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Flexible, cost-efficient polymer solar cells for low-performance photovoltaics

Kristofer Tvingstedt and Olle Inganas

Microfluidic deposition of metal grids can facilitate printing methods for building solar cells on flexible carriers without costly transparent electrodes.

Electronic polymers and molecules for photovoltaic energy applications may lead to the use of inexpensive materials with power conversion efficiencies that, though not as great as silicon photovoltaics, compare favorably with other thin-film technologies. The main advantage of organic polymers is low production cost for large-area devices manufactured with the help of printing technology. Electrodes should also be economical.

Evaporation or sputtering of a metal electrode is not the cost driver. But it certainly requires considerable energy. Increased indium demand, used in ITO (indium tin oxide) transparent electrodes and flat screens, has provoked a tenfold price rise in recent years. This will forestall ITO use in low-performance photovoltaics, due to competition from the steadily growing display industry. The alternatives are carbon nanotube electrodes[1] and metallic polymer conductors. Both can provide sufficient electrical transport and optical transparency. The preparation of carbon nanotubes in pure metallic form remains possible but problematic.

When first reporting on ITO-free polymer solar cells,[2] we observed that the low conductance of that generation of transparent metallic polymers would require a small mesh metal grid to create low-impedance current collectors. Later we showed how different preparation methods of transparent polymer electrodes affect both charge injection and transport when used as buffer layers in ITO-based plastic photovoltaics.[3] Now we present one route to such layers with a later generation of the transparent electrode, using diethylene glycol-poly(3,4-ethylenedioxythiophene) poly(styrenesulfonate), or DEG-PEDOT(PSS), in combination with a silver (Ag) grid (see Figure 1).

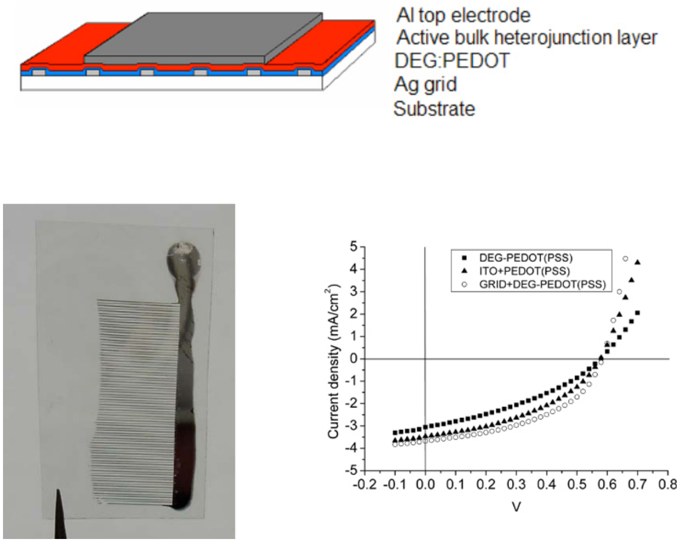

Figure 1. *(top) Cell exploiting the Ag grid. (lower left) Ag grid on plastic sheet. (lower right) Current-voltage characteristics from three cells exploiting electrodes based on PEDOT(PSS). The three electrodes compared include one pure DEG-PEDOT(PSS), one (ITO)+PEDOT(PSS), and one exploiting Ag grid+DEG-PEDOT(PSS). PEDOT(PSS): Poly(3,4-ethylenedioxythiophene) poly-(styrenesulfonate). DEG: Diethylene glycol. ITO: Indium tin oxide.*

The grid itself was deposited by microfluidic methods using a rubber stamp. Capillary action filled the rubber channels with a silvering fluid for electroless deposition of flat Ag layers. The roughness of the DEG-PEDOT-coated Ag deposits was low, a necessity as the active layer thickness was only 50–100nm. Surface resistance of the 100nm-thick Ag layer was 0.5ohm/square and the 160nm PEDOT(PSS) layer spin-coated on top provided a layer with a sheet resistance of 5kohm/square. The transparency of the metal grid in the 400–650nm range was now comparable

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to that of the ITO reference layers we used, and superior in the near infrared region. Inasmuch as a PEDOT(PSS) layer is mandatory in both types of Ag grid and the ITO global layers, we considered such transparency to demonstrate moderate optical loss due to reflection at the Ag grid.

Analyzing the tradeoff between optical transmission and series resistance of the Ag grid/PEDOT overlayer, we found that a 6% area coverage of the Ag pattern can balance the electrical losses in current collectors. This figure depends on geometry, thickness, and conductivity, but indicates that loss of total power is minor. The optimized electrode grids form bars 40μm wide separated at a distance of 600μm and covering areas of ~ 4cm^2. On this scale, we find that electrodes of Ag grid/DEG-PEDOT compare in performance to ITO/PEDOT(PSS) when used for a low bandgap alternating copolymers of polyfluorene and a fullerene polymer blend.[4] Because the grid and PEDOT layers are produced by fluid deposition, the technology is fully compatible with printing on flexible sheets at low temperatures.

Requiring even higher conductivity and transparency for polymer anodes should provide strong impetus to materials chemists. If goals can be met with concomitant stability and function, many square kilometers of coatings will be used in plastic photovoltaics. Furthermore, if high-performance transparent polymer cathodes deposited from fluids were to become available, transparent solar cells without metallic cathodes could be designed and produced for aesthetic appeal as well as for energy conversion, offering attractive possibilities for architects and for building integration. They would also be relevant to multiple bandgap solar cells in tandem construction, where cells optimized for different spectral portions of the solar input could enable higher power conversion efficiency. A small step toward such transparent cathodes and anodes also relies on different forms of PEDOT.[5]

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Author Information

Olle Inganas and Kristofer Tvingstedt
Biomolecular and Organic Electronics
Center for Organic Electronics
Linköping University
Linköping, Sweden

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