

# Lighting up polymer LEDs through nanotechnology

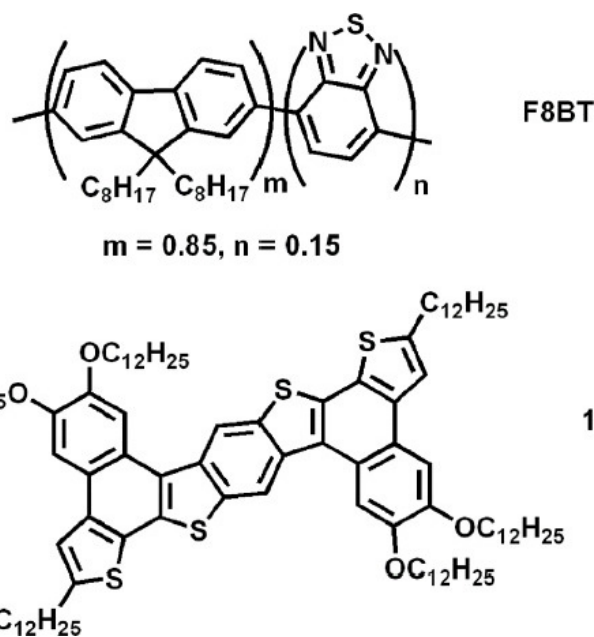
Jian Wang, Qiaoli Niu, Yan Zhou, Lei Wang, Junbiao Peng, Jian Pei, and Yong Cao

*Organic nanowires self-assembled in situ and integrated into polymer LEDs double the device performance without complicating fabrication.*

Organic LEDs (OLEDs) are considered drivers of next-generation flat-panel display technology. They are characterized by lightweight, thin-panel, wide-angle, high self-electroluminescent efficiencies, and low power consumption. Polymer LEDs (PLEDs) are commonly fabricated using a solution process, which is simpler, cheaper, more scalable, and more versatile than the vacuum-deposition process generally employed to construct small-molecule LEDs. Improving PLEDs, in particular their luminous efficiency, has been the focus of sustained research and developments in the past two decades. Integrating nanostructures into PLEDs is a promising new approach to improve device performance.

PLEDs have been developed using nanostructure materials as emitters,<sup>1</sup> functional layers,<sup>2</sup> and dopants.<sup>3</sup> For example, titanium-dioxide (TiO<sub>2</sub>) nanoparticles could be employed as electron-injection cathodes to achieve better device performance.<sup>2</sup> However, more than ten steps are needed to prepare a nano-TiO<sub>2</sub> film, and lengthy, sustained stirring as well as high-temperature sintering are also required. The use of magnetic nanoparticles, such as Co<sub>70</sub>Fe<sub>30</sub> (0.1% by weight), as electron traps doped into light-emitting polymers with aluminum as the cathode increases the quantum efficiency by 32%.<sup>3</sup> Yet, to prepare the blended film, magnetron sputtering, mechanical scraping, spin coating, and ultrasonication are employed. Maintaining the simplicity of the PLED fabrication process while improving device performance is quite challenging.

PLEDs are 'dual-injection' devices in which electrons and holes are injected from the opposite electrodes into an active emissive layer. To achieve a high luminous efficiency, it is of great importance that the electrons and holes are balanced. Here, we introduce a novel approach to improve the performance of PLEDs by blending organic nanowires as the hole-transporting

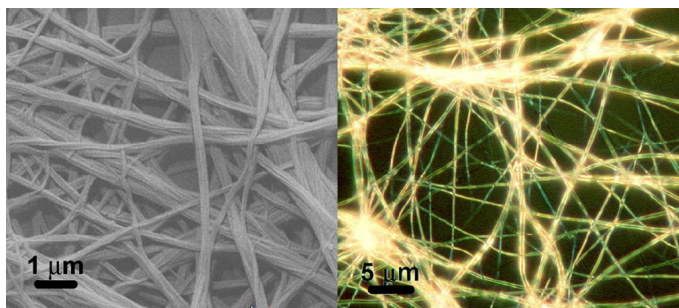


**Figure 1.** Chemical structures of the light-emitting polymer poly(9,9-dioctylfluorene-co-benzothiadiazole) (F8BT), and of the organic-nanowire compound 1.

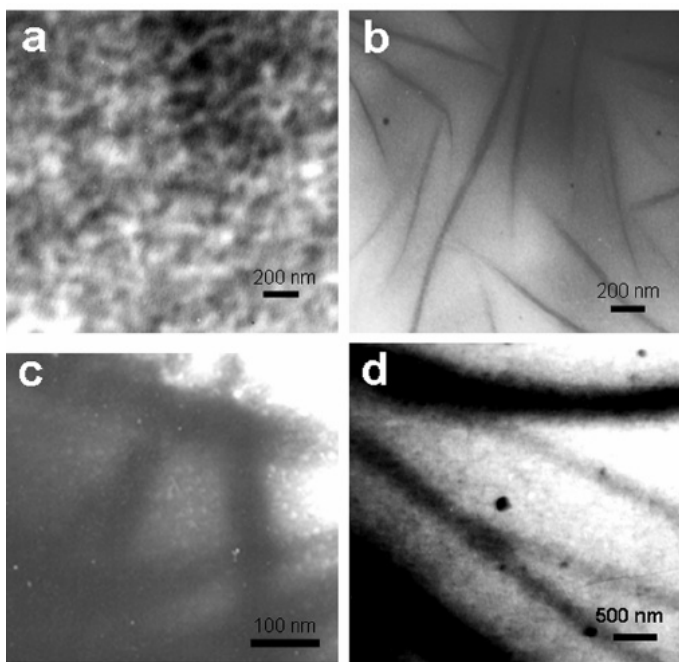
material into the electron-dominated polymer matrix.<sup>4</sup> The fabrication of the nanoscale-blended film is as simple as ordinary polymer blending, which only involves mixing of the contributing solutions. After evaporation of the blended solution's solvent through spin coating, organic molecules (see Figure 1) self-assemble in situ into nanowires. An additional advantage of the solution process is that the weight ratio of the blended compound can be controlled precisely.

The organic nanowires self-assemble from a novel, planar, highly-substituted condensed-benzothiophene derivative. The molecules have a strong tendency to self-assemble into 1D nanostructures due to their six long alkyl chains and nine fused aryl rings. Scanning-electron microscopy and polarized optical-

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**Figure 2.** Scanning-electron microscopy (left) and polarized optical-microscopy (right) images of the nanowires self-assembled on Si wafer and glass, respectively.



**Figure 3.** Transmission electron-microscopy images of the films doped with F8BT at (a) 2.5, (b) 5, (c) 10, and (d) 15% by weight.

microscopy images of the self-assembled nanowires are shown in Figure 2. The field-effect-transistor (FET) devices based on individual microwires composed of the analogous molecules exhibit p-channel FET characteristics, suggesting that the holes are the majority carriers inside the organic nanowires.

The uniform distribution of the hole-transporting organic nanowires inside the electron-dominated light-emitting polymer poly(9,9-dioctylfluorene-co-benzothiadiazole) (see Figure 1)<sup>5</sup> balances the holes and the electrons, leading to an increase in their radiative recombination and an enhanced luminous efficiency. PLEDs achieve almost double the light-emitting ef-

iciency at a concentration of 2.5% by weight of the organic nanowires. In addition, the size of the self-assembled organic nanowires can be tuned by changing the concentration of the organic molecules inside the polymer matrix. Increasing the concentration from 2.5 to 5, 10, and 15% by weight, the nanowire diameters increase from about 10nm to 20, 50 and 100nm, respectively, and the length increases to several microns (see Figure 3).

Preparing PLEDs for display and eventually in solid-state lighting applications requires a great leap in their performance. Improving the luminous efficiency of PLEDs while keeping their fabrication process simple remains a challenge. We have introduced a solid-state nanostructured PLED of which the construction is based on the integration of self-assembled organic nanowires via a simple mixing process, with a semiconducting conjugated polymer as the emitting layer. Since the organic nanowires are self-assembled in situ, the nanoscale-controlled device-fabrication process is not only simple, but also retains the advantages of the solution process commonly used to construct PLEDs. The novel approach we have provided will find, we expect, wide applications for OLEDs.

#### Author Information

Jian Wang, Qiaoli Niu, Lei Wang, Junbiao Peng, and Yong Cao

Institute of Polymer Optoelectronic Materials and Devices  
South China University of Technology  
Guangzhou, China

Jian Wang is an expert in organic electronics. After receiving his PhD from the University of California at Santa Barbara in 2000, he worked for DuPont Displays as device scientist and project manager. He was appointed as full professor at South China University of Technology in 2006. His current research interests focus on both applications of organic nanowires and LED-based flat-panel displays.

Yan Zhou and Jian Pei

College of Chemistry  
Peking University  
Beijing, China

Jian Pei is professor of organic electronics at the College of

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Chemistry of Peking University in Beijing (China). He joined the University of California at Santa Barbara as a postdoctoral fellow in 1998 after having obtained his PhD from Peking University in 1995. His research interests include the synthesis of novel organic pi-conjugated molecular materials and their applications as organic nanowires.

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