A speedier way to evaluate organic photovoltaics

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Time-resolved microwave conductivity promises to be a faster, easier evaluation method for organic solar cells that could help engineers screen optoelectronics without first building them into a device.

Researchers of organic photovoltaic cells (OPVs) focus great attention on producing a low-cost, bendable, large-area device that can be fabricated via a roll-to-roll process.\textsuperscript{1,2} The great flexibility inherent in organic materials makes them promising candidates for such applications. But their widespread use has been hindered by low power conversion efficiencies (PCEs) and instability over long operation times in comparison with their inorganic counterparts. PCE in particular is considerably affected by many factors, such as the photoabsorption spectrum (optical band gap), the highest occupied and lowest unoccupied molecular orbitals of the electron donor and acceptor molecules, exciton formation and diffusion, and charge separation and transport. The complicated interplay of parameters intrinsic to the material or device (e.g., electrode work function, interface barrier, and buffer layer) and extrinsic (e.g., impurities) makes evaluation and optimization of an OPV quite time-consuming.

There are potential alternatives to building a new device each time a researcher needs to characterize a new OPV. Several non-contact techniques have been proposed, such as transient absorption spectroscopy,\textsuperscript{3} terahertz time-domain spectroscopy,\textsuperscript{4} and flash-photolysis time-resolved microwave conductivity (FP-TRMC).\textsuperscript{5} But transient absorption spectroscopy can detect only the density of charge carriers in an OPV, not their velocity. And terahertz time-domain spectroscopy uses wavelengths too short to detect subtle photoconductivity signals in OPVs.

FP-TRMC uses microwaves to excite charge carriers (electrons and ‘holes,’ e.g., spaces where electrons might fill in) in an OPV. When the charge carriers vibrate, they discharge some of the microwave energy. That loss can be detected in the microwave signal and reveals both the density and velocity of the charge carriers. It is sensitive enough to detect even subtle signals. We tested FP-TRMC and found a good correlation between the

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**Figure 1.** Left: Organic photovoltaic cell (OPV) device with current-voltage (J-V) curve. Center: Chemical structures of methanofullerene (PCBM) (bottom) and poly(3-hexylthiophene) (P3HT), where S is sulfur, R indicates a hydrocarbon, and n/2 means the structure shown is half of the polymer’s repeated unit (top). Right: Flash-photolysis time-resolved microwave conductivity (FP-TRMC) measurement with transient photoconductivity signal.

**Figure 2.** Correlation between device efficiency (PCE) and FP-TRMC maximum ($\Phi \Sigma \mu_{\max}$) in P3HT:PCBM = 1:1. oDCB: Ortho-dichlorobenzene. CB: Chlorobenzene. CF: Chloroform. (Reproduced with permission of Wiley-Vch.\textsuperscript{5})

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We also note that FP-TRMC transients are relatively unaffected by chemical impurities. Figure 3(a) shows the current-voltage curves of the solar cells in the presence of 0, 0.2, 1, and 5 wt% Pd complex, tetrakis(triphenylphosphine)palladium(0), also written as Pd(PPh$_3$)$_4$. It is a typical catalyst of Suzuki polycondensation. Upon increasing Pd concentration, PCE decreased to about the half of the original value. However, FP-TRMC transients shown in Figure 3(b) were not significantly changed. Vigorous purification of synthesized polymers is indispensable for improving device performance. In contrast, FP-TRMC experiments do not need such laborious purification, leading to the stable and speedy evaluation of BHJ films.

We found the minimum charge carrier mobility to be $0.22 \text{cm}^2\text{V}^{-1}\text{s}^{-1}$ in P3HT:PCBM = 1:1 film along with 3.26% PCE. The mobilities proved by FP-TRMC were found to scale with the PCE, suggesting that local charge carrier motion has an impact on overall device performance. We expect the good correlation between FP-TRMC and PCE will make FP-TRMC an easy screening method for surveying the potential of optoelectronic materials. We hope to apply this technique in the future to low-bandgap materials being developed all over the world.