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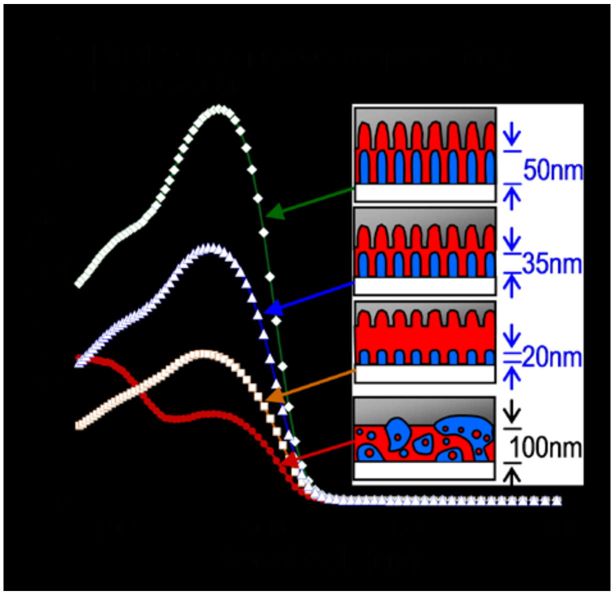
Polymer semiconductors become sophisticated



Short-circuit external quantum efficiency spectra of interpenetrating heterostructure ITO/ PEDT:PSSH/ PFB/ F8BT/ Ca/ Al PVs with different PFB thicknesses, compared to a bulk-distributed heterostructure diode. The lateral length scale of the columnar nanostructured is 200nm

As Singapore embarks on the field of printable plastic electronics as a potential area of focus for the country's next economic push, the discovery by the team of the new technology for designing highly sophisticated and efficient semiconductor devices holds promise to be a cornerstone of future advances in this high-value arena, which promises to revolutionize current lighting technology and energy generation methods using organic polymers, the stuff that plastic is made up, based on a revolutionary new concept of heterostructures.

Heterostructures are interfaces of two or more materials with carefully selected energy-level, bandgap or refractive-index differences that enable charge-carriers, excitons and photons to be manipulated within layers as thin as a few nanometers. By controlling these energy offsets, they have played the central role in maximizing the performance and efficiencies of silicon and other band semiconductors, and also in evaporated molecular semiconductors. However, it has proven very difficult to make similar heterostructures in polymer semiconductors because of the problem of re-dissolution of the underlying polymer films when the overlayers are deposited.

The team of researchers from Organic Nano-Device Lab (ONDL) at NUS, in collaboration with researchers from the University of Cambridge, have now found a way to overcome this by employing a tiny amount of an azide photocrosslinker that has been developed in-house as a photocrosslinking additive. In a paper published in Nature Materials 9 (2010) 152 this year, they reported efficient photocrosslinking through alkyl side chains without modifying the crucial electronic structure of the pi-conjugated polymer backbone. Their report shows it is now possible to design new and more sophisticated semiconductor device architectures with an unprecedented degree of control. This also opens up new possibilities in the fundamental research into the energy-level alignment physics of these materials. Patent applications have been filed by NUS.

For example, their methodology has been applied to solve a fundamental challenge in polymer organic solar cell research to demonstrate a controlled heterostructure necessary for efficient exciton dissociation while providing for high carrier collection efficiencies. In a particular diagnostic test structure with polymer donor and acceptors, the team has achieved a 5-fold improvement in efficiency. To illustrate the versatility of the methodology, the team has also employed the methodology to create semiconductor interlayers that can make more energy-efficient polymer LED devices. These devices provide a greener alternative suitable for replacing fluorescent lighting in the future, since no mercury is used in their production, and the required thin-film large-area lighting form can be efficiently produced.

"This discovery paves the way for the next generation of highly-efficient light-emitting diodes and solar cells from organic polymer semiconductor materials," says Ms Rui-Qi Png, NUS graduate student and lead author of the report. Using heterostructures as a building block, NUS and Cambridge researchers are now working on projects that could eventually make possible power-efficient large-area lighting films that can stick onto tables and walls, for example, and also solar cell films that can be aesthetically go onto windows.

"Organic polymer semiconductor materials already have the advantage of being easy to deposit using low-temperature additive processing which are inherently energy efficient. Our work brings this one step further to enable new technologies in printable plastic electronics," adds Professor Peter Ho, principal investigator from the Department of Physics, NUS.

"For this work we went through a number of development cycles of iterative materials chemistry and device work to achieve this that took us several years," says Professor Lay-Lay Chua, principal investigator from the Department of Chemistry, NUS. The scientists had to first develop a new approach to photocrosslinking of polymer semiconductors. Although a number of chemistries to do photocrosslinking already existed, none was found entirely satisfactory when applied to polymer semiconductors due to the stringent demands for high electronic quality in semiconductors. "We took some time to figure out that what was causing issues with a particularly attractive class of crosslinkers was the close molecular interaction between the crosslinker and the polymer. Once we have realised this, it set us on a path to finding molecular engineering ways to suppress this interaction. And it worked."

This breakthrough was developed together with the groups led by Professor Sir Richard Friend, NUS Tan Chin Tuan Centennial Professor and Cavendish Professor at the University of Cambridge, and Dr Jeremy Burroughes, Chief Technology Officer at Cambridge Display Technology. It was partially funded by MOE and A*STAR SERC Thematic Strategic Research Programme on Polymer and Molecular Devices.

The ONDL team does fundamental studies on the structural properties and device spectroscopy of organic conjugated semiconducting polymers so as to make paradigm improvements and breakthroughs in high-mobility transistors, high-efficiency solar cells and light-emitting diodes, and ink-jet printing. They also research on solution-processable graphene that is compatible with spin-coating, spraying and ink-jet printing deposition technologies for practical optical and electronic applications.