Exciton and Charge Trapping in Molecular Engineered Conjugated polymers for High-Performance Light-Emitting Diodes

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Project Summary:

The operation of polymer light-emitting diodes (LEDs) involves the injection of both holes and electrons from opposite electrodes, their transport in the bulk material, recombination to form excitons, and the radiative decay of the singlet excitons. Since the mobility of electrons and holes in most conjugated polymers are quite different, under a high operating electric field (> 10^5 V/cm), a large percentage of the higher mobility carriers can be swept through the polymer without forming excitons, resulting in a low light emission. Therefore, an important task for achieving efficient LEDs is to maximize the recombination of injected charge carriers before they get discharged at the electrodes. The efficient capture of electrons and holes can be realized utilizing molecular engineered conjugated polymers containing randomly distributed lower-energy segments. The electrons and/or holes trapped at these lower-energy segments cause a build up in local charge density, which could enhance the possibility of attracting oppositely charged carries. In addition to direct or sequential trapping of electrons and holes on these lower-energy sites, the excitions formed on higher-energy segments will also transfer to these lower-energy sites through Förster energy transfer. This will increase the device efficiency as well due to the red-shift of the emission relative to the absorption edge, which could lead to lower self-absorption losses. Typically, the maximum distance over which Förster energy transfer can occur is 3-5 nm, therefore, it is very crucial to tune the incorporation ratio of the lower-energy monomers to optimize the charge trapping, charge transporting and energy transfer properties.

In an effort to improve the device performance, a series of fluorene based copolymers with a small amount (less than 10 mol-%) randomly distributed electron-deficient low bandgap moieties (PF-DTS, PF-TCNPT, PF-FCNPF) were developed (Figure 1). These low-energy moieties with electron-deficient nature are designed to increase electron-affinity of the resulting polymers and to facilitate charge recombination through their function as charge trapping sites for both holes and electrons. Photoluminescence (PL) studies showed that efficient Föster energy transfer from the higher-energy fluorene segments to the lower-energy dithienosile-containing segments can be achieved only in solid state due to intra- and inter-molecular interactions. While in the dilute solution, incomplete energy transfer was observed because of the large distance between the polymer chains (Figure 2). Bright green emission was obtained from these copolymers, which could be attributed to the efficient Förster energy transfer and balanced charge injection and transport. A double-layer device using PF9-DTS as the emitting layer and an *in-situ* polymerized bis-tetraphenylenebiphenyldiamine-perfluorocyclobutane (BTPD-PFCB) as the hole-transporting layer demonstrates a low turn-on voltage at 4.6 V, a brightness greater than 25,900 cd/m^2 and a maximum external quantum efficiency of 1.64 %, which could be attributed to both the improved charge injection and charge recombination in this polymer by optimizing the content of electron-deficient dithienosile units.

Publications, Presentations, and Proposals:

Publications:

1. **M. S. Liu**, J. Luo, A. K-Y. Jen, **"**Efficient Green Light-Emitting Diodes from Silole-Containing Copolymers", *Chem. Mater*. (submitted).
2. F-I. Wu, D. S. Reddy, C. F. Shu, **M. S. Liu**, A. K-Y. Jen, "A Novel Oxadiazole-Containing Polyfluorene with Efficient Blue Electroluminescence", *Chem. Mater*. **15**, 269 (2003)
3. C. F. Shu, R. Dodda, F. I. Wu, **M. S. Liu**, A. K-Y. Jen, "Highly Efficient Blue Light-Emitting Diodes from Polyfluorene Containing Bipolar Pendent Groups", *Macromolecules* (in press).
4. **M. S. Liu,** X. Z. Jiang, P. Herguth, S. Liu, A. K.-Y. Jen, "Development of Efficient Electron-Transporting Polymers for Light-Emitting Diodes"**,** *Proc. SPIE* **4800**, 130 (2003).

Presentations:

1. "Development of Efficient Light-Emitting Polymers for Flat Panel Displays" The Puget Sound Chapter of ASM International Meeting, Seattle, Washington, March 11, 2003.
2. **"**Development of Efficient Electron-Transporting Polymers for Light-Emitting Diodes" The International Society for Optical Engineering (SPIE) Conference, Seattle, Washington, July 7-July 24, 2002.

Selected Figures:

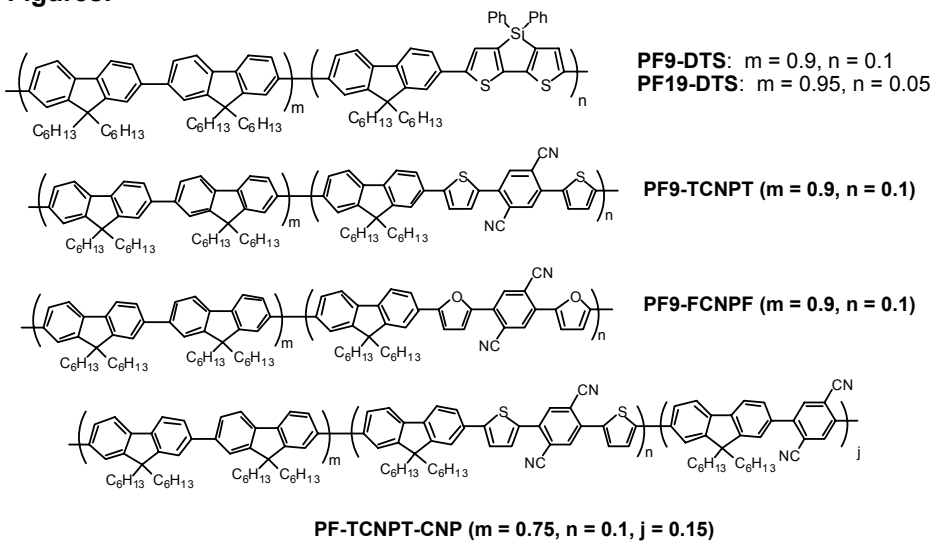

Figure 1. Chemical Structure of Polymers investigated.

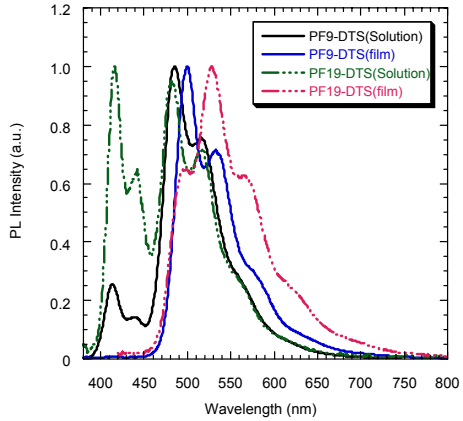

Figure 2. PL spectra of PF9-DTS and PF19 -DTS in solution and film.