IFLs created from pi-conjugated polymers improve performance and stability of optoelectronic devices

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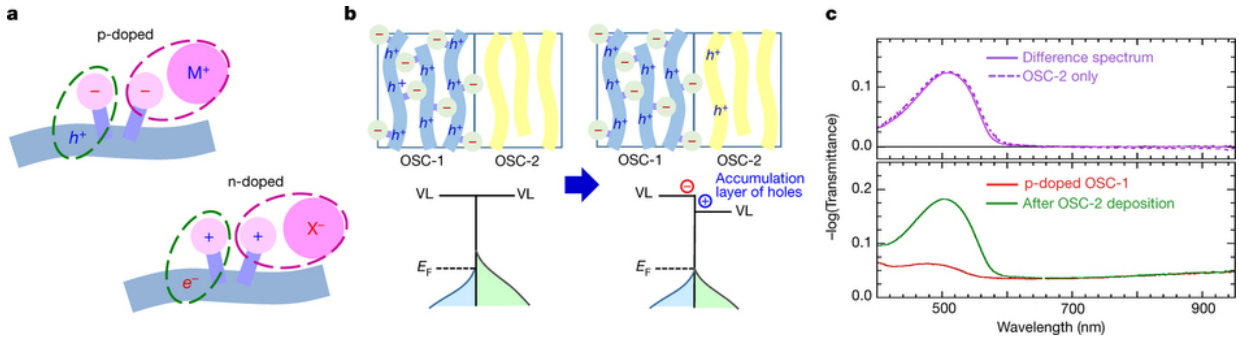

Stabilization of the doping profile by counter-ion immobilization in self-compensated doped polymer organic semiconductors. Credit: (c) *Nature* (2016). DOI: 10.1038/nature20133

(Phys.org)—A team of researchers from Singapore and the U.K. has found that using a particular type of polymer allowed for creating interfacial layers (IFLs) in optoelectronic devices with improved performance and stability. In their paper published in the journal *Nature*, the team describes their technique and their results when they made actual devices using the polymer. Antonio Facchetti with Northwestern University offers a News & Views piece on the work done by the team in the same journal issue and outlines some of the benefits of self-compensated polymers as well as some of the hurdles that will need to be

overcome before they can be used in commercial products.

To make optoelectronic devices a layering technique is used—a thin film conductor is caused to be in contact with a semiconductor allowing an electric charge to move between them—to facilitate the transfer an IFL is placed between them. But as Facchetti notes, conventional IFLs are considered to be inefficient—improvements would allow greater efficiency in solar cells, for example. In this new effort, the researchers suggest a particular type of polymer, part of a group called π-conjugated polymers—a type of stable polymer with high doping content that has a self-compensation mechanism that involves covalently bonded counter ions that serve to block the migration of dopants—they offer not only improved efficiency but stronger performance and more stability. But, as Facchetti also notes, most such polymers in their native state are not able to transfer large numbers of charged particles—to overcome that problem the researchers used a chemical doping process that caused the charge carriers to become denser which in turn caused the polymer to become much more conductive.

To test their ideas, the researchers modified several devices (solar cells, LEDs, photodiodes, etc.), replacing conventional IFLs with ones they had created and then tested their performance. The team reports that the expected improvements in efficiency were realized, which they note, suggests such polymers have the potential to improve the efficiency of a wide variety of optoelectronic devices. More work will need to be done though before that can be proven—first it remains to be seen if such polymers can be scaled up and then it must be shown that they can stand up to the rigors of real-world demands.

More information: Cindy G. Tang et al. Doped polymer semiconductors with ultrahigh and ultralow work functions for ohmic contacts, *Nature* (2016). DOI: 10.1038/nature20133

Abstract

To make high-performance semiconductor devices, a good ohmic contact between the electrode and the semiconductor layer is required to inject the maximum current density across the contact. Achieving ohmic contacts requires electrodes with high and low work functions to inject holes and electrons respectively, where the work function is the minimum energy required to remove an electron from the Fermi level of the electrode to the vacuum level. However, it is challenging to produce electrically conducting films with sufficiently high or low work functions, especially for solution-processed semiconductor devices. Hole-doped polymer organic semiconductors are available in a limited work-function range, but hole-doped materials with ultrahigh work functions and, especially, electron-doped materials with low to ultralow work functions are not yet available. The key challenges are stabilizing the thin films against de-doping and suppressing dopant migration. Here we report a general strategy to overcome these limitations and achieve solution-processed doped films over a wide range of work functions (3.0–5.8 electronvolts), by charge-doping of conjugated polyelectrolytes and then internal ion-exchange to give self-compensated heavily doped polymers. Mobile carriers on the polymer backbone in these materials are compensated by covalently bonded counter-ions. Although our self-compensated doped polymers superficially resemble self-doped polymers, they are generated by separate charge-carrier doping and compensation steps, which enables the use of strong dopants to access extreme work functions. We demonstrate solution-processed ohmic contacts for high-performance organic light-emitting diodes, solar cells, photodiodes and transistors, including ohmic injection of both carrier types into polyfluorene—the benchmark wide-bandgap blue-light-emitting polymer organic semiconductor. We also show that metal electrodes can be transformed into highly efficient hole- and electron-injection contacts via the self-assembly of these doped polyelectrolytes. This consequently allows ambipolar field-effect transistors to be transformed into high-performance p- and n-channel transistors. Our

strategy provides a method for producing ohmic contacts not only for organic semiconductors, but potentially for other advanced semiconductors as well, including perovskites, quantum dots, nanotubes and two-dimensional materials.