

Full-Color Emission in Multicomponent Metal–Organic Frameworks via Linker Installation

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ABSTRACT: Herein, we demonstrate that linker installation (LI) through postsynthesis is an effective strategy to insert emissive second linkers into single-linker-based metal–organic frameworks (MOFs) to tune the emission properties of multicomponent MOFs. Full-color emission, including white-light emission, can be achieved via such a LI process.

Luminescent metal–organic frameworks (LMOFs) have received tremendous attention in recent years for their potential in energy-efficient lighting applications as a result of their highly tunable structures and chemical compositions, as well as nearly unlimited choices of emissive guest species, which have enabled the development of many MOF-based host–guest systems.^{1–4} In general, the emission behaviors of LMOFs depend mainly on the metal nodes,⁵ linkers, and guests, where linker- and guest-based systems possess more advantages compared with metal node-based ones.^{6–8} In host–guest-based LMOF composites, various dye molecules can be encapsulated into different kinds of MOF structures via *in situ* trapping or ion exchange procedures.^{9–16} Owing to the diversity of MOFs and a vast variety of choices of guest species, full-color-emissive LMOFs, including those that emit white light, have been realized. However, compared with pure organic-linker-based LMOFs, the host–guest-based composites often suffer from low thermal stability and photostability, which must be addressed. While extensive studies have been done on pure linker-based yellow-emitting LMOFs,^{17–20} only a few papers report the strategy to tune the emission properties via linker and structure engineering,^{8,21} including multicomponent MOFs (MC-MOFs) with well-established structures,^{8,22,23} which is likely due to the fact that (i) the synthesis of linkers with different emission colors is usually complex and time-consuming^{8,21} and (ii) some organic linkers with targeted emission colors cannot be used directly to form MOFs.²⁴ Therefore, the main challenge here is how to synthesize organic linkers with excellent and desired emission properties under facile conditions and prepare the corresponding MOFs using these ligands. For example, to facilitate further advancement of LMOFs-based phosphors for solid-state lighting applications, it is crucial to develop an effective strategy to obtain linker-based MOFs with full-color emissions including white light.

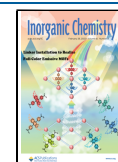
Except using a direct method to synthesize MOFs, postsynthesis modification has been proven as an alternative and effective strategy to endow special properties to pristine MOFs, including metal exchange, ligand exchange, ligand modification, and so on.^{25–28} In 2015, Zhou and co-workers reported a novel and useful approach to synthesizing MC-

MOFs with precise placement of the functional groups via linker installation (LI).²⁹ After that, LI has been employed as a useful strategy to enhance the stability and sorption behaviors of different types of MOF structures with various functional linkers,^{29–35} which has facilitated MOF applications in various fields such as catalysis^{32,36} and sensing.³⁷

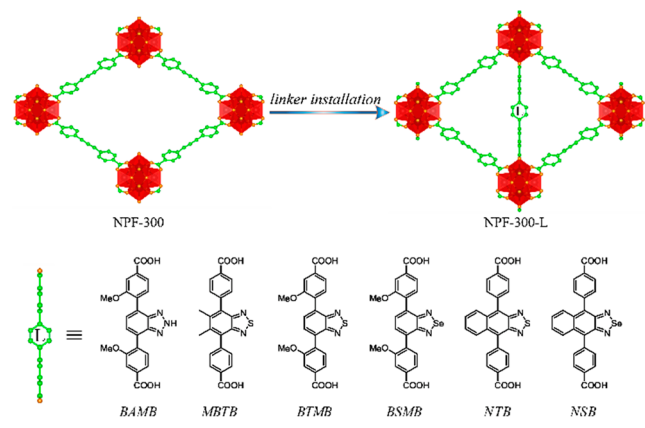
According to the LI strategy, we conceive that full-color emission may be realized by installing organic linkers with tunable emission properties in pristine nonfluorescent MOF structures. Furthermore, it is highly possible to realize white-light emission (WLE) by installing the appropriate red-green-blue- or yellow-blue-emissive organic linker pairs. To prove our hypothesis, we chose NPF-300 as the pristine MOF, which shows a negligible emission property.³⁰ On the other hand, because of the tunable emission properties of 2,1,3-benzothiadiazole and its analogues,^{38–40} a series of benzothiadiazole-dicarboxylic acid-based organic linkers (L), 4,4'-(2H-benzo[d][1,2,3]triazole-4,7-diyl)bis(3-methoxybenzoic acid) (BAMB), 4,4'-(5,6-dimethylbenzo[c][1,2,5]thiadiazole-4,7-diyl)dibenzoic acid (MBTB), 4,4'-(benzo[c][1,2,5]thiadiazole-4,7-diyl)bis(3-methoxybenzoic acid) (BTMB),⁴¹ 4,4'-(benzo[c][1,2,5]selenadiazole-4,7-diyl)bis(3-methoxybenzoic acid) (BSMB), 4,4'-(naphtho[2,3-c][1,2,5]thiadiazole-4,9-diyl)dibenzoic acid (NTB), and 4,4'-(naphtho[2,3-c][1,2,5]selenadiazole-4,9-diyl)dibenzoic acid (NSB), were synthesized via linker engineering under mild conditions.^{42,43} These ligands emit lights of a broad range of colors, from blue to red, and are ideal for use as the second linker to be installed in the NPF-300 [Zr₆O₄(OH)₈(H₂O)₄linker]₂ pristine structure. Full-color emission can be anticipated from the resultant MC-NPF-300-L series (Scheme 1). WLE can be expected by exciting a yellow-emitting MC-NPF-300-L with a blue-light source. More importantly, this strategy can be applied to other

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Scheme 1. Schematic Diagram Illustrating the Use of the LI approach to Realize Full-Color Emission of NPF-300-L and Molecular structures of the Organic Linkers Used in the Present Work



MOF systems, such as PCN-700.²⁹ By careful tuning of the concentrations of the linker pairs of 2-aminoterephthalic acid ($\text{NH}_2\text{-BDC}$; blue-emitting) and NTB (orange-emitting), high-quality WLE can also be realized. The present work demonstrates that LI indeed is an effective strategy for achieving full-color emissions, including WLE, in MC-MOFs via linker engineering.

NPF-300 was synthesized according to the reported work with some modification.³⁰ Briefly, a 5 mL vial containing 3 mL of *N,N*-dimethylformamide (DMF), 23.3 mg of ZrCl_4 , 10 mg of 5',5'''-(buta-1,3-diyne-1,4-diyl)bis([1,1':3',1''-terphenyl]-4,4''-dicarboxylic acid), and 700 mg of benzoic acid was put in a preheated oven at 120 °C for 3 days. Colorless single crystals were obtained after cooling to room temperature. After thorough washing with DMF and hexane, crystal samples of NPF-300 with well-matching powder X-ray diffraction (PXRD) patterns to the simulated NPF-300 were obtained (Figure S1). NPF-300 crystallizes in the orthorhombic crystal system with a *Cmmm* space group and a scu topology, in which each a Zr_6 cluster connects to eight tetraprotic carboxylate linkers and eight terminal $\text{H}_2\text{O}/\text{OH}^-$ groups (Figure S2). The distance between the unsaturated metal sites of two neighboring Zr_6 clusters perpendicular to the *c* axis is 15.1 Å. The lengths of the chosen second linkers are all around 15.4 Å. These results make NPF-300 an ideal platform to insert the chosen emissive second linkers by replacing the $\text{H}_2\text{O}/\text{OH}^-$ groups on the cluster.

To prove that the proposed second linkers can be installed in the NPF-300 structure, the pristine MOF sample was dispersed in the DMF solution of these second linkers (L), and the mixture was heated at 80 °C for 24 h to yield NPF-300-L. The resulting MC-MOFs were thoroughly washed using DMF until no fluorescence signal was detected from the supernatant. The successful formation of NPF-300-L was confirmed by single-crystal X-ray diffraction. As an example, the crystal structure of NPF-300-MBTB is depicted in Figure 1 and Table S1. After a successful installation of MBTB, each Zr_6 cluster is 10-connected to eight primary linkers and two MBTB by replacement of the $\text{OH}^-/\text{H}_2\text{O}$ groups on the primary Zr_6 cluster of NPF-300 to form NPF-300-MBTB, which was further confirmed by ^1H NMR on the acid-digested NPF-300-L (Figures S3–S8). As shown in Figure 2a, the PXRD patterns of all NPF-300-L synthesized by this method match well with

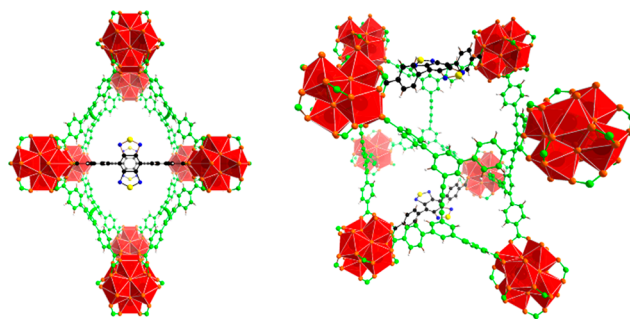


Figure 1. Single-crystal structure of NPF-300-MBTB viewed from different directions.

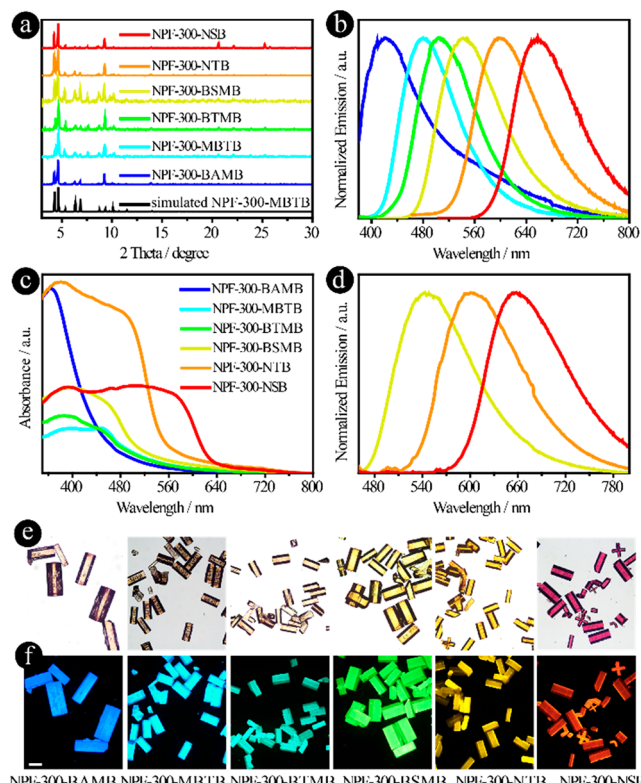


Figure 2. PXRD patterns (a), solid-state PL spectra under UV excitation (b) and UV-vis spectra (c) of NPF-300-L and solid-state PL spectra of NPF-300-BSMB, NPF-300-NTB, and NPF-300-NSB under 450 nm excitation (d), and single-crystal images of NPF-300-L under daylight (e) and under 365 nm excitation (f). Scale bar: 200 μm .

those of the simulated NPF-300-MBTB, confirming the high crystallinity of this isorecticular series and the nature of single-crystal-to-single-crystal transformation during LI.

Solid-state photoluminescence (PL) of NPF-300-L was then investigated. As shown in Figure 2b, blue, cyan, blue-green, green-yellow, orange, and red emissions were recorded for NPF-300-BAMB, NPF-300-MBTB, NPF-300-BTMB, NPF-300-BSMB, NPF-300-NTB, and NPF-300-NSB with emission peak maxima centered at 420, 480, 505, 545, 600, and 660 nm, respectively, which is consistent with the color changes of the corresponding single crystals under daylight and 365 nm excitation (Figure 2e,f). The corresponding quantum yields are 2.2%, 5.7%, 16.4%, 9.7%, 1.2%, and 5.3% at 365 nm excitation. The above results indicate that LI indeed is a powerful strategy to obtain full-color emission in MC-MOFs with suitable linker

engineering. The solid-state UV–vis absorption spectra shown in Figure 2c are consistent with the highest occupied molecular orbital–lowest unoccupied molecular orbital gaps of the second ligands, with the highest and lowest values of the absorption edges for NPF-300-BAMB and NPF-300-NSB, respectively.^{42,43} NPF-300-BSMB, NPF-300-NTB, and NPF-300-NSB show stronger absorption in the blue-light range compared with other NPF-300-L compounds, indicating that they are well blue-excitable and will have higher efficiency when excited by a blue-light source rather than a UV-light source. Indeed, under 450 nm excitation, enhanced PL intensities were observed for these three MOFs with corresponding quantum yields of 9.0%, 1.4%, and 6.2%, respectively (Figures 2d and S9). A WLE can be obtained by coating yellow-emitting NPF-300-BSMB on a blue LED chip (Figure S10).

In order to demonstrate the generalizability of the LI approach in achieving WLE in a single MC-MOF, we selected PCN-700 as a pristine MOF. As shown in Figure 3a, two

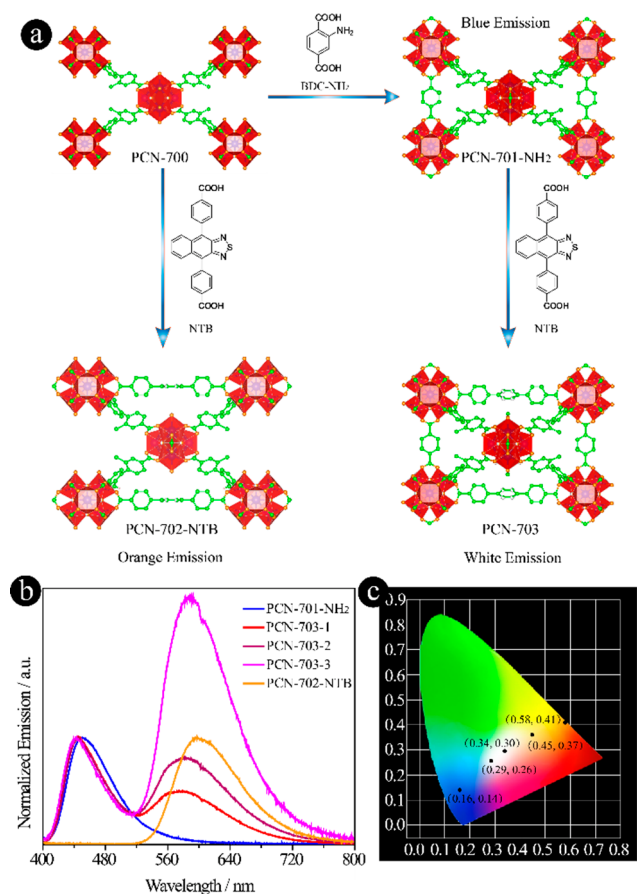


Figure 3. Schematic diagram of sequential LI for generating WLE (a). Solid-state PL spectra under 365 nm excitation (b) and the corresponding CIE chromaticity coordinates (c) of PCN-701-NH₂, PCN-702-NTB, and PCN-703 with increased concentration of NTB.

linkers of different lengths can be sequentially installed into this MOF (Figures S11 and S12).²⁹ To create WLE, two linkers with blue and yellow emission were chosen. NH₂-BDC (the blue emitter) and PCN-701-NH₂ (Figure 3a) was prepared according to the previously reported method.²⁹ The successful formation of PCN-701-NH₂ was confirmed by PXRD and ¹H NMR analysis (Figures S13 and S14). PCN-

701-NH₂ emits blue light ($\lambda_{\text{em}} = 450 \text{ nm}$) with a corresponding photoluminescence quantum yield (PLQY) of 26.4% under 365 nm excitation (Figure 3b). The excellent blue emission of PCN-701-NH₂ inspired us to install a yellow-emitting linker subsequent to achieving WLE in one crystal structure, for which NTB was used (Figure 3a). As shown in Figure 3b, the PL peak of NTB gradually increased with increasing concentration of NTB, which also exhibits a significant blue shift compared with that in pure PCN-702-NTB (Figure S15). The CIE chromaticity coordinates gradually varied from (0.16, 0.14) of PCN-701-NH₂ to (0.45, 0.37) of PCN-703-3, and WLE can be realized at (0.34, 0.30) for PCN-703-2 (Figure 3c). The PXRD patterns of all PCN-703-*n* (*n* = 1–3) samples are almost identical with that of PCN-701-NH₂ (Figure S16), owing to the fact that the installation concentration of NTB into PCN-701-NH₂ is very low and no obvious effect on the crystal structure can be measured. The measured PLQYs, calculated correlated color temperature, and color-rendering index values for PCN-703-2 are 8.6%, 4475 K, and 83.4, respectively. The color is similar to natural white light and is human eye-friendly.

In conclusion, various organic linkers with tunable emission properties have been successfully installed in a model MOF structure, NPF-300, to achieve full-color emission. WLE can be realized by excitation of yellow-emitting NPF-300-BSMB with a blue-light source or by the sequential installation of blue- and orange-emissive linkers into PCN-700. The present work demonstrates that LI is an effective strategy for tuning the emission energy and color of MC-MOFs and will facilitate the development of LMOF-based materials for solid-state lighting and other applications, such as photocatalysis and sensing.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge at <https://pubs.acs.org/doi/10.1021/acs.inorgchem.1c02977>.

Materials, MOF synthesis, ¹H NMR and PL spectra, PXRD patterns, and other additional information (PDF)

■ Accession Codes

CCDC 2109845 contains the supplementary crystallographic data for this paper. These data can be obtained free of charge via www.ccdc.cam.ac.uk/data_request/cif, or by emailing 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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Notes

The authors declare no competing financial interest.

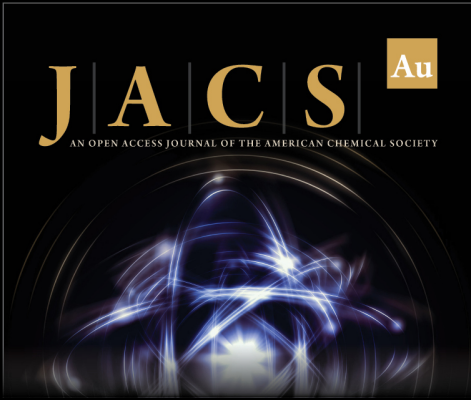
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REFERENCES


- (1) Allendorf, M. D.; Bauer, C. A.; Bhakta, R. K.; Houk, R. J. Luminescent metal-organic frameworks. *Chem. Soc. Rev.* **2009**, *38* (5), 1330–1352.
- (2) Cui, Y.; Yue, Y.; Qian, G.; Chen, B. Luminescent Functional Metal–Organic Frameworks. *Chem. Rev.* **2012**, *112* (2), 1126–1162.
- (3) Lustig, W. P.; Li, J. Luminescent metal–organic frameworks and coordination polymers as alternative phosphors for energy efficient lighting devices. *Coord. Chem. Rev.* **2018**, *373*, 116–147.
- (4) Liu, X.-Y.; Lustig, W. P.; Li, J. Functionalizing Luminescent Metal–Organic Frameworks for Enhanced Photoluminescence. *ACS Energy Lett.* **2020**, *5* (8), 2671–2680.
- (5) Xiao, J.; Song, L.; Liu, M.; Wang, X.; Liu, Z. Intriguing pH-modulated Luminescence Chameleon System based on Postsynthetic Modified Dual-emitting Eu³⁺@Mn-MOF and Its Application for Histidine Chemosensor. *Inorg. Chem.* **2020**, *59* (9), 6390–6397.
- (6) Qiu, L.; Yu, C.; Wang, X.; Xie, Y.; Kirillov, A. M.; Huang, W.; Li, J.; Gao, P.; Wu, T.; Gu, X.; Nie, Q.; Wu, D. Tuning the Solid-State White Light Emission of Postsynthetic Lanthanide-Encapsulated Double-Layer MOFs for Three-Color Luminescent Thermometry Applications. *Inorg. Chem.* **2019**, *58* (7), 4524–4533.
- (7) Zheng, X.; Zhao, Y.; Jia, P.; Wang, Q.; Liu, Y.; Bu, T.; Zhang, M.; Bai, F.; Wang, L. Dual-Emission Zr-MOF-Based Composite Material as a Fluorescence Turn-On Sensor for the Ultrasensitive Detection of Al³⁺. *Inorg. Chem.* **2020**, *59* (24), 18205–18213.
- (8) Cornelio, J.; Zhou, T.-Y.; Alkass, A.; Telfer, S. G. Systematic Tuning of the Luminescence Output of Multicomponent Metal–Organic Frameworks. *J. Am. Chem. Soc.* **2018**, *140* (45), 15470–15476.
- (9) Sun, C. Y.; Wang, X. L.; Zhang, X.; Qin, C.; Li, P.; Su, Z. M.; Zhu, D. X.; Shan, G. G.; Shao, K. Z.; Wu, H.; Li, J. Efficient and tunable white-light emission of metal-organic frameworks by iridium-complex encapsulation. *Nat. Commun.* **2013**, *4*, 2717.
- (10) Cui, Y.; Song, T.; Yu, J.; Yang, Y.; Wang, Z.; Qian, G. Dye Encapsulated Metal–Organic Framework for Warm-White LED with High Color-Rendering Index. *Adv. Funct. Mater.* **2015**, *25* (30), 4796–4802.
- (11) Wen, Y.; Sheng, T.; Zhu, X.; Zhuo, C.; Su, S.; Li, H.; Hu, S.; Zhu, Q.-L.; Wu, X. Introduction of Red-Green-Blue Fluorescent Dyes into a Metal–Organic Framework for Tunable White Light Emission. *Adv. Mater.* **2017**, *29* (37), 1700778.
- (12) Glembocky, V.; Frenette, M.; Mottillo, C.; Durantini, A. M.; Gostick, J.; Strukil, V.; Friscic, T.; Cosa, G. Highly Photostable and Fluorescent Microporous Solids Prepared via Solid-State Entrapment of Boron Dipyrromethene Dyes in a Nascent Metal–Organic Framework. *J. Am. Chem. Soc.* **2018**, *140*, 16882–16887.
- (13) Chen, Y.; Yu, B.; Cui, Y.; Xu, S.; Gong, J. Core–Shell Structured Cyclodextrin Metal–Organic Frameworks with Hierarchical Dye Encapsulation for Tunable Light Emission. *Chem. Mater.* **2019**, *31* (4), 1289–1295.
- (14) Wang, Z.; Zhu, C.-Y.; Mo, J.-T.; Fu, P.-Y.; Zhao, Y.-W.; Yin, S.-Y.; Jiang, J.-J.; Pan, M.; Su, C.-Y. White-Light Emission from Dual-Way Photon Energy Conversion in a Dye-Encapsulated Metal–Organic Framework. *Angew. Chem., Int. Ed.* **2019**, *131* (0), 9854–9859.
- (15) Liu, X. Y.; Li, Y.; Tsung, C. K.; Li, J. Encapsulation of yellow phosphors into nanocrystalline metal-organic frameworks for blue-excitable white light emission. *Chem. Commun.* **2019**, *55* (72), 10669–10672.
- (16) Liu, X. Y.; Xing, K.; Li, Y.; Tsung, C. K.; Li, J. Three Models To Encapsulate Multicomponent Dyes into Nanocrystal Pores: A New Strategy for Generating High-Quality White Light. *J. Am. Chem. Soc.* **2019**, *141* (37), 14807–14813.
- (17) Gong, Q.; Hu, Z.; Deibert, B. J.; Emge, T. J.; Teat, S. J.; Banerjee, D.; Mussman, B.; Rudd, N. D.; Li, J. Solution Processable MOF Yellow Phosphor with Exceptionally High Quantum Efficiency. *J. Am. Chem. Soc.* **2014**, *136* (48), 16724–16727.
- (18) Hu, Z.; Huang, G.; Lustig, W. P.; Wang, F.; Wang, H.; Teat, S. J.; Banerjee, D.; Zhang, D.; Li, J. Achieving exceptionally high luminescence quantum efficiency by immobilizing an AIE molecular chromophore into a metal-organic framework. *Chem. Commun.* **2015**, *51* (15), 3045–3048.
- (19) Lustig, W. P.; Wang, F.; Teat, S. J.; Hu, Z.; Gong, Q.; Li, J. Chromophore-Based Luminescent Metal–Organic Frameworks as Lighting Phosphors. *Inorg. Chem.* **2016**, *55* (15), 7250–7256.
- (20) Lustig, W. P.; Shen, Z.; Teat, S. J.; Javed, N.; Velasco, E.; O’Carroll, D. M.; Li, J. Rational design of a high-efficiency, multivariate metal–organic framework phosphor for white LED bulbs. *Chem. Sci.* **2020**, *11* (7), 1814–1824.
- (21) Newsome, W. J.; Ayad, S.; Cordova, J.; Reinheimer, E. W.; Campiglia, A. D.; Harper, J. K.; Hanson, K.; Uribe-Romo, F. J. Solid State Multicolor Emission in Substitutional Solid Solutions of Metal–Organic Frameworks. *J. Am. Soc. Chem.* **2019**, *141*, 11298–11303.
- (22) Pang, Q.; Tu, B.; Li, Q. Metal–organic frameworks with multicomponents in order. *Coord. Chem. Rev.* **2019**, *388*, 107–125.
- (23) Qin, J.-S.; Du, D.-Y.; Li, M.; Lian, X.-Z.; Dong, L.-Z.; Bosch, M.; Su, Z.-M.; Zhang, Q.; Li, S.-L.; Lan, Y.-Q.; Yuan, S.; Zhou, H.-C. Derivation and Decoration of Nets with Trigonal-Prismatic Nodes: A Unique Route to Reticular Synthesis of Metal–Organic Frameworks. *J. Am. Chem. Soc.* **2016**, *138* (16), 5299–5307.
- (24) Qin, J. S.; Yuan, S.; Zhang, L.; Li, B.; Du, D. Y.; Huang, N.; Guan, W.; Drake, H. F.; Pang, J.; Lan, Y. Q.; Alsalmeh, A.; Zhou, H. C. Creating Well-Defined Hexabenzocoronene in Zirconium Metal–Organic Framework by Postsynthetic Annulation. *J. Am. Chem. Soc.* **2019**, *141* (5), 2054–2060.
- (25) Yin, Z.; Wan, S.; Yang, J.; Kurmoo, M.; Zeng, M.-H. Recent advances in post-synthetic modification of metal–organic frameworks: New types and tandem reactions. *Coord. Chem. Rev.* **2019**, *378*, 500–512.
- (26) Wang, Z.; Cohen, S. M. Postsynthetic modification of metal–organic frameworks. *Chem. Soc. Rev.* **2009**, *38* (5), 1315–1329.
- (27) Islamoglu, T.; Goswami, S.; Li, Z.; Howarth, A. J.; Farha, O. K.; Hupp, J. T. Postsynthetic Tuning of Metal–Organic Frameworks for Targeted Applications. *Acc. Chem. Res.* **2017**, *50* (4), 805–813.
- (28) Tanabe, K. K.; Cohen, S. M. Postsynthetic modification of metal–organic frameworks—a progress report. *Chem. Soc. Rev.* **2011**, *40* (2), 498–519.
- (29) Yuan, S.; Lu, W.; Chen, Y. P.; Zhang, Q.; Liu, T. F.; Feng, D.; Wang, X.; Qin, J.; Zhou, H. C. Sequential linker installation: precise placement of functional groups in multivariate metal-organic frameworks. *J. Am. Chem. Soc.* **2015**, *137* (9), 3177–3180.


- (30) Zhang, X.; Frey, B. L.; Chen, Y. S.; Zhang, J. Topology-Guided Stepwise Insertion of Three Secondary Linkers in Zirconium Metal-Organic Frameworks. *J. Am. Chem. Soc.* **2018**, *140* (24), 7710–7715.
- (31) Pang, J.; Yuan, S.; Qin, J. S.; Lollar, C. T.; Huang, N.; Li, J.; Wang, Q.; Wu, M.; Yuan, D.; Hong, M.; Zhou, H. C. Tuning the Ionicity of Stable Metal-Organic Frameworks through Ionic Linker Installation. *J. Am. Chem. Soc.* **2019**, *141* (7), 3129–3136.
- (32) Pang, J.; Di, Z.; Qin, J. S.; Yuan, S.; Lollar, C. T.; Li, J.; Zhang, P.; Wu, M.; Yuan, D.; Hong, M.; Zhou, H. C. Precisely Embedding Active Sites into a Mesoporous Zr-Framework through Linker Installation for High-Efficiency Photocatalysis. *J. Am. Chem. Soc.* **2020**, *142* (35), 15020–15026.
- (33) Chen, C. X.; Wei, Z. W.; Jiang, J. J.; Zheng, S. P.; Wang, H. P.; Qiu, Q. F.; Cao, C. C.; Fenske, D.; Su, C. Y. Dynamic Spacer Installation for Multirole Metal-Organic Frameworks: A New Direction toward Multifunctional MOFs Achieving Ultrahigh Methane Storage Working Capacity. *J. Am. Chem. Soc.* **2017**, *139* (17), 6034–6037.
- (34) Chen, C. X.; Wei, Z.; Jiang, J. J.; Fan, Y. Z.; Zheng, S. P.; Cao, C. C.; Li, Y. H.; Fenske, D.; Su, C. Y. Precise Modulation of the Breathing Behavior and Pore Surface in Zr-MOFs by Reversible Post-Synthetic Variable-Spacer Installation to Fine-Tune the Expansion Magnitude and Sorption Properties. *Angew. Chem., Int. Ed.* **2016**, *55* (34), 9932–9936.
- (35) Berseneva, A. A.; Martin, C. R.; Galitskiy, V. A.; Ejegbavwo, O. A.; Leith, G. A.; Ly, R. T.; Rice, A. M.; Dolgoplova, E. A.; Smith, M. D.; Zur Loye, H. C.; DiPrete, D. P.; Amoroso, J. W.; Shustova, N. B. "Boarding-Up": Radiation Damage and Radionuclide Leaching Kinetics in Linker-Capped Metal-Organic Frameworks. *Inorg. Chem.* **2020**, *59*, 179–183.
- (36) Yuan, S.; Chen, Y. P.; Qin, J. S.; Lu, W.; Zou, L.; Zhang, Q.; Wang, X.; Sun, X.; Zhou, H. C. Linker Installation: Engineering Pore Environment with Precisely Placed Functionalities in Zirconium MOFs. *J. Am. Chem. Soc.* **2016**, *138* (28), 8912–8919.
- (37) Li, J.; Yuan, S.; Qin, J.-S.; Pang, J.; Zhang, P.; Zhang, Y.; Huang, Y.; Drake, H. F.; Liu, W. R.; Zhou, H.-C. Stepwise Assembly of Turn-on Fluorescence Sensors in Multicomponent Metal–Organic Frameworks for inVitrO Cyanide Detection. *Angew. Chem., Int. Ed.* **2020**, *59* (24), 9319–9323.
- (38) Chen, L.; Wang, L.; Jing, X.; Wang, F. Color tuning of Novel 2,1,3-Naphthothiadiazole and 2,1,3-Benzoselenadiazole based D-A-D' Type dopants to realize highly efficient saturated red emission in non-polar solvents. *J. Mater. Chem.* **2011**, *21* (28), 10265–10267.
- (39) Wei, P.; Duan, L.; Zhang, D.; Qiao, J.; Wang, L.; Wang, R.; Dong, G.; Qiu, Y. A new type of light-emitting naphtho[2,3-c][1,2,5]thiadiazole derivatives: synthesis, photophysical characterization and transporting properties. *J. Mater. Chem.* **2008**, *18* (7), 806–818.
- (40) Benson, S.; Fernandez, A.; Barth, N. D.; deMoliner, F.; Horrocks, M.H.; Herrington, C.S.; Abad, J.L.; Delgado, A.; Kelly, L.; Chang, Z.; Feng, Y.; Nishiura, M.; Hori, Y.; Kikuchi, K.; Vendrell, M. SCOTfluors: Small, Conjugatable, Orthogonal, and Tunable Fluorophores for In Vivo Imaging of Cell Metabolism. *Angew. Chem., Int. Ed.* **2019**, *58* (21), 6911–6915.
- (41) Angioni, E.; Marshall, R. J.; Findlay, N. J.; Bruckbauer, J.; Breig, B.; Wallis, D. J.; Martin, R. W.; Forgan, R. S.; Skabara, P. J. Implementing fluorescent MOFs as down-converting layers in hybrid light-emitting diodes. *J. Mater. Chem. C* **2019**, *7* (8), 2394–2400.
- (42) 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*, 10547–10552.
- (43) 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. *Angew. Chem., Int. Ed.* **2021**, *60*, 25048–25054.



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