ACS Partner Journal

POLYMER SCIENCE & TECHNOLOGY

https://pubs.acs.org/PolySciTech

Comment

From Light to Logic: Micron-Scale Doping Enables Flexible Organic Circuits

Chengwen Wu and Ting Lei*

Cite This: https://doi.org/10.1021/polymscitech.5c00099

Read Online

ACCESS | Metrics & More | Article Recommendations

Precise spatial doping has long been fundamental to modern silicon-based electronics, enabling the creation of high-performance devices with complex architectures and fine control over charge transport. In contrast, organic semiconductors (OSCs), despite their potential for flexible, lightweight, and solution-processable electronics, have struggled to achieve such precise doping. Traditional doping approaches in OSCs often rely on spontaneous chemical reactions that lack spatial selectivity, severely limiting the resolution and reproducibility of doping patterns.

In a groundbreaking advance, Pei et al.[1] present a transformative strategy using inactive photoactivable dopants (iPADs) (Figure 1). These dopants remain chemically inert during processing and storage, only converting into highly reactive species only upon exposure to UV light. This mechanism enables precise, micron-scale, regionally controlled n-type doping of OSCs, achieving conductivities exceeding 30 S/cm and spatial resolutions as fine as 1 μm. The method is not only powerful but also versatile, compatible with various n-type OSCs and adaptable to different device architectures.

Furthermore, this light-triggered approach integrates seamlessly with scalable fabrication techniques such as roll-to-roll printing and advanced photolithography, paving the way for high-density organic integrated circuits. Overall, Pei et al.'s work represents a major milestone, opening new possibilities for patterned, high-performance, and miniaturized organic electronic devices.

Molecular Design of Light-Triggered n-Dopant. Several photoinduced doping strategies based on hole or electron transfer have been reported previously,[2] but their doping efficiency and spatial resolution remain insufficient to meet practical requirements. This work introduces a novel chemical approach to organic semiconductor doping that addresses long-standing challenges in spatial control and efficiency. The designed inactive photoactivable dopants (iPADs) remain stable and inactive under normal conditions but undergoes a unique 6π electrocyclization reaction when exposed to ultraviolet light. This light-triggered transformation converts the iPAD into a highly reactive species (PAD) that can initiate efficient n-type doping within the organic semiconductor matrix. Notably, this photochemical reaction is irreversible and cannot be induced by heat, allowing precise spatial and temporal control over the doping process (Figure 2). Experimental characterization demonstrates that the doping performance of this innovative dopant rivals that of widely used small-molecule dopants such as (4-(1,3-dimethyl-2,3-dihydro-1H-benzoimidazol-2-yl)phenyl)dimethylamine (*N*-DMBI). By combining the advantages of strong doping capability with high spatial resolution, this chemical design represents a significant advance toward fabricating finely patterned organic electronic devices with improved performance and stability.

Generality and Applications of Light-Triggered n-Doping. This approach demonstrates remarkable generality, underscoring its potential as a universal strategy for advancing organic electronics. The authors systematically investigated the doping behavior of four distinct iPADs (Figure 2) across a variety of widely studied n-type organic semiconductors, including N2200,[3] PzDPP-2FT,[4] and others recognized for their promising electronic properties. Comprehensive UV–vis–NIR spectroscopy and conductivity measurements confirmed that efficient and stable n-type doping could be successfully achieved in all tested OSC systems. Notably, iPAD-2 emerged as the most reactive, yielding doped films with higher doping levels, enhanced conductivity, and exceptional thermal stability. These results indicate that iPAD-2 performs comparably to, or even surpasses, conventional small-molecule dopants.

In addition to material versatility, this light-triggered strategy shows broad applicability in device fabrication. In organic field-effect transistors (OFETs), its high-spatial-resolution doping enables selective modification of the channel or contact regions, effectively reducing surface trap states, enhancing carrier mobility, lowering contact resistance, and ultimately improving overall device performance.[5] Moreover, this doping method supports the construction of complementary inverters and shows great potential for developing organic integrated circuits (IC). This method also demonstrates promise in organic thermoelectric and flexible optoelectronic devices. In thermoelectric devices, this doping method enables achieving a high power factor while facilitating the regionally controlled construction of the n-leg through UV irradiation. This light-triggered doping method can also be used to build LED

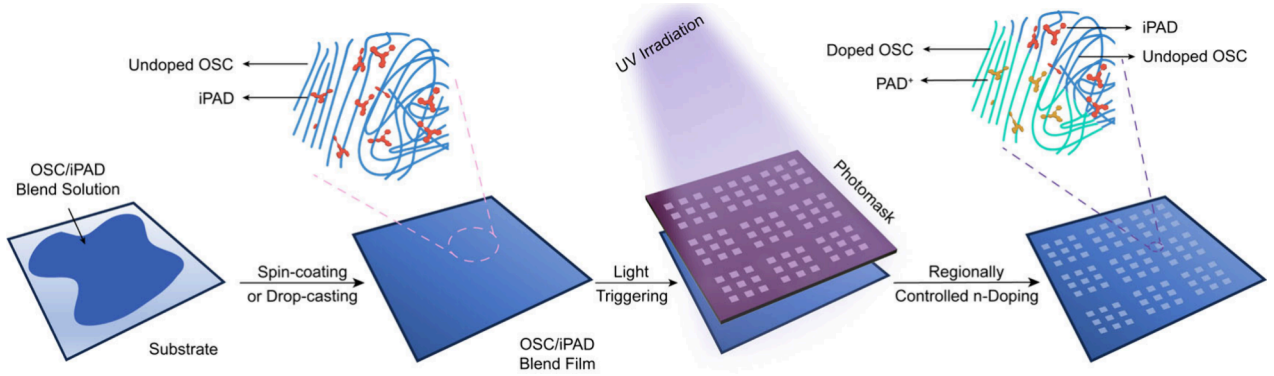

Figure 1. Schematics of the light-triggered doping method (redrawn according to ref 1).

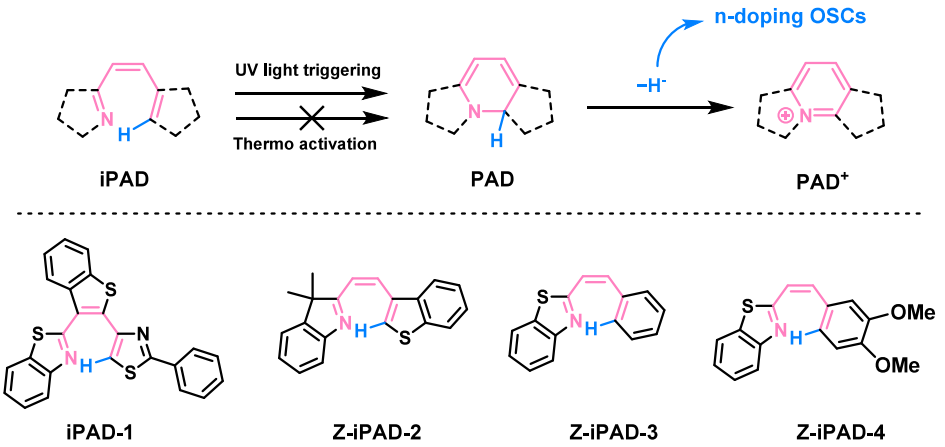

Figure 2. Molecular design of light-triggered n-dopants (redrawn according to ref 1).

control circuits on flexible substrates, demonstrating potential for flexible optoelectronic devices. Characterization using conductive atomic force microscopy (C-AFM) and other techniques confirmed a spatial resolution down to 1 μm, stable performance over extended periods, and the possibility of further improvement toward submicron-scale resolution.

Pei et al. developed a series of light-triggered n-type dopants, providing a powerful new tool for precise patterning of organic semiconductors. These dopants enable regionally selective doping of organic devices via standard photolithography, offering both high efficiency and stability. This approach facilitates the fabrication of large-area, flexible organic IC with fine spatial control. The innovation opens new possibilities for micro- and submicron-scale processing and integration of organic semiconductors, representing a significant breakthrough in the field with promising potential for industrial-scale manufacturing.

AUTHOR INFORMATION

Corresponding Author

Ting Lei − *National Key Laboratory of Advanced Micro and Nano Manufacture Technology, Key Laboratory of Polymer Chemistry and Physics of Ministry of Education, School of Materials Science and Engineering, Peking University, Beijing 100871, P.R. China*; orcid.org/0000-0001-8190-9483; Email: tinglei@pku.edu.cn

Author

Chengwen Wu − *National Key Laboratory of Advanced Micro and Nano Manufacture Technology, Key Laboratory of Polymer Chemistry and Physics of Ministry of Education, School of Materials Science and Engineering, Peking University, Beijing 100871, P.R. China*

Complete contact information is available at: https://pubs.acs.org/10.1021/polymscitech.5c00099

Notes

The authors declare no competing financial interest.

ACKNOWLEDGMENTS

This work is supported by Beijing Natural Science Foundation (JQ22006).

REFERENCES

(1) Wang, X.-Y.; Ding, Y.-F.; Zhang, X.-Y.; Zhou, Y.-Y.; Pan, C.-K.; Li, Y.-H.; Liu, N.-F.; Yao, Z.-F.; Chen, Y.-S.; Xie, Z.-H.; Huang, Y.-F.; Xu, Y.-C.; Wu, H.-T.; Huang, C.-X.; Xiong, M.; Ding, L.; Yu, Z.-D.; Li, Q.-Y.; Zheng, Y.-Q.; Wang, J.-Y.; Pei, J. Light-Triggered Regionally Controlled n-Doping of Organic Semiconductors. *Nature* **2025**, *642* (8068), 599.

(2) Lin, X.; Wegner, B.; Lee, K. M.; Fusella, M. A.; Zhang, F.; Moudgil, K.; Rand, B. P.; Barlow, S.; Marder, S. R.; Koch, N.; Kahn, A. Beating the Thermodynamic Limit with Photo-Activation of n-Doping in Organic Semiconductors. *Nat. Mater.* **2017**, *16* (12), 1209.

(3) Liu, J.; Shi, Y.; Dong, J.; Nugraha, M. I.; Qiu, X.; Su, M.; Chiechi, R. C.; Baran, D.; Portale, G.; Guo, X.; Koster, L. J. A. Overcoming Coulomb Interaction Improves Free-Charge Generation and Thermoelectric Properties for n-Doped Conjugated Polymers. *ACS Energy Lett.* **2019**, *4* (7), 1556.

(4) Yan, X.; Xiong, M.; Deng, X.-Y.; Liu, K.-K.; Li, J.-T.; Wang, X.-Q.; Zhang, S.; Prine, N.; Zhang, Z.; Huang, W.; Wang, Y.; Wang, J.-Y.;

https://doi.org/10.1021/polymscitech.5c00099
Polym. Sci. Technol. XXXX, XXX, XXX−XXX

Gu, X.; So, S. K.; Zhu, J.; Lei, T. Approaching Disorder-Tolerant Semiconducting Polymers. *Nat. Commun.* **2021**, *12*, 5723.
(5) Xu, Y.; Sun, H.; Liu, A.; Zhu, H.; Li, W.; Lin, Y.; Noh, Y. Doping: A Key Enabler for Organic Transistors. *Adv. Mater.* **2018**, *30* (46), 1801830.

https://doi.org/10.1021/polymscitech.5c00099
Polym. Sci. Technol. XXXX, XXX, XXX−XXX