCBM molecule which acts as an electron acceptor. By controlling the phase separation between these two materials it is possible to create a morphology where excitons can reach P3HT:PCBM interfaces where they form charge transfer states. In this form the excitations have longer lifetimes, they can diffuse to the interfaces with the metallic contacts which allows the extraction of the charges.

Organic semiconductors on the other hand can be deposited on a variety of substrates including flexible and transparent plastics. Thin films of soluble conjugated polymers can be prepared by solution processing methods (for example spin coating) and patterning can be achieved at low cost easily using inkjet printing technologies. Stimulated by these possibilities several devices based on organic polymers were realized including: light emitting diodes that were first fabricated in the

Optoelectronics group in Cambridge, bipolar/ambipolar field effect transistors, photodetectors and photovoltaic cells. However organic materials suffer from two main limitations for photovoltaic cell applications. The excitons are strongly bound due to the low dielectric constant in these materials, and the low mobilities in organic materials excitons can diffuse only on distances of the order of 10nm before they recombine which is too short to reach an electrode interface where exciton dissociation can occur. In donor/acceptor (typically polymer/fullerene) blends the lifetime of the excited states is extended because excitons have time to diffuse to an interface between donor and acceptor molecules where excitons are separated to form a state with much longer lifetimes. An example of a typical material that takes advantage of the donor-acceptor strategy to achieve high power conversion efficiency P3HT:PCBM is shown on Fig. 1. It is believed that the charge transfer states which are formed in this way, consist of a hole localized on a polymer molecule interacting with an electron localized on a fullerene. However little is known about their exact nature, in particular if electron and hole still form a bound state or if they behave as free carriers (for a discussion see [1] and references therein).

The aim of this project is to investigate the nature of these charge transfer states by coupling them to a multimode microwave resonator combined with an optical spectroscopy setup [2]. The proposed microwave domain experiments offer several new possibilities as compared to optical spectroscopy techniques. Due to the very high quality factor of the superconducting resonators $Q \sim 10^4$ it is possible to investigate the photo-excitations under very weak light excitation amplitudes where photoexcitations interact only weakly. By comparing the dielectric response of the photoexcitations and the photo-induced spin resonance signal we aim to measure directly the localization length of the photo-excitations. Finally, the simultaneous measurements of the real and imaginary parts of the dielectric constant which is made possible by working with a resonant technique is also very appealing since it allows to distinguish between bound and mobile carriers. Special emphasis will be placed on experiments on singlet fission systems and high mobility crystals (pentacene,ruberene) [3]. These experiments will be complimented by more conventional magneto-transport studies of the same materials [4].

The internship will provide local support through St Catharine college, http://www.caths.cam.ac.uk.

References :

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