

# Tuning and Directing Energy Transfer from the Blue to Near-Infrared Range in Multicomponent Metal–Organic Frameworks with *seh* Topology

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**ABSTRACT:** Luminescent metal–organic frameworks (MOFs) are emerging as one of several promising materials to study light-harvesting and energy-transfer processes. However, it is still a big challenge to tune and direct energy transfer in luminescent MOFs-based light-harvesting system. Herein, a series of new light-harvesting zinc-based luminescent MOFs with *seh* underlying topology were reported by successfully integrating 2,1,3-benzothiadiazole and its derivative-based carboxylic acids and pyridine-contained linkers into one structure. The strong spectra overlap between the emission and absorption spectra of carboxylic acids and pyridine-type linkers afforded an ideal platform to realize efficient energy transfer from the blue to near-infrared range. This work provides a novel approach to the rational design and synthesis of MOFs-based multicomponent light-harvesting materials with tunable energy transfer to mimic natural photosynthetic processes.

Light-harvesting and subsequent energy transfer are essential steps for solar energy utilization in photosynthesis.<sup>1–5</sup> Natural light-harvesting has inspired considerable research interest in the development of artificial materials to mimic and understand these processes, which might facilitate the development of a highly efficient artificial photosynthesis. In recent years, benefiting from their highly tunable structures and crystalline nature, luminescent metal–organic frameworks (MOFs) have been used as great platforms to study energy transfer.<sup>6–8</sup> Among these MOFs, pillar-layered MOFs with ordered linker distribution<sup>9–13</sup> and mixed-linker-based MOFs with disordered linker distribution<sup>14–16</sup> are two promising structural models to integrate linkers with different emission and absorption behaviors and have been proven to be promising candidates to achieve highly efficient light-harvesting and energy transfer. Our group has reported that linker installation also is a useful approach to achieving energy transfer in the whole visible spectrum using full-color-emissive MOFs and second linkers.<sup>17</sup> Up to now, however, it is still a great challenge to tune and direct energy transfer in the whole visible light and even near-infrared range using multicomponent MOFs with well-defined structural and optical control, which could be ascribed to two reasons. First, it is difficult to synthesize multiple organic linkers with excellently matched emission and absorption spectra as the energy donors and acceptors. Second, except for pillar-layered MOFs, it is very difficult to one-pot-prepare multicomponent MOFs by integrating two or more linkers into one structure for energy transfer, even though several works have been reported to incorporate more than two kinds of linkers inside the MOF matrix with ordered linker distribution<sup>18–23</sup> via a one-pot synthesis.

In our previous work, a number of 2,1,3-benzothiadiazole and its derivative-based carboxylic acids<sup>17,24,25</sup> and pyridine-

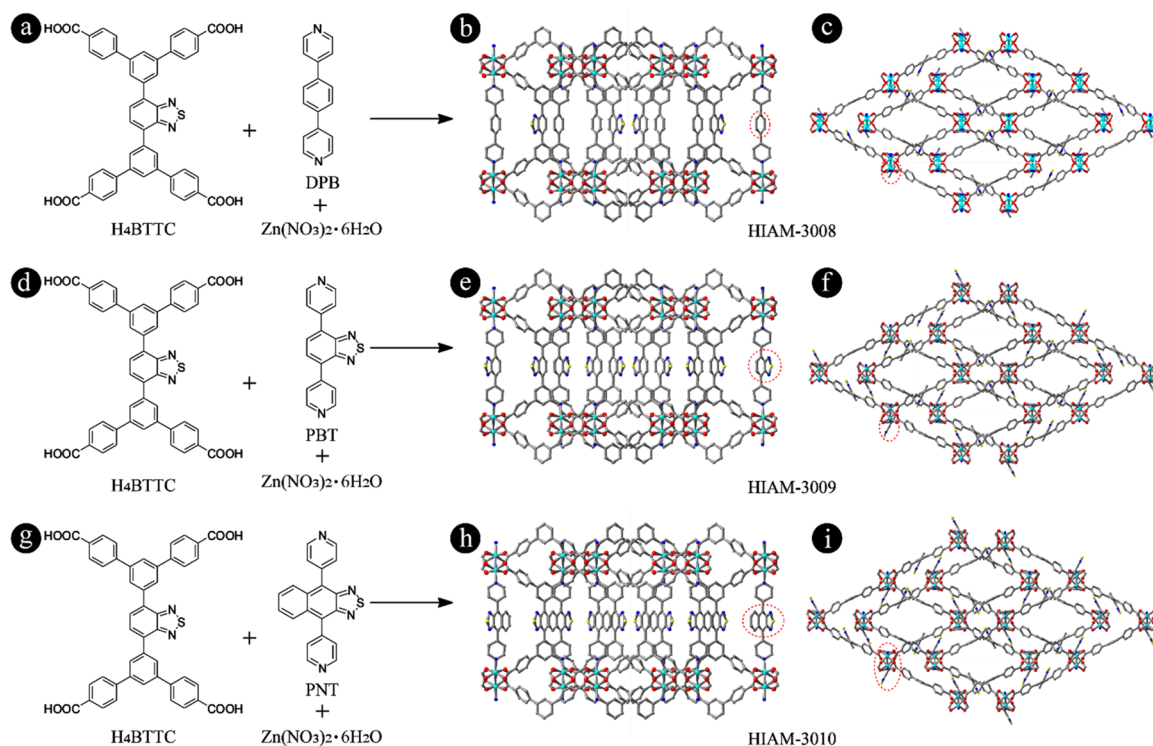
contained<sup>26</sup> linkers have been reported with tunable emission and absorption behaviors from deep blue to near-infrared. Therefore, *scu*-type MOFs with full-color emission were constructed, where full-color-emissive second linkers can be easily inserted by linker installation to form multicomponent MOFs. As a result, tunable energy transfer was achieved in the resultant MOFs due to substantial overlap between the emission and absorption spectra of the pristine and second linkers. We thus envision that pillar-layered MOFs might be constructed to realize tunable energy transfer in a broad light range using these carboxylic acids and pyridine-based linkers.

Bearing the aforementioned discussion in mind, 5',5''-(benzo[*c*][1,2,5]thiadiazole-4,7-diyl)bis([1,1':3',1''-terphenyl]-4,4''-dicarboxylic acid) (H<sub>4</sub>BTTC) and the bipyridine-based linkers 4,7-di(pyridine-4-yl)benzo[*c*][1,2,5]thiadiazole (PBT) and 4,9-di(pyridine-4-yl)naphtho[2,3-*c*][1,2,5]thiadiazole (PNT) (Figure 1) were first chosen as the three organic linkers to prepare pillar-layered MOFs due to their excellent optical properties according to our previous work.<sup>17,24,26</sup> To study the effect from benzo[*c*][1,2,5]thiadiazole and naphtho[2,3-*c*][1,2,5]thiadiazole on the single-crystal structure, 1,4-di(pyridine-4-yl)benzene (DPB) was also used as an organic linker to prepare the corresponding luminescent MOFs. The zinc-based framework HIAM-3008 (HIAM = Hoffmann Institute of Advanced Materials; 30 = zinc) was prepared using a typical synthesis route, as depicted in Figure 1a: a 5 mL vial containing 4 mL of *N,N*-

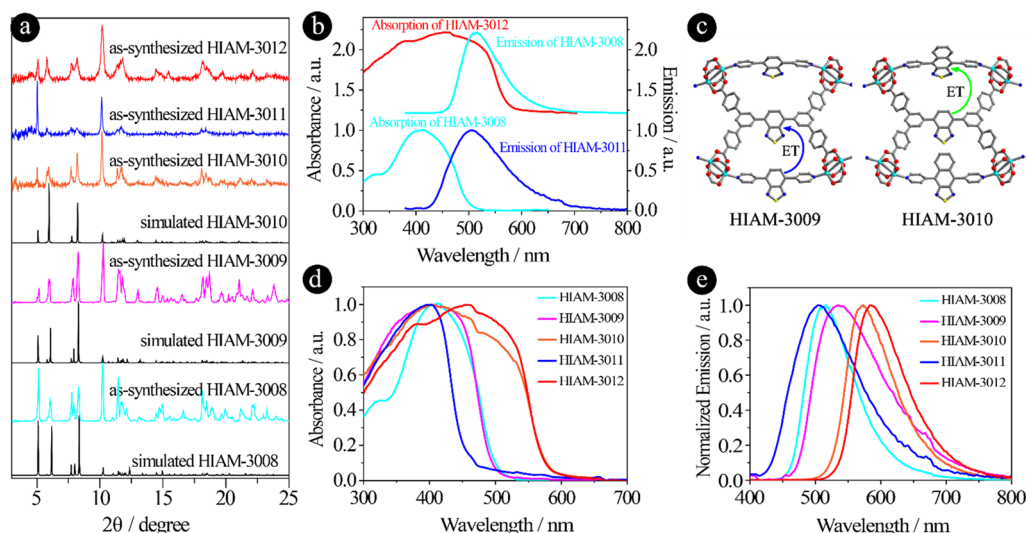
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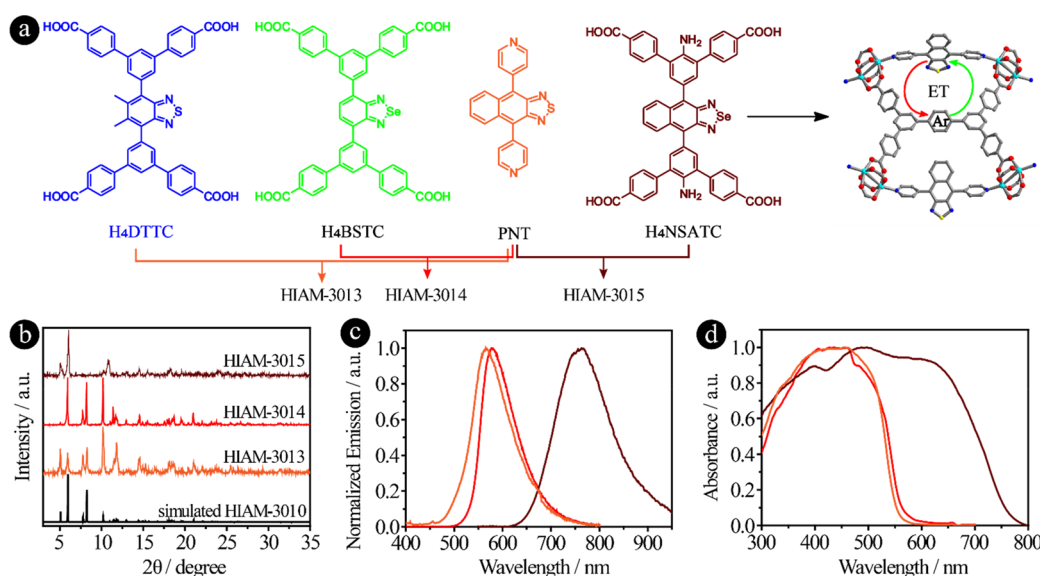
**Figure 1.** Molecular structures of H<sub>4</sub>BTTC (a), DPB (a), PBT (d), and PNT (g). Single-crystal structures of HIAM-3008 (b and c), HIAM-3009 (e and f), and HIAM-3010 (h and i) viewed along the *a* (b, e, and h) and *c* (c, f, and i) axes.



**Figure 2.** PXRD patterns of simulated HIAM-3008, HIAM-3009, and HIAM-3010 and experimental PXRD patterns of the as-synthesized HIAM-3008–HIAM-3012 (a). Absorption and emission spectra of HIAM-3008, HIAM-3011, and HIAM-3012 to illustrate spectral overlap (b). Schematic diagram illustrating energy transfer from BPT to BTTC in HIAM-3009 and from BTTC to NPT in HIAM-3010 (c). Normalized solid-state UV–vis absorption (d) and emission spectra (e) for HIAM-3008–HIAM-3012.

dimethylformamide (DMF), 14.9 mg of  $\text{Zn}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$ , 11.6 mg of DPB, and 19.2 mg of H<sub>4</sub>BTTC was placed in a preheated oven at 100 °C for 2 days to obtain light-yellow crystals (Figure S1). Usually pillar-layered MOFs should be obtained via the combination of tetratopic carboxylate and bipyridine.<sup>9,12,27–29</sup> However, surprisingly, single-crystal X-ray diffraction (XRD) analysis revealed that HIAM-3008 is not a pillar-layered MOF, which crystallizes in the orthorhombic crystal system with the *Ibam* space group (Table S1). As depicted in Figures 1b,c and S2, two zinc(II) atoms are

bridged by four carboxylate groups from four fully deprotonated H<sub>4</sub>BTTC linkers to form a binuclear “paddle-wheel”  $\text{Zn}_2(\text{COO})_4$ , which is common in pillar-layered MOFs. These four BTTC linkers did not form a layer in HIAM-3008. The rest of the coordination sites on two zinc(II) atoms are occupied by two nitrogen atoms from two DPB. The 6-connected (6-c) building units are extended to generate a 2-fold-interpenetrated 3D network. From the topological view, the BTTC<sup>4−</sup> linkers and  $\text{Zn}_2(\text{COO})_4$  secondary building units can be considered as 4-c and 6-c nodes, respectively. Also, the



**Figure 3.** Linker structures for synthesizing HIAM-3013, HIAM-3014, and HIAM-3015 (a). PXRD patterns of simulated HIAM-3009 and experimental HIAM-3013, HIAM-3014, and HIAM-3015 (b). Emission (c) and absorption (d) spectra of HIAM-3013, HIAM-3014, and HIAM-3015.

framework of HIAM-3008 can be simplified as a *seh*-4,6-*Imma* underlying net with a point symbol of  $\{3^2 \cdot 6^2 \cdot 7^2\}\{3^4 \cdot 4^2 \cdot 6^4 \cdot 7^5\}$ .<sup>30</sup>

Then HIAM-3009 (Figure S3), using H<sub>4</sub>BTTC and PBT as linkers (Figure 1d), and HIAM-3010 (Figure S4), using H<sub>4</sub>BTTC and PNT as linkers (Figure 1g), were prepared according to a method similar to that of HIAM-3008. As expected, the same *seh* underlying net was obtained (Figure 1e,f,h,i), which means that the structure of pyridine-based linkers has no effect on the single-crystal structures (Figure 1b,e,h). The phase purity of these MOFs was confirmed by the great agreement between the simulated XRD and experimental powder XRD (PXRD) patterns of the as-synthesized samples (Figure 2a).

To investigate the potential energy transfer between BTTC and PBT in HIAM-3009 and between BTTC and PNT in HIAM-3010, a tetratopic carboxylic acid, 5',5'''-(2,5-difluoro-1,4-phenylene)bis([1,1':3',1''-terphenyl]-4,4''-dicarboxylic acid) (H<sub>4</sub>FTPC), was utilized to synthesize the same *seh*-type MOFs with PBT (HIAM-3011) and PNT (HIAM-3012) as colinkers (Figure S5), respectively. In HIAM-3011 and HIAM-3012, the emission and absorption will be governed by the PBT and PNT linkers. The almost identical PXRD patterns between HIAM-3011, HIAM-3012, and simulated HIAM-3010 indicate that HIAM-3011 and HIAM-3012 possess the same structures as HIAM-3008 to HIAM-3010 (Figure 2a).

To ensure efficient energy transfer between PBT and BTTC in HIAM-3009 and between BTTC and PNT in HIAM-3010, the absorption spectrum of the acceptor and the emission spectrum of the donor should have enough overlap. Therefore, the absorption and emission spectra of HIAM-3008, HIAM-3011, and HIAM-3012 were studied first. The solid-state spectra in Figure 2b show that HIAM-3008 has an absorption edge at about 500 nm and an emission spectrum from 450 to 700 nm. HIAM-3011 exhibits an emission spectrum between 420 and 700 nm, and HIAM-3012 shows an absorption edge at around 580 nm. The significant spectral overlap between the absorption spectrum of HIAM-3008 (acceptor) and the emission spectrum of HIAM-3011 (donor) and between the absorption spectrum of HIAM-3012 (acceptor) and the

emission spectrum of HIAM-3008 (donor) suggests that energy transfer will occur from PBT to BTTC and from BTTC to PNT when they are integrated in HIAM-3009 and HIAM-3010 (as depicted in Figure 2c). The emissions of each linker in the DMF solution were also recorded as references to demonstrate the emission in the prepared multicomponent MOFs (Figure S6).

Then the solid-state UV-vis absorption and emission spectra were measured for HIAM-3008 to HIAM-3012 to explore energy transfer between linkers in HIAM-3009 and HIAM-3010. It should be noted that no significant shifts were observed for the absorption edges between HIAM-3008 and HIAM-3009, HIAM-3010, and HIAM-3012 (Figure 2d), which demonstrates that absorption is mainly governed by BTTC for HIAM-3008 and HIAM-3009 and PNT for HIAM-3010 and HIAM-3012, respectively. As shown in Figure 2e, the emission maxima are 505, 516, 535, 573, and 584 nm for HIAM-3011, HIAM-3008, HIAM-3009, HIAM-3010, and HIAM-3012, respectively. These results indicate that energy transfer indeed occurs from PBT to BTTC in HIAM-3009 and from BTTC to PNT in HIAM-3010, which was confirmed by the decreased lifetime of PBT in HIAM-3009 (5.38 ns) compared with that in HIAM-3011 (13.41 ns) (Figure S7). However, compared with the emission spectra of HIAM-3008 and HIAM-3011, 19 and 30 nm redshifts were measured for HIAM-3009, while compared with that of HIAM-3012, a 11 nm hypochromatic shift was recorded for HIAM-3010. These phenomena can be ascribed to the linker proximity and orientation effect on the aggregation states of the linker, which will affect the emission behaviors.

To further tune and direct energy transfer from the visible light to near-infrared range in these kinds of multicomponent MOFs, three other tetratopic carboxylic acids, {5',5'''-(5,6-dimethylbenzo[*c*][1,2,5]thiadiazole-4,7-diyl)bis([1,1':3',1''-terphenyl]-4,4''-dicarboxylic acid) (H<sub>4</sub>DTTC), 5',5'''-(benzo[*c*][1,2,5]selenadiazole-4,7-diyl)bis([1,1':3',1''-terphenyl]-4,4''-dicarboxylic acid)) (H<sub>4</sub>BSTC), and 5',5'''-(naphtho[2,3-*c*][1,2,5]selenadiazole-4,9-diyl)bis(2'-amino-[1,1':3',1''-terphenyl]-4,4''-dicarboxylic acid) (H<sub>4</sub>NSATC)}, and PNT were



employed for further exploration (Figure 3a), in which the emissions of these four linkers locate in the blue, green, orange, and near-infrared ranges. The corresponding MOFs, HIAM-3013–HIAM-3015, were prepared using a method similar to that of HIAM-3010. The isostructural nature of these three MOFs with HIAM-3010 was confirmed via the almost identical PXRD patterns, as shown in Figure 3b.

Then the solid-state emission and absorption properties of HIAM-3013–HIAM-3015 were measured to study energy transfer between the two integrated linkers. As shown in Figure 3c, the emissions were recorded with peak maxima at 565, 577, and 763 nm for HIAM-3013, HIAM-3014, and HIAM-3015, respectively. Energy transfer occurs from tetratopic carboxylic acids to PNT in HIAM-3013 and HIAM-3014, which is the same as that in HIAM-3010, while for HIAM-3015, the emission maximum was recorded at 763 nm and the emission from PNT completely disappeared, indicative of an efficient energy transfer from PNT to NSATC. This result can be attributed to the fact that the mission wavelength of a PNT-based MOF overlaps substantially with the absorption wavelength of a H<sub>4</sub>NSATC-based MOF, as reported in our previous works.<sup>25,26</sup> The absorption spectra of HIAM-3013 and HIAM-3014 are almost the same and similar to that of a PNT-based pillar-layered MOF (HIAM-3002)<sup>26</sup> but are significantly red-shifted compared with those of H<sub>4</sub>DTTC- and H<sub>4</sub>BSTC-based Zr- or Y-MOFs,<sup>17</sup> while the absorption spectrum was governed by NSATC in HIAM-3015, which is similar to the NSATC-constructed Y-MOF.<sup>25</sup> These results demonstrate that the present multicomponent MOF structures can be utilized as platforms to tune and direct energy transfer from the blue light to near-infrared range by choosing the appropriate organic linkers, where 2,1,3-benzothiadiazole and its derivative-based D–A–D-type compounds provide an abundant linker pool with highly tunable emission and absorption behaviors.

In conclusion, a series of multicomponent Zn-MOFs with well-defined structure were constructed using 2,1,3-benzothiadiazole and its derivative-based carboxylic acids and pyridine-contained linkers. Due to the controllable emission and absorption properties of these linkers, energy transfer between the carboxylic acid- and pyridine-based linkers can be well-tuned and directed from the blue to near-infrared range. This work offers a novel multicomponent MOF platform to control energy transfer and further confirm the superiority of 2,1,3-benzothiadiazole and its derivative-based organic linkers.

## ■ ASSOCIATED CONTENT

### SI Supporting Information

The Supporting Information is available free of charge at <https://pubs.acs.org/doi/10.1021/acs.inorgchem.3c00904>.

Materials, characterizations, synthesis of MOF, single-crystal structures, and other additional information (PDF)

### Accession Codes

CCDC 2177786, 2249344, and 2249345 contain the supplementary crystallographic data for this paper. These data can be obtained free of charge via [www.ccdc.cam.ac.uk/data\\_request/cif](http://www.ccdc.cam.ac.uk/data_request/cif), or by emailing [data\\_request@ccdc.cam.ac.uk](mailto:data_request@ccdc.cam.ac.uk), or by contacting The Cambridge Crystallographic Data Centre, 12 Union Road, Cambridge CB2 1EZ, UK; fax: +44 1223 336033.

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### Author Contributions

The manuscript was written through contributions of all authors.

### Notes

The authors declare no competing financial interest.

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## ■ REFERENCES

- (1) Scholes, G. D.; Fleming, G. R.; Olaya-Castro, A.; van Grondelle, R. Lessons from nature about solar light harvesting. *Nat. Chem.* **2011**, *3* (10), 763–774.
- (2) Barber, J.; Tran, P. D. From natural to artificial photosynthesis. *J. R. Soc. Interface* **2013**, *10* (81), 20120984.
- (3) Barber, J.; Andersson, B. Revealing the blueprint of photosynthesis. *Nature* **1994**, *370* (6484), 31–34.
- (4) Van Grondelle, R.; Dekker, J. P.; Gillbro, T.; Sundstrom, V. Energy transfer and trapping in photosynthesis. *Biochim. Biophys. Acta, Bioenerg.* **1994**, *1187* (1), 1–65.

- (5) Cheng, Y.-C.; Fleming, G. R. Dynamics of Light Harvesting in Photosynthesis. *Annu. Rev. Phys. Chem.* **2009**, *60* (1), 241–262.
- (6) So, M. C.; Wiederrecht, G. P.; Mondloch, J. E.; Hupp, J. T.; Farha, O. K. Metal–organic framework materials for light-harvesting and energy transfer. *Chem. Commun.* **2015**, *51* (17), 3501–3510.
- (7) Kung, C. W.; Goswami, S.; Hod, I.; Wang, T. C.; Duan, J.; Farha, O. K.; Hupp, J. T. Charge Transport in Zirconium-Based Metal–Organic Frameworks. *Acc. Chem. Res.* **2020**, *53* (6), 1187–1195.
- (8) Yu, J.; Li, X.; Deria, P. Light-Harvesting in Porous Crystalline Compositions: Where We Stand toward Robust Metal–Organic Frameworks. *ACS Sustainable Chem. Eng.* **2019**, *7* (2), 1841–1854.
- (9) Lee, C. Y.; Farha, O. K.; Hong, B. J.; Sarjeant, A. A.; Nguyen, S. T.; Hupp, J. T. Light-harvesting metal-organic frameworks (MOFs): efficient strut-to-strut energy transfer in bodipy and porphyrin-based MOFs. *J. Am. Chem. Soc.* **2011**, *133* (40), 15858–15861.
- (10) Son, H.-J.; Jin, S.; Patwardhan, S.; Wezenberg, S. J.; Jeong, N. C.; So, M.; Wilmer, C. E.; Sarjeant, A. A.; Schatz, G. C.; Snurr, R. Q.; Farha, O. K.; Wiederrecht, G. P.; Hupp, J. T. Light-Harvesting and Ultrafast Energy Migration in Porphyrin-Based Metal–Organic Frameworks. *J. Am. Chem. Soc.* **2013**, *135* (2), 862–869.
- (11) Williams, D. E.; Rietman, J. A.; Maier, J. M.; Tan, R.; Gretyak, A. B.; Smith, M. D.; Krause, J. A.; Shustova, N. B. Energy Transfer on Demand: Photoswitch-Directed Behavior of Metal-Porphyrin Frameworks. *J. Am. Chem. Soc.* **2014**, *136* (34), 11886–11889.
- (12) Dolgoplova, E. A.; Williams, D. E.; Gretyak, A. B.; Rice, A. M.; Smith, M. D.; Krause, J. A.; Shustova, N. B. A Bio-inspired Approach for Chromophore Communication: Ligand-to-Ligand and Host-to-Guest Energy Transfer in Hybrid Crystalline Scaffolds. *Angew. Chem., Int. Ed.* **2015**, *54* (46), 13639–13643.
- (13) Danowski, W.; Castiglioni, F.; Sardjan, A. S.; Krause, S.; Pfeifer, L.; Roke, D.; Comotti, A.; Browne, W. R.; Feringa, B. L. Visible-Light-Driven Rotation of Molecular Motors in a Dual-Function Metal–Organic Framework Enabled by Energy Transfer. *J. Am. Chem. Soc.* **2020**, *142* (19), 9048–9056.
- (14) Park, K. C.; Seo, C.; Gupta, G.; Kim, J.; Lee, C. Y. Efficient Energy Transfer (EnT) in Pyrene- and Porphyrin-Based Mixed-Ligand Metal–Organic Frameworks. *ACS Appl. Mater. Interfaces* **2017**, *9* (44), 38670–38677.
- (15) Jia, J.; Gutiérrez-Arzaluz, L.; Shekhar, O.; Alsadun, N.; Czaban-Jóźwiak, J.; Zhou, S.; Bakr, O. M.; Mohammed, O. F.; Eddaoudi, M. Access to Highly Efficient Energy Transfer in Metal–Organic Frameworks via Mixed Linkers Approach. *J. Am. Chem. Soc.* **2020**, *142* (19), 8580–8584.
- (16) Chakraborty, A.; Ilic, S.; Cai, M.; Gibbons, B. J.; Yang, X.; Slamowitz, C. C.; Morris, A. J. Role of Spin–Orbit Coupling in Long Range Energy Transfer in Metal–Organic Frameworks. *J. Am. Chem. Soc.* **2020**, *142* (48), 20434–20443.
- (17) Ren, D.; Xia, H.-L.; Zhou, K.; Wu, S.; Liu, X.-Y.; Wang, X.; Li, J. Tuning and Directing Energy Transfer in the Whole Visible Spectrum through Linker Installation in Metal–Organic Frameworks. *Angew. Chem., Int. Ed.* **2021**, *60* (47), 25048–25054.
- (18) Liu, L.; Konstas, K.; Hill, M. R.; Telfer, S. G. Programmed Pore Architectures in Modular Quaternary Metal–Organic Frameworks. *J. Am. Chem. Soc.* **2013**, *135* (47), 17731–17734.
- (19) Liu, L.; Telfer, S. G. Systematic Ligand Modulation Enhances the Moisture Stability and Gas Sorption Characteristics of Quaternary Metal–Organic Frameworks. *J. Am. Chem. Soc.* **2015**, *137* (11), 3901–3909.
- (20) Liu, L.; Zhou, T.-Y.; Telfer, S. G. Modulating the Performance of an Asymmetric Organocatalyst by Tuning Its Spatial Environment in a Metal–Organic Framework. *J. Am. Chem. Soc.* **2017**, *139* (39), 13936–13943.
- (21) Cornelio, J.; Zhou, T.-Y.; Alkaş, A.; Telfer, S. G. Systematic Tuning of the Luminescence Output of Multicomponent Metal–Organic Frameworks. *J. Am. Chem. Soc.* **2018**, *140* (45), 15470–15476.
- (22) Tu, B.; Diestel, L.; Shi, Z.-L.; Bandara, W. R. L. N.; Chen, Y.; Lin, W.; Zhang, Y.-B.; Telfer, S. G.; Li, Q. Harnessing Bottom-Up Self-Assembly To Position Five Distinct Components in an Ordered Porous Framework. *Angew. Chem., Int. Ed.* **2019**, *58* (16), 5348–5353.
- (23) Pang, Q.; Tu, B.; Li, Q. Metal–organic frameworks with multicomponents in order. *Coord. Chem. Rev.* **2019**, *388*, 107–125.
- (24) Wu, S.; Ren, D.; Zhou, K.; Xia, H. L.; Liu, X. Y.; Wang, X.; Li, J. Linker Engineering toward Full-Color Emission of UiO-68 Type Metal–Organic Frameworks. *J. Am. Chem. Soc.* **2021**, *143* (28), 10547–10552.
- (25) Xia, H.-L.; Zhou, K.; Guo, J.; Zhang, J.; Huang, X.; Luo, D.; Liu, X.-Y.; Li, J. Amino group induced structural diversity and near-infrared emission of yttrium-tetracarboxylate frameworks. *Chem. Sci.* **2022**, *13* (32), 9321–9328.
- (26) Xia, H.-L.; Zhou, K.; Wu, S.; Ren, D.; Xing, K.; Guo, J.; Wang, X.; Liu, X.-Y.; Li, J. Building an Emission Library of Donor-Acceptor-Donor Type Linker-Based Luminescent Metal–Organic Frameworks. *Chem. Sci.* **2022**, *13*, 8036–8044.
- (27) Farha, O. K.; Malliakas, C. D.; Kanatzidis, M. G.; Hupp, J. T. Control over Catenation in Metal–Organic Frameworks via Rational Design of the Organic Building Block. *J. Am. Chem. Soc.* **2010**, *132* (3), 950–952.
- (28) Chen, Q.; Xian, S.; Dong, X.; Liu, Y.; Wang, H.; Olson, D. H.; Williams, L. J.; Han, Y.; Bu, X.-H.; Li, J. High-Efficiency Separation of n-Hexane by a Dynamic Metal–Organic Framework with Reduced Energy Consumption. *Angew. Chem., Int. Ed.* **2021**, *60* (19), 10593–10597.
- (29) ZareKarizi, F.; Joharian, M.; Morsali, A. Pillar-layered MOFs: functionality, interpenetration, flexibility and applications. *J. Mater. Chem. A* **2018**, *6* (40), 19288–19329.
- (30) Blatov, V. A.; Proserpio, D. M. Topological relations between three-periodic nets. II. Binodal nets. *Acta Cryst. A* **2009**, *65* (3), 202–212.

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