

## Final Technical Report

**Project Title:** Interfacial Engineering for Highly Efficient-Conjugated Polymer-Based Bulk Heterojunction Photovoltaic Devices

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**Project Objective:** To improve the performance of organic photovoltaic devices by developing new electro-active materials with improved absorption and mobility, optimizing the interfaces between semiconductors and electrodes, and fabricating high efficiency tandem cells.

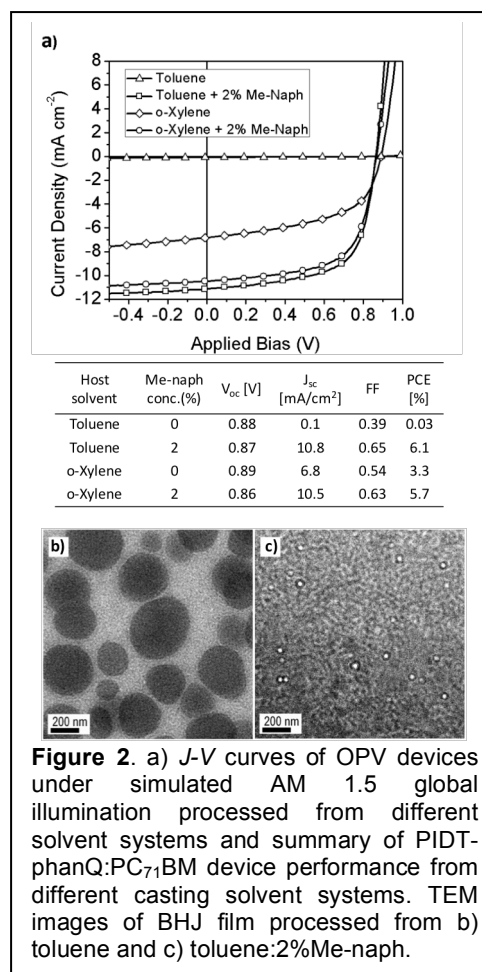
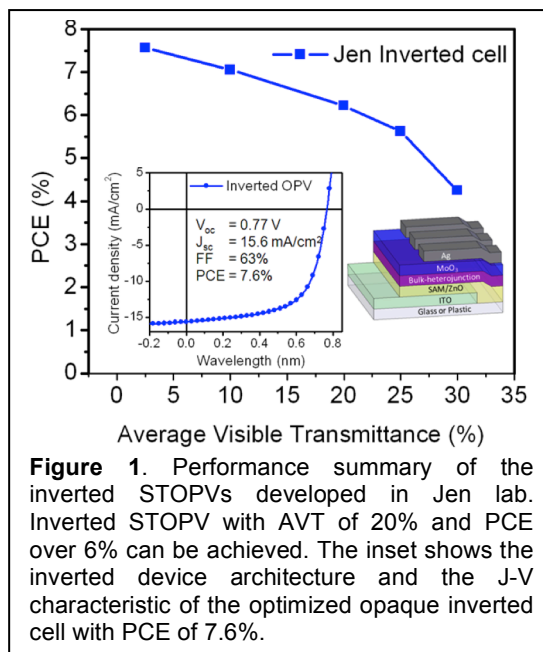
**Background:** The aim of our proposal is to apply interface engineering approach to improve charge extraction, guide active layer morphology, improve materials compatibility, and ultimately allow the fabrication of high efficiency tandem cells. Specifically, we aim at developing:

- i. Interfacial engineering using small molecule self-assembled monolayers
- ii. Nanostructure engineering in OPVs using polymer brushes
- iii. Development of efficient light harvesting and high mobility materials for OPVs
- iv. Physical characterization of the nanostructured systems using electrostatic force microscopy, and conducting atomic force microscopy
- v. All-solution processed organic-based tandem cells using interfacial engineering to optimize the recombination layer currents
- vi. Theoretical modeling of charge transport in the active semiconducting layer

The material development effort is guided by advanced computer modeling and surface/interface engineering tools to allow us to obtain better understanding of the effect of electrode modifications on OPV performance for the investigation of more elaborate device structures. The materials and devices developed within this program represent a major conceptual advancement using an integrated approach combining rational molecular design, material, interface, process, and device engineering to achieve solar cells with high efficiency, stability, and the potential to be used for large-area roll-to-roll printing. This may create significant impact in lowering manufacturing cost of polymer solar cells for promoting clean renewable energy use and preventing the side effects from using fossil fuels to impact environment.

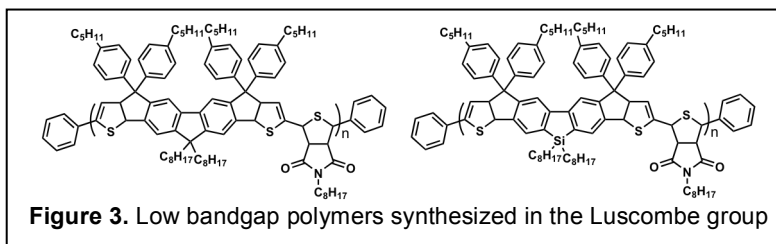
## Task 1: Development of new materials for high-performance solar cells

- We have fabricated high efficiency inverted structure OPV cells with optimum power conversion efficiency (PCE) up to 7.6% based on the BHJ blends of PBDTTT-C-T: PC<sub>71</sub>BM, the efficiency which is comparable to the best reported number of conventional structure device of the same BHJ blends (**Figure 1**). It was found that interfacial modification by a C<sub>60</sub>-based self-assembled monolayer (SAM) between the ZnO and the BHJ layers was crucial to achieve the optimum PCE, otherwise, the PCEs could be 20% lower. We have also demonstrated highly efficient semi-transparent devices in the same inverted architecture by controlling the thickness of the top silver electrode. By reducing the thickness of the top silver layer from the original 100 nm to various thicknesses of 50 nm, 30 nm, 20 nm, and 10 nm, the average transmittance of the devices within the visible spectrum between 370 nm and 740 nm increased accordingly from the original 2.5% to 10.5%, 19.8%, 25.6%, and 29.6%, as well as the PCE decreased from 7.56% to 7.05%, 6.22%, 5.62%, and 4.25%. These state-of-the-art PCEs of OPV devices with different transmittance show great promise on the applications such as energy-harvesting windows.
- One of the focuses in this project is to demonstrate highly efficient BHJ solar cells from simple processing steps using completely halogen-free casting solvents. Halogen-free solvent processing is attractive for large-scale module manufacturing from life cycle assessment and sustainable development points of view. Therefore, we developed eco-friendly PV ink formulations that are more “green” and compatible with roll-to-roll processes. Several non-halogenated solvents such as toluene and o-xylene are identified and show good solubility for our low bandgap



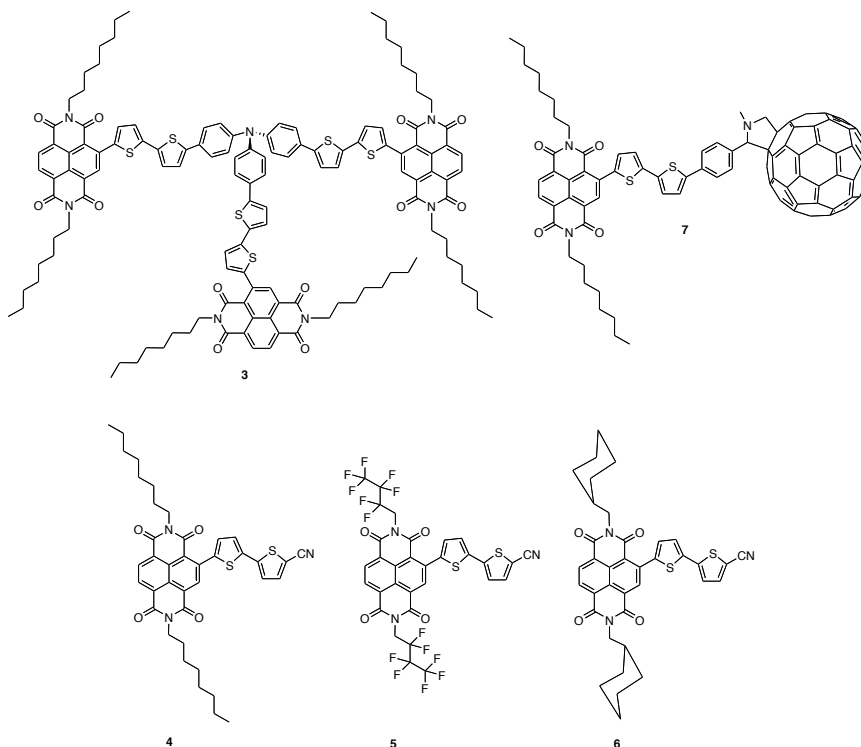
polymer (PIDT-PhanQ). However, one of the major limitations for using non-halogenated aromatic solvents for processing of BHJ film is due to the low solubility of fullerenes in those solvents. To alleviate the problem of low fullerene solubility in toluene and o-xylene, we design a new solvent system by adding small fraction of a more potent solvent for PC71BM to the processing fluid. We identify the halogen-free 1-methylnaphthalene (Me-naph) as solvent additive due to its exceptional fullerene solubility. To test the effects of Me-naph as a solvent additive on PIDT-phanQ : PC71BM blends, we investigated different concentrations of Me-naph in toluene and o-xylene and optimized the device performance. **Figure 2** summarizes the J-V characteristics and photovoltaic parameters for devices processed from different solvent systems. The PIDT-phanQ : PC71BM BHJ solar cells cast from toluene and o-xylene both showed significantly inferior efficiencies compared to  $PCE > 6\%$  for devices cast from o-DCB. However, when small volume of Me-naph was added to the casting solutions, OPV devices completely recoup device efficiency due to the recovery of  $J_{sc}$  (greater than  $10 \text{ mA cm}^{-2}$ ) and FF (greater than 0.60) while maintaining the  $V_{oc}$  at about 0.87 V. The optimized device was obtained from 2 vol % of Me-naph in toluene with  $PCE = 6.1\%$ , comparable in efficiency to reported o-DCB-cast devices. To the best of our knowledge this is currently the highest efficiency reported for halogen-free solvent processed OPV devices. Halogen-free organic solvents are more attractive processing solvents since their aggregate environmental accumulation can be mitigated with comparative ease, making them more compatible with sustainable large-scale manufacturing. Our finding represents a significant step towards environmental friendly process for the manufacturing of OPVs and we will further apply these PV inks in R2R process to verify the device performance.

- In the previous quarter, we had reported a PCE of 4.3% using the polymers shown in **Figure 3** with PC<sub>61</sub>BM. This quarter has involved optimizing the active layer morphology even further and we have now obtained devices with PCEs greater than 5%. The next step will involve using PC<sub>71</sub>BM instead of PC<sub>61</sub>BM as the acceptor material to increase light absorption in the devices.
- 3-D n-type semiconductors with improved light absorption compared to fullerene derivatives



There is a clear need for alternative acceptor materials that - like PCBM - possess favorable electron-transporting and processing properties, but which also absorb strongly in the solar spectrum, have energy levels significantly different from those of fullerene-based acceptors, and exhibit diversification regarding derivatization and functionalization. In summary, it is desirable to have electron acceptors with the combination of the following properties: 1) ability to optimize the bandgaps of acceptor molecules for maximum absorption of the solar spectrum; 2) more tunable LUMO level than PCBM to have suitable electron affinity and give rise to a higher open circuit

voltage; 3) nanophase separation to increase the interfacial area and enhance exciton dissociation; 4) well-defined monodisperse chemical structures, glass-forming (amorphous) properties, and homogeneous isotropic charge transport and optical properties; 5) inherent solubility of three-dimensional (3-D) systems to limit the need for additional electronically inert solubilizing moieties such as alkyl chains in the molecule; 6) combination of adequate processability and 3-D isotropic charge-carrier mobility to simplify the fabrication of devices by printing technique suitable for large area, flexible substrates; 7) controlled synthesis and purification without batch to batch variations, broad molecular-weight distributions, or end-group contamination.



In this project, we have rationally designed and synthesized several electron acceptors **3-7** trying to achieve optimized properties (**Figure 4**). Electron acceptor **3** with three-branch pyramidal configuration and optimized  $\pi$ -conjugated branches has optimized solubility, light absorption in the solar spectrum, electron density, LUMO and HOMO, and charge transport. Electron acceptors of **4-6** possess T-shape unsymmetric molecular geometry and bulky group to prevent aggregation, good and stable electron mobility of naphthalenediimide, light absorption in the solar spectrum (weak intramolecular charge transfer) and complementary to that of p-type polymers, cyano groups to fine-tune electron density, LUMO and HOMO, and good processability. Electron acceptor of **7** has the combined characteristic of  $C_{60}$  and  $\pi$ -conjugated branch such as ability to accept electron from a wide range of semiconducting polymers at ultrafast (10–12 fs) time scale, nanoscale interpenetrating network, good charge-carrier mobility even in composite form, light absorption in the solar spectrum (weak intramolecular charge transfer) and complementary to that of p-type polymers, and good processability. We have characterized optical (UV-Vis absorption), electrochemical (redox potential, reversibility), electronic (bandgap, HOMO, LUMO) properties, thin-film charge carrier mobility and morphology of these electron acceptors, and will fabricate and test bulk heterojunction organic photovoltaic cells based on them and low bandgap

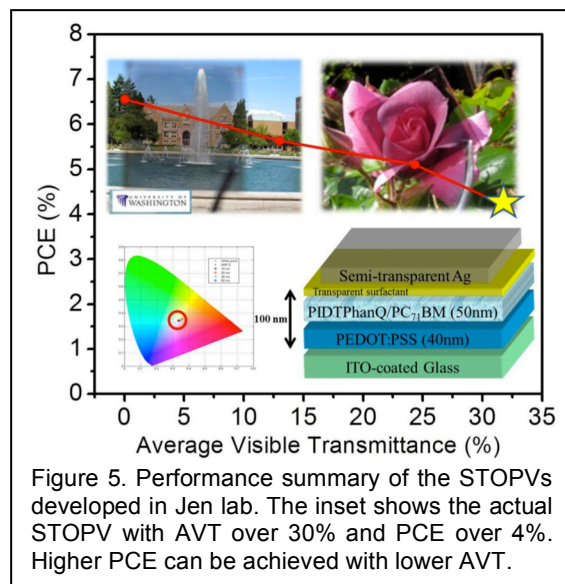
polymers.

## Task 2: Interfacial layer development for efficient charge transport and collection

- Development of new solution processable buffer layer is important to improve the performance of OPVs. Although devices based on the commonly used PEDOT:PSS hole transport layer (HTL) show good performance, the high acidity and electrical inhomogeneity of PEDOT:PSS film limit its application in OPVs with long term stability. For these reasons, we have developed a new class of thermally crosslinkable hole-transporting materials (X-HTMs) as anode buffer layers for OPVs. The crosslinking condition, optical, electrical, and electrochemical properties of these X-HTMs were studied in details to investigate their suitability to function as an anode buffer layer. The hole-mobilities of the newly developed HTMs have been tuned systematically through rational molecular design. Chemical p-doping of the X-HTMs was further employed to improve the conductivity and optical transparency of these X-HTMs in order to reduce the electrical resistance in the devices. The best device performance can be achieved by using a bilayer hybrid HTL structure with one doped layer on top of an undoped layer, which provides both efficient hole-transporting and electron-blocking properties at the BHJ/ITO interface. The devices based on the bilayer structure gave increased  $J_{sc}$  and FF when compared to devices using only the single-layer X-HTL. As a result the performance of the devices show comparable performance to that using PEDOT:PSS as the HTL. The development of these X-HTMs provides an excellent opportunity to achieve simultaneously good solvent resistance, hole-transport, interfacial contact with minimized energy barrier, conductivity, and electron-blocking ability which are all very important for the future development of highly efficient anode buffer layer for OPVs.

## Task 3: Device and interface engineering for organic solar cells

- Realization of semitransparent organic photovoltaic cells (STOPV) is an important step toward the solution to the problems encountered in new applications such as power-generating tinted thin films coated on the screens of the laptops, automobile windshields, house windows, foldable curtains, and other architectural and fashion applications. Besides semitransparency, window integrated applications require a reasonable transparency perception and good color rendering properties in order to be suitable for realistic scene illumination. However, the current performance of STOPV is much lower ( $PCE < 3\%$ ) and average visible transmittance ( $AVT < 15\%$ ) than their opaque counterpart and significant advancement for STOPV must be achieved before they can be considered as viable commercial products. We have designed a novel semi-transparent organic photovoltaic device (STOPV) through the simultaneous optimization of ultra-thin active layer and easily



accessible transparent electrode configuration. The targeted STOPV demonstrated both remarkably high power conversion efficiency and high average visible-light transmissivity with neutral color perception (**Figure 5**). First, we developed an ultra-thin active layer of PIDT-PhanQ and PC<sub>71</sub>BM based on our previous achievements with the assistance of optical modeling. According to optical modeling simulation, we found that an ultra-thin photoactive layer (~50 nm) of PIDT-PhanQ and PC<sub>71</sub>BM could possess the light absorption as efficient as the thick case (~90 nm) under further optimization of electrode from Ca/Al to Ag. Not only the ultra-thin characteristic but also the absorption located around near infrared region (NIR) of PIDT-PhanQ makes itself a promising candidate for STOPV with good color rendering property. In addition, a highly transparent bilayer cathode combining an easily-processed fullerene surfactant and ultra-thin Ag (20 nm) was exploited and utilized to improve the overall device transmittance and performance. Beside the advantages of significantly tuning the work function of cathode, sufficiently extracting electrons, and enhancing photocurrent generation, the surfactant fullerene also served as an efficient seed layer to increase the density of Ag nucleation sites, to enhance the lateral film growth, and then effectively improve the surface of the ultra-thin Ag from bumpy to smooth, where the bumpy island-like domain was commonly induced by the clustered growth of Ag. This efficient transparent bilayer cathode in combination with the ultra-thin high light-absorption active layer leads to an novel STOPV, which shows high power conversion efficiency of 4.2 % and high average visible-light transmissivity up to 32 % with neutral color perception close to white light. This result provides a promising approach for constructing efficient light-harvesting devices for use as solar-power generating windows in future green buildings.

#### Significant Accomplishments:

- Integrate new material design, interface engineering, and morphology optimization to demonstrate single-layer device with **PCE of 7.6%**.
- Develop environmental-friendly PV ink formulations that are more “green” and compatible with roll-to-roll process.
- Demonstrate semi-transparent OPV cells with high power conversion efficiency (**>5%**) and visible light transmittance (**>25%**) for potential use in integrated window applications.

#### Publications:

1. Sun, Y.; Chien, S.-C.; Yip, H.-L.; Zhang, Y.; Chen, K.-S.; Zeigler, D. F.; Chen, F.-C.; Lin, B.; Jen, A. K.-Y. “Chemically Doped and Cross-linked Hole-Transporting Materials as an Efficient Anode Buffer Layer for Polymer Solar Cells” *Chemistry of Materials*, (2011), 23, 5006.
2. Tillack, A. F.; Noone, K. M.; MacLeod, B.; Nordlund, A. D.; Nagle, K. P.; Bradley, J. A.; Hau, S. K.; Yip, H.-L.; Jen, A. K.-Y.; Seidler, G. T.; and Ginger, D. S. “Surface Characterization of Polythiophene:Fullerene Blends on Different Electrodes using Near Edge X-Ray Absorption Fine Structure Spectroscopy,” *ACS Appl. Mater. and Inter.* **2011**, 3, 726.
3. Cho, N.; Yip, H.-L.; Davies, J. A.; Kazarinoff, P. D.; Zeigler, D. F.; Durban, M. M.; Segawa, Y.; O'Malley, K. M.; Luscombe, C. K.; Jen, A. K.-Y. “In-situ Crosslinking and n-

Doping of Semiconducting Polymers and Their Application as Efficient Electron-Transporting Materials in Inverted Polymer Solar Cells” *Advanced Energy Materials*, **(2011)**, 1, 1148.

4. O'Malley, K. M.; Li, C.-Z.; Yip, H.-L.; Jen, A. K.-Y. “Enhanced Open-Circuit Voltage in High Performance Polymer/Fullerene Bulk-Heterojunction Solar Cells by Cathode Modification with a C<sub>60</sub> Surfactant, *Advanced Energy Materials*, **2012**, 2, 82.
5. Li, C.-Z.; Yip, H.-L.; Jen, A. K.-Y. “Functional Fullerenes for Organic Photovoltaics” Invited Feature Article, *Journal of Materials Chemistry*, **2012**, 22 (10), 4161.
6. Zeigler, D. F.; Chen, K.-S.; Zhang, Y.; Yip, H.-L.; Jen, A. K.-Y. “Tunable Light-Harvesting Polymers Containing Embedded Dipolar Chromophores for Polymer Solar Cell Applications”, *Journal of Polymer Science: Part A Polymer Chemistry*, **2012**, 50(7), 1362.
7. Yip, H.-L.; Jen, A. K.-Y. “Recent Advanced in Solution Processed Interfacial Materials for Efficient and Stable Polymer Solar Cells” Invited Feature Article, *Energy and Environmental Science*, **2012**, 5(3), 5994.
8. Zou, J.; Zhong, Y.; Yip, H.-L.; Gao, Y.; Jen, A. K.-Y.” Integrating Low Bandgap Polymer into High Performance Inverted Polymer Solar Cells: Device Characterization, Optical Modeling and Hole Transporting Layer Modification”, *Advanced Functional Materials*, DOI: 10.1002/adfm.201102937.
9. Sun, Y.; Chien, S.-C.; Yip, H.-L.; Chen, K.-S.; Zhang, Y.; Davies, J. A.; Chen, F.-C.; Lin, B.; Jen, A. K.-Y. “Improved Thin Film Morphology and Bulk-Heterojunction Solar Cell Performance through Systematic Tuning of Surface Energy of Conjugated Polymers” *Journal of Materials Chemistry*, **2012**, 22(12), 5587.
10. Li, C.-Z.; Yip, H.-L.; Oh, S.-H.; O'Malley, K. M.; Sun, Y.; Zhang, Y.; Cho, N.; Jen, A. K.-Y. “Effective Interfacial Layer to Enhance Efficiency of Polymer Solar Cells via Solution-Processed Fullerene-Surfactants”, *Journal of Materials Chemistry*, **2012**, 22(17), 8574.
11. Chen, K.-S.; Yip, H.-L.; Schlenker, C. W.; Ginger, D. S.; Jen, A. K.-Y. “Halogen-Free Solvent Processing for Sustainable Development of High Efficiency Organic Solar Cells”, *Submitted*.
12. Zhang, Y.; Zou, J.; Cheuh, C.-C.; Yip, H.-L.; Sun, Y.; Jen, A. K.-Y. “Efficient Polymer Solar Cells Based on Conjugated Polymer of Cyclopentadithiophene and Fluorobenzothiadiazole”, *Submitted*.
13. Zhang, Y.; Chien, S.-C.; Chen, K.-S.; Yip, H.-L.; Sun, Y.; Davies, J. A.; Chen, F.-C.; Jen, A. K.-Y. “Increased Open Circuit Voltage in Fluorinated Benzothiadiazole-Based Alternating Conjugated Polymers”, *Chemical Communications*, **2011**, 47(39), 11026.
14. Li, C.-Z.; Chien, S.-C.; Yip, H.-L.; Chueh, C.-C.; Chen, F.-C.; Jen, A. K.-Y. “Facile Synthesis of 56  $\pi$ -Electron 1,2-Dihydromethano-[60]PCBM and its Application for Thermally Stable Polymer Solar Cells” *Chemical Communications*, **2011**, 47(36), 10082.
15. Sun, Y.; Chien, S.-C.; Yip, H.-L.; Zhang, Y.; Chen, K.-S.; Zeigler, D. F.; Chen, F.-C.; Lin, B.; Jen, A. K.-Y. “High-Mobility Low-Bandgap Conjugated Copolymers Based on Indacenodithiophene and Thiadiazolo[3,4-c]pyridine Units for Thin Film Transistor and Photovoltaic Applications” *Journal of Materials Chemistry*, **2011**, 21, 13247.
16. Zhang, Y.; Zou, J.; Yip, H.-L.; Chen, K.-S.; Davies, J. A.; Sun, Y.; Jen, A. K.-Y. “Synthesis, Characterization, Charge Transport and Photovoltaic Properties of Dithienobenzoquinoxaline- and Dithienobenzopyridopyrazine-Based Conjugated Polymers”, *Macromolecules*, **2011**, 44, 4752.
17. Zhang, Y.; Zou, J.; Yip, H.-L.; Chen, K.-S.; Zeigler, D. F.; Sun, Y.; Jen, A. K.-Y. “Development of Indacenodithiophene and Quinoxaline-Based Conjugated Polymers for Efficient Polymer Solar Cells”, *Chemistry of Materials*, **2011**, 23, 2289.

18. Cho, N.; Yip, H.-L.; Hau, S. K.; Chen, K.-S.; Kim, T.-W.; Davies, J. A.; Zeigler, D. F.; Jen, A. K.-Y. "N-doping of Thermally Polymerizable Fullerenes as an Electron Transporting Layer for Inverted Polymer Solar Cells", *Journal of Materials Chemistry*, 2011, 21, 6956.
19. Gao, Y.; Yip, H.-L.; Chen, K.-S.; O'Malley, K. M.; Acton, O.; Sun, Y.; Ting, G.; Chen, H.; Jen, A. K.-Y. "Surface Doping of Conjugated Polymers by Graphene Oxide and Its Application for Organic Electronic Devices", *Advanced Materials*, 2011, 23, 1903.
20. Durban, M. M.; Kazarinoff, P. D.; Segawa, Y.; Luscombe, C. K. "Synthesis and characterization of solution-processible ladderized n-type naphthalene bisimide copolymers for OFET applications" *Macromolecules*, 2011, 44, 4721.
21. Mazzio, K.; Yuan, M. J.; Okamoto, K.; Luscombe, C. K. "Oligoselenophene Derivatives Functionalized with a Diketopyrrolopyrrole Core for Molecular Bulk Heterojunction Solar Cells" *ACS Appl. Mater. Inter.*, 2011, 3, 271.
22. Yuan, M. J.; Rice, A. H.; Luscombe, C. K. "Benzo[2,1-b;3,4-b']dithiophene-Based Low Bandgap Polymers for Photovoltaic Applications" *J. Polym. Sci. Part A: Polym. Chem.*, 2011, 49, 701.
23. Yang, P.; Zhou, X.; Cao, G.; Luscombe, C. K. "P3HT:PCBM polymer solar cell with TiO<sub>2</sub> nanotube aggregates in the active layer." *J. Mater. Chem.*, 2010, 20, 2612.
24. Doubina, N.; Stoddard, M.; Bronstein, H. A.; Jen, A. K. Y.; Luscombe, C. K. "The effects of binding ligand variation on the nickel catalyzed externally initiated polymerization of 2-bromo-3-hexyl-5-iodothiophene." *Macromol. Chem. Phys.*, 2009, 210, 1966.
25. Doubina, N.; Ho, A.; Jen, A. K. Y.; Luscombe, C. K. "Effect of initiators on the Kumada catalyst-transfer polycondensation reaction." *Macromolecules*, 2009, 42, 7670.
26. Bull, T. A.; Pingree, L. S.; Jenekhe, S. A.; Ginger, D. S.; Luscombe, C. K. "The role of mesoscopic PCBM crystallites in solvent vapor annealed copolymer solar cells." *ACS Nano*, 2009, 3, 627.
27. Hau, S. K.; Yip, H.-L.; Chen, K.-S.; Zou, J.; Jen, A. K.-Y, "Solution Processed Inverted Tandem Polymer Solar Cells with Self-Assembled Monolayer Modified Interfacial Layers", *Appl. Phys. Lett.*, 2010, 97(25), 253307 (Also selected for publication in the *Virtual Journal of Nanoscale Science and Technology*)
28. Duan, C.; Chen, K.-S.; Huang, F.; Yip, H.-L.; Liu, S.; Zhang, J.; Jen, A. K.-Y.; Cao, Y. "Synthesis, Characterization, and Photovoltaic Properties of Carbazole-Based Two-Dimensional Conjugated Polymers with Donor- $\pi$ -Bridge-Acceptor Side Chains" *Chem. Mater.*, 2010, 22(23), 6444.
29. Sun, Y.; Gong, X.; Hsu, B. B. Y.; Yip, H.-L.; Jen, A. K.-Y.; Heeger, A. J. "Solution-Processed Cross-linked Hole Selective Layer for Polymer Solar Cells in the inverted Structure" *Appl. Phys. Lett.*, 2010, 97(19), 193310.
30. Huang, F.; Chen, K.-S.; Yip, H.-L.; Hau, S. K.; Acton, O.; Zhang, Y.; Luo, J.; Jen, A. K.-Y. "Development of New Conjugated Polymers with Donor- $\pi$ -Bridge-Acceptor Side Chains for High Performance Solar Cells." *Journal of the American Chemical Society* 2009, 131(39), 13886.
31. Hau, S. K.; Yip, H.-L.; Zou, J.; Jen, A. K.-Y. "Indium tin oxide-free semi-transparent inverted polymer solar cells using conducting polymer as both bottom and top electrodes." *Organic Electronics* 2009, 10(7), 1401-1407.
32. Zhang, Y.; Yip, H.-L.; Acton, O.; Hau, S. K.; Huang, F.; Jen, A. K.-Y.. "A Simple and Effective Way of Achieving Highly Efficient and Thermally Stable Bulk-Heterojunction Polymer Solar Cells Using Amorphous Fullerene Derivatives as Electron Acceptor", *Chemistry of Materials*, 2009, 21(13), 2598-2600
33. Hau, S. K.; Yip, H.-L.; K. Leong; Jen, A. K.-Y. "Spraycoating of Ag nanoparticle electrodes for inverted polymer solar cells" *Organic Electronics* 2009, 10, 719.



34. Yip, H.-L.; Hau, S. K.; Baek, N. S.; Ma, H.; Jen, A. K.-Y. "Polymer Solar Cells That Use Self Assembled-Monolayer-Modified ZnO/Metals as Cathodes" *Advanced Materials* **2008**, 20, 2376.
35. Yip, H.-L.; Hau, S. K.; Baek, N. S.; Jen, A. K.-Y. "Self-Assembled Monolayer Modified ZnO/Metal Bilayer Cathodes for Polymer:Fullerene Bulk-Heterojunction Solar Cells" *Applied Physics Letters* **2008**, 92, 193313.
36. Hau, S. K.; Yip, H.-L.; Baek, N. S., Ma, H.; Jen A. K.-Y. "Interfacial Modification to Improve Inverted Polymer Solar Cells" *Journal of Materials Chemistry* **2008**, 18, 5113.
37. Hau, S. K.; Yip, H.-L.; Baek, N. S., Zou, J.; O' Mellay, K.; Jen A. K.-Y. "Air-Stable Inverted Flexible Polymer Solar Cells Using Zinc Oxide Nanoparticles as an Electron Seletive Layer" *Applied Physics Letters* **2008**, 92, 253301
38. Hau, S. K.; Yip, H.-L.; Ma, H.; Jen A. K.-Y. "High Performance Ambient Processed Inverted Polymer Solar Cells through Interfacial Modification with a Fullerene Self-Assembled Monolayer" *Applied Physics Letters* **2008**, 93, 233304.
39. Baek, N. S., Hau, S. K. Yip, H.-L.; Chen, K.-S.; Acton, O.; Jen A. K.-Y. "High Performance Amorphous Metallated  $\pi$ -Conjugated Polymers for Field-Effect Transistors and Polymer Solar Cells" *Chemistry of Materials* 2008, 20, 5734.
40. Lee Y. Park, Andrea M. Munro, D. S. Ginger, "Controlling Film Morphology in Conjugated Polymer:Fullerene Blends with Surface Patterning" *J. Am. Chem. Soc.*, **2008**, 130, 15916.