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Well-defined chiral dinuclear copper-catalyzed tandem asymmetric propargylic amination–carboxylative cyclization sequence toward chiral 2-oxazolidinone derivatives†

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We report a novel strategy for the synthesis of chiral 2-oxazolidinones *via* a dinuclear copper-catalyzed asymmetric propargylic amination–carboxylative cyclization sequence of propargylic esters with nucleophilic alkyl amines under ambient pressure of carbon dioxide. A variety of chiral 2-oxazolidinones featuring an exocyclic methylene moiety was obtained in good yields with high enantioselectivities *via* a one-pot operation.

Introduction

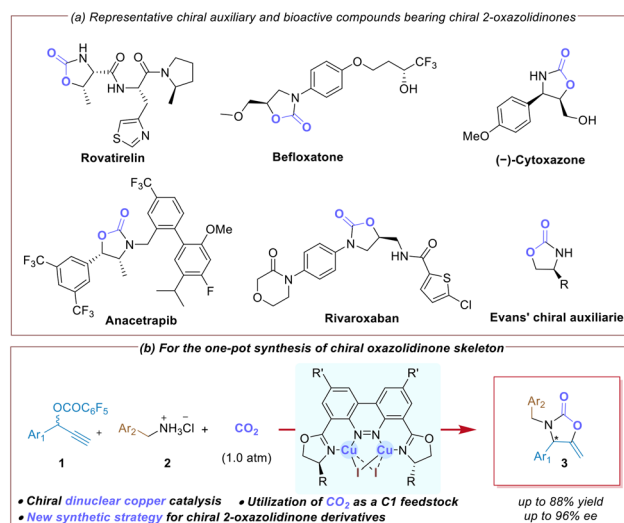
Five-membered heterocyclic compounds like 2-oxazolidinones have found wide ranging applications in medicinal chemistry, organic synthesis and agrochemistry (Scheme 1a).¹ Moreover, chiral 2-oxazolidinones have been shown to be of great significance in the realm of asymmetric synthesis, serving as a versatile class of chiral auxiliaries or ligands in the stereoselective synthesis of enantioenriched compounds.² Therefore, the efficient synthesis of chiral 2-oxazolidinones and their derivatives is of great interest in organic chemistry and medicinal sciences.³

Utilization of carbon dioxide (CO₂) as an inexpensive, non-toxic, and renewable C1 feedstock has attracted attention in the past decades.⁴ A variety of methods has been developed for the synthesis of achiral 2-oxazolidinones through the cyclization of propargylamines and carbon dioxide.⁵ However, the

use of CO₂ in catalytic asymmetric tandem reactions for the synthesis of chiral 2-oxazolidinones in one pot is largely underdeveloped.^{6,7} In this context, two elegant methods have been developed for the synthesis of chiral *N*-aryl 2-oxazolidinones based on a tandem process, including the synthesis of chiral propargylamines from an asymmetric aldehyde–alkyne–amine (A³) coupling reaction⁶ or an asymmetric transfer hydrogenation of alkynyl ketimines,⁷ followed by a carboxylative cyclization with CO₂. However, the synthesis of chiral 2-oxazolidinones bearing an exocyclic methylene motif has been less explored. Therefore, the development of a novel catalytic strat-

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Scheme 1 Asymmetric propargylic amination–carboxylative cyclization sequence toward chiral 2-oxazolidinone derivatives.



egy for the asymmetric synthesis of chiral 2-oxazolidinones derivatives is still highly desirable.³

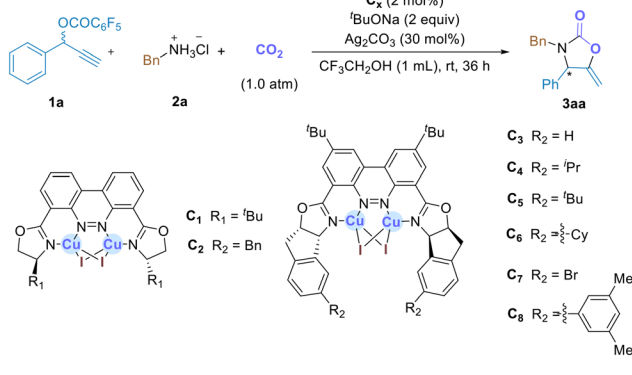
Although various bi/multi-nuclear copper complexes have been reported,⁸ their applications in asymmetric catalysis are still much less developed.⁹ Recently, we disclosed the successful development of a series of binuclear copper catalysts¹⁰ based on chiral benzo[*c*]cinnoline dioxazoline frameworks,¹¹ and their applications in catalytic asymmetric propargylic substitution reactions. Since van Maarseveen and Nishibayashi's pioneering work in 2008,¹² copper-catalyzed asymmetric propargylic amination of propargylic esters has been an efficient method for the synthesis of chiral propargyl amines.¹³ Herein, we report a novel strategy for the synthesis of chiral 2-oxazolidinones *via* a dinuclear copper-catalyzed asymmetric propargylic amination–carboxylative cyclization sequence of propargylic esters with alkyl amine hydrochlorides under an ambient pressure of carbon dioxide (Scheme 1b).¹⁴ A variety of chiral 2-oxazolidinones featuring an exocyclic methylene motif and a *N*-alkyl group was obtained in good yields with excellent enantioselectivities.

Results and discussion

Reaction development and scope

The studies were initiated by taking the reaction of propargyl carbonate (**1a**) with benzylamine hydrochloride (**2a**) under an atm of CO₂ as the model reaction and the feasibility of the proposed asymmetric propargylic amination–carboxylative cyclization sequence using the binuclear Cu complexes **C**₁–**C**₈ as catalysts was investigated. A careful survey of the reaction parameters using catalyst **C**₁ revealed that the reaction proceeded well in CF₃CH₂OH at room temperature for 36 h in the presence of ^tBuONa (2.0 equiv.) and Ag₂CO₃ (30 mol%) as additives, affording the desired product **3aa** in 51% yield with 73% ee (Table 1, entry 1). Under otherwise identical conditions, other bicopper catalysts, **C**₂–**C**₈, with different substituents on the oxazoline units or the cinnoline backbone of the ligands were subsequently evaluated in the reaction (Table 1, entries 2–8). The reaction catalyzed by **C**₂, with a benzyl group on the oxazoline unit, gave product **3aa** in 54% yield with 70% ee (entry 2). To our delight, upon using catalyst **C**₃ with the ligand derived from 2-aminoindanol, the desired product **3aa** was obtained with an improved ee value of 79% (entry 3). The reaction using catalyst **C**₄, with increased steric hindrance of the oxazoline units, led to a significant improvement in the ee to 85% (entry 4). Using catalyst **C**₅ featuring further enhanced steric hindrance of the oxazolyl moiety, the ee value of **3aa** was increased to 87% (entry 5). Proceeding further by using **C**₆ bearing cyclohexyl groups on the indanyl scaffold as the catalyst, the reaction afforded **3aa** in good isolated yield (64%) with excellent enantioselectivity (91% ee, entry 6). However, the introduction of an electron-withdrawing (–Br) group on the indanyl scaffold of catalyst **C**₇ significantly decreased the enantioselectivity of the reaction (entry 7). In addition, catalyst **C**₈, with large steric hindrance on the indenyl scaffold, was

Table 1 Investigation of the dinuclear copper-catalyzed asymmetric propargylic amination–carboxylative cyclization sequence^a



Entry	Cat.	Yield ^b (%)	ee ^c (%)
1	C ₁	51	73 (<i>S</i>)
2	C ₂	54	70 (<i>S</i>)
3	C ₃	49	79 (<i>R</i>)
4	C ₄	64	85 (<i>R</i>)
5	C ₅	59	87 (<i>R</i>)
6	C ₆	70 (64) ^d	91 (<i>R</i>)
7	C ₇	54	65 (<i>R</i>)
8	C ₈	47	70 (<i>R</i>)

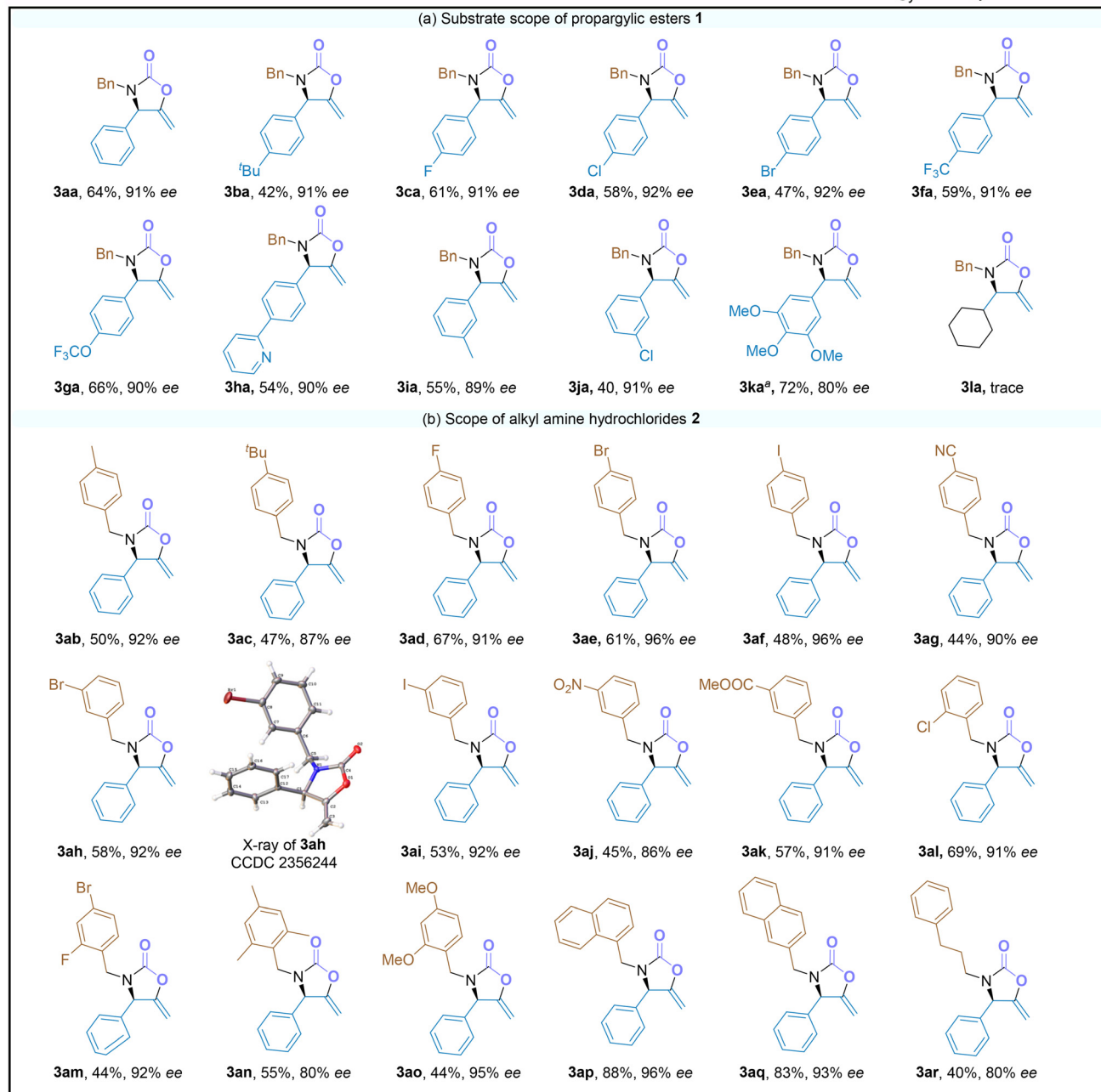
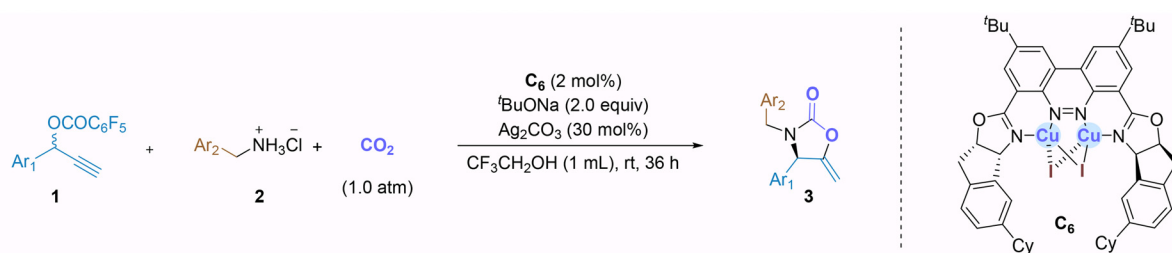
^a Unless otherwise noted, reaction conditions are as follows: **1a** (0.1 mmol), **2a** (0.15 mmol), ^tBuONa (2.0 equiv.), Ag₂CO₃ (30 mol%), **C**_x (2 mol%), CF₃CH₂OH (1 mL), rt, 36 h. ^b ¹H NMR yield using mesitylene as the internal standard. ^c The ee value of **3aa** was determined by HPLC on a chiral column IA. ^d Isolated yield.

also tested, resulting in poor catalytic performance (47% yield, 70% ee) (entry 8). Furthermore, various silver salts had similar impact on the reaction and Ag₂CO₃ was found to be optimal for the reaction (see the ESI† for reaction details). In addition, free benzylamine was also tested under the optimized conditions (as shown in entry 6), and the desired product was obtained in 74% yield with slightly lower ee (88%). In comparison to free amines, amine hydrochloride salts present a more appealing option due to their widespread commercial availability, cost-effectiveness, and relative stability under atmospheric conditions.¹⁵

Reaction scope

Under the optimized reaction conditions, the scope of propargyl carbonates **1** was first explored in the reaction with benzylamine hydrochloride **2a**, and the results are shown in Scheme 2a. The propargyl carbonates bearing either electron-donating (–^tBu) or electron-withdrawing (–F, Cl, Br, CF₃, –OCF₃ and pyridine-containing carbonate) substituents at the *para*-position of the aryl group reacted smoothly with **2a**, affording the corresponding 2-oxazolidinones **3ba**–**3ha** in 42–66% yields with 90–92% ee. Substrates bearing *meta*-methyl, *meta*-chloro, and 3,4,5-trimethoxy substituted arenes were also amenable to the procedure, and the reactions provided **3ia**–**3ka** in good yields (40–72%) with 80–91% ee. However, the reactions using the cycloalkyl substituted propargylic carbonate **1l** only provided a trace amount of the corresponding product **3la**.





Scheme 2 Substrate scope. Reaction conditions: unless otherwise noted, all reactions were carried out using **1** (0.1 mmol), **2** (0.15 mmol), *t*BuONa (2.0 equiv.), Ag₂CO₃ (30 mol%), **C₆** (2.0 mol%), CF₃CH₂OH (1.0 mL), rt, 36 h. ^a Leaving group of the propargyl substrate = OBoc.

Subsequently, the scope of alkyl amines hydrochloride **2** was further evaluated in the reactions with propargyl carbonate **1a** (Scheme 2b). To our delight, this catalytic system exhibi-

ted good tolerance toward various hydrochloride salts of alkyl amines. For instance, the reactions of benzylamines bearing either electronic donating (–Me, and –*t*Bu) or withdrawing (–F,



–Br, –I and –CN) groups on the phenyl ring afforded the corresponding products **3ab–3ag** in 44–67% yields with good enantioselectivities (87–96% ee). Changing the substituents of the benzylamines from the *para*- to *meta*- or *ortho*-position had no negative effect on the catalysis, smoothly leading to products **3ah–3al** in 45–69% yields with 86–92% ee. The absolute configuration of **3ah** was established as (*R*) by X-ray crystallography (CCDC 2356244[†]), while those of other chiral 2-oxazolidinone products were assigned by analogy. The catalytic system also turned out to be effective for the reactions of poly-substituted benzylamines **2m–2o**, giving the corresponding products **3am–3ao** in 44–55% yields with 80–95% ee. Furthermore, amine substrates containing an α - or a β -naphthyl group (**2p** and **2q**) were compatible with the protocol, and the reactions gave the corresponding products **3ap** and **3aq** in 83–88% yields with 93–96% ee. In addition, a primary amine hydrochloride bearing a long alkyl chain, such as **2r**, was also a suitable substrate, leading to the formation of the desired 2-oxazolidinone **3ar** in 40% yield with 80% ee. Notably, a variety of important functional groups, including –OMe, –F, –Br, –Cl, –I, –CF₃, –OCF₃, –CO₂Me, –CN, and –NO₂, was tolerated in the reaction, and the corresponding products showed good compatibility for downstream transformations.

Synthetic applications and control experiments

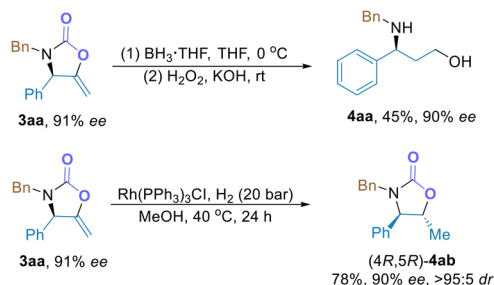
5-Methylene 2-oxazolidinones are useful chiral building blocks, as demonstrated by a two-step transformation of **3aa** to the synthetically useful chiral γ -amino alcohol **4aa** without any erosion of ee value (Scheme 3a). In addition, catalytic

hydrogenation of the exocyclic C=C double bond of **3aa** using Rh(PPh₃)₃Cl as the catalyst provided (4*R*,5*R*)-**4ab** in high yield (78%) with excellent diastereoselectivity (>95:5 dr). To gain an insight into the reaction mechanism, control experiments were carried out (Scheme 3b). Under otherwise standard conditions, the reaction of **1a** and **2a** in the absence of Ag₂CO₃ delivered the target product **3aa** in a low yield of only 21% with 91% ee, along with the generation of a substantial amount of **3aa'** with similar ee value (66%, 90% ee), suggesting that Ag₂CO₃ might promote the carboxylative cyclization of **3aa'** in the title reaction. This was confirmed by the reaction of the intermediate **3aa'** with CO₂ and without Ag₂CO₃ or the Cu catalyst; in this case, the cyclization product **3aa** was formed in only 19% yield. In contrast, the reaction of intermediate **3aa'** with CO₂ in the presence of Ag₂CO₃ or the binuclear Cu catalyst gave **3aa** in significantly improved yields of 74% and 70%, respectively. These results indicated that the title reaction is a tandem binuclear Cu-catalyzed asymmetric propargylic amination and Ag₂CO₃ promoted the carboxylative cyclization process. The copper catalyst in the first step may also have positive effect on the cyclization process. In addition, the enantioselectivity of **3aa** was determined in the propargylic amination step.

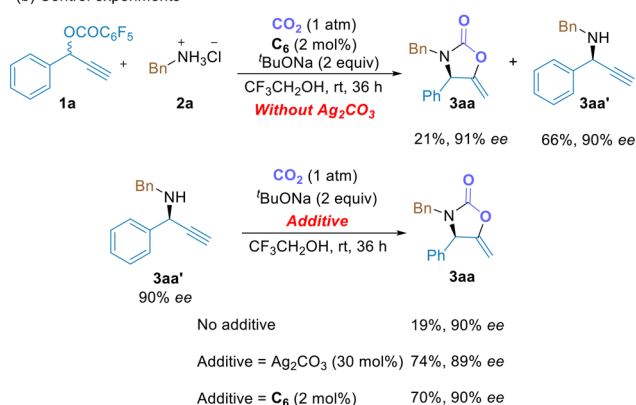
Proposed transition state model

Based on the X-ray crystallographic structure of product **3ah** and previous computational studies by our group,¹⁰ we proposed a stereochemical model to rationalize the observed chiral induction of the system using catalyst **C₁** (Scheme 4). Due to the large steric bulkiness of the –^{*t*}Bu and the –OCOC₆F₅ moieties located on the upper part of the ligand plane, the nucleophilic alkyl amines would preferentially attack the terminal carbon of the allene moiety from the bottom side. Subsequent carboxylative cyclization of the resulting chiral propargylamine with CO₂ would form the cycloadduct (*S*)-**3aa** with retention of the stereochemistry, which is consistent with the results obtained using **C₁** as the catalyst.

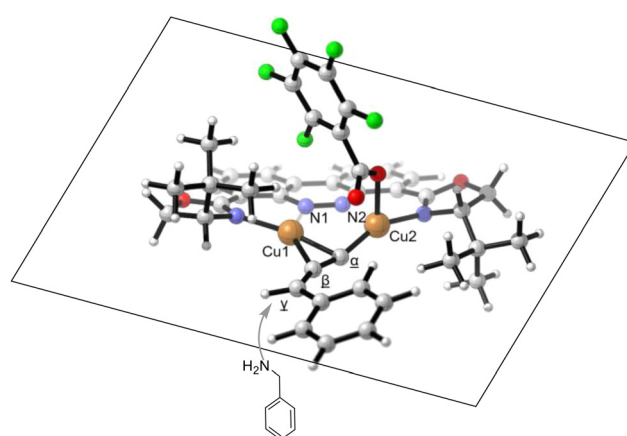
(a) Synthetic applications



(b) Control experiments



Scheme 3 Synthetic applications and control experiments.



Scheme 4 Proposed chiral induction model based on the catalyst **C₁**.



Conclusions

In summary, we have developed an efficient dinuclear copper-catalyzed asymmetric propargylic amination–carboxylative cyclization sequence of propargylic esters with alkyl amine hydrochlorides and CO₂, affording a variety of chiral 2-oxazolidinones bearing an exocyclic methylene moiety in good yields with high enantioselectivities.

Author contributions

Y. L., Q. C., and X. W. directed the project; Y. L., P. L., Z. F., L. S. and Q. C. performed all the experiments and analyzed all the data; Y. L., Q. C. and X. W. wrote the manuscript with contributions from all authors.

Data availability

The data supporting this article have been included as part of the ESI.[†]

Conflicts of interest

There are no conflicts to declare.

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References

- (a) M. R. Barbachyn and C. W. Ford, Oxazolidinone Structure–Activity Relationships Leading to Linezolid, *Angew. Chem., Int. Ed.*, 2003, **42**, 2010–2023; (b) T. A. Mukhtar and G. D. Wright, Streptogramins, Oxazolidinones, and Other Inhibitors of Bacterial Protein Synthesis, *Chem. Rev.*, 2005, **105**, 529–542.
- (a) G. Diaz-Muñoz, I. L. Miranda, S. K. Sartori, D. Cristina Rezende and M. Alves Nogueira Diaz, Use of chiral auxiliaries in the asymmetric synthesis of biologically active compounds: A review, *Chirality*, 2019, **31**, 776–812; (b) L. Y. Chen and P. Q. Huang, Evans' Chiral Auxiliary-Based Asymmetric Synthetic Methodology and Its Modern Extensions, *Eur. J. Org. Chem.*, 2024, 1–25; (c) V. Zadsirjan and M. M. Heravi, Oxazolidinones as Chiral Auxiliaries in the Asymmetric 1,4-Conjugate Addition Reaction Applied to the Total Synthesis of Natural Products: A Supplemental Mini-Review, *Curr. Org. Synth.*, 2018, **15**, 3–20; (d) E. Nicolás, K. C. Russell and V. J. Hruby, Asymmetric 1,4-addition of organocuprates to chiral α , β -unsaturated *N*-acyl-4-phenyl-2-oxazolidinones: a new approach to the synthesis of chiral β -branched carboxylic acids, *J. Org. Chem.*, 1993, **58**, 766–770; (e) M. T. Crimmins and A. L. Choy, An Asymmetric Aldol-Ring-Closing Metathesis Strategy for the Enantioselective Construction of Oxygen Heterocycles: An Efficient Approach to the Enantioselective Synthesis of (+)-Laurencin, *J. Am. Chem. Soc.*, 1999, **121**, 5653–5660; (f) A. Padarti, D. Kim and H. Han, Highly Stereoselective 2-Oxonio-Cope Rearrangement: A Platform Enabling At-Will Control of Regio-, Enantio-, and Diastereoselectivity in the Vinylogous Aldol Reactions of Aldehydes, *Org. Lett.*, 2018, **20**, 756–759; (g) V. Vigneswaran, S. N. MacMillan and D. C. Lacy, β -Amino Phosphine Mn Catalysts for 1,4-Transfer Hydrogenation of Chalcones and Allylic Alcohol Isomerization, *Organometallics*, 2019, **38**, 4387–4391; (h) J. M. Fraile, J. I. García, C. I. Herrerías, J. A. Mayoral, O. Reiser, A. Socuyllos and H. Werner, The Role of Binding Constants in the Efficiency of Chiral Catalysts Immobilized by Electrostatic Interactions: The Case of Azabis(oxazoline)–Copper Complexes, *Chem. – Eur. J.*, 2004, **10**, 2997–3005.
- (a) F. Y. Wang, T. L. Yang, T. Wu, L. S. Zheng, C. C. Yin, Y. J. Shi, X.-Y. Ye, G. Q. Chen and X. M. Zhang, Asymmetric Transfer Hydrogenation of α -Substituted- β -Keto Carbonitriles via Dynamic Kinetic Resolution, *J. Am. Chem. Soc.*, 2021, **143**, 2477–2483; (b) N. S. Barta, D. R. Sidler, K. B. Somerville, S. A. Weissman, R. D. Larsen and P. J. Reider, Practical Modifications and Applications of the Sharpless Asymmetric Aminohydroxylation in the One-Pot Preparation of Chiral Oxazolidin-2-ones, *Org. Lett.*, 2000, **2**, 2821–2824; (c) C. G. Espino and J. Du Bois, A Rh-Catalyzed C-H Insertion Reaction for the Oxidative Conversion of Carbamates to Oxazolidinones, *Angew. Chem., Int. Ed.*, 2001, **40**, 598–600; (d) L. E. Overman and T. P. Remarchuk, Catalytic Asymmetric Intramolecular Aminopalladation: Enantioselective Synthesis of Vinyl-Substituted 2-Oxazolidinones, 2-Imidazolidinones, and 2-Pyrrolidinones, *J. Am. Chem. Soc.*, 2002, **124**, 12–13; (e) Y. Cui and C. He, A Silver-Catalyzed Intramolecular Amidation of Saturated C-H Bonds, *Angew. Chem., Int. Ed.*, 2004, **43**, 4210–4212; (f) D. B. Berkowitz and G. Maiti, Following an ISES Lead: The First Examples of Asymmetric Ni (0)-Mediated Allylic Amination, *Org. Lett.*, 2004, **6**, 2661–2664; (g) H. Lebel, K. Huard and S. Lectard, *N*-Tosyloxycarbamates as a Source of Metal Nitrenes: Rhodium-Catalyzed C-H Insertion and Aziridination Reactions, *J. Am. Chem. Soc.*, 2005, **127**, 14198–14199; (h) D. N. Barman and K. M. Nicholas, Copper-Catalyzed Intramolecular C–H Amination, *Eur. J. Org. Chem.*, 2011, 908–911; (i) Y. Fukata, K. Asano and S. Matsubara,



- Procedure-Controlled Enantioselectivity Switch in Organocatalytic 2-Oxazolidinone Synthesis, *J. Am. Chem. Soc.*, 2013, **135**, 12160–12163; (j) Q. L. Wang, X. F. Tan, Z. Y. Zhu, X. Q. Dong and X. M. Zhang, New synthetic strategy for chiral 2-oxazolidinones derivatives via rhodium-catalyzed asymmetric hydrogenation, *Tetrahedron Lett.*, 2016, **57**, 658–662; (k) W. Li, M. Wollenburg and F. Glorius, Enantioselective synthesis of 2-oxazolidinones by ruthenium(II)-NHC-catalysed asymmetric hydrogenation of 2-oxazolones, *Chem. Sci.*, 2018, **9**, 6260–6263; (l) Y. H. Liu, Z. Y. Yi, X. L. Yang, H. Wang, C. C. Yin, M. Y. Wang, X. Q. Dong and X. M. Zhang, Efficient Access to Chiral 2-Oxazolidinones via Ni-Catalyzed Asymmetric Hydrogenation: Scope Study, Mechanistic Explanation, and Origin of Enantioselectivity, *ACS Catal.*, 2020, **10**, 11153–11161; (m) P. K. Yu, D. Y. Chen, Y. W. Liu, C. C. Yin, Q. X. Liu and H. F. Zhou, Synthesis of Chiral 2-Oxazolidinones by Ruthenium-Catalyzed Asymmetric Transfer Hydrogenation of 2-Oxazolones, *Adv. Synth. Catal.*, 2023, **365**, 1–7.
- 4 (a) D. M. D'Alessandro, B. Smit and J. R. Long, Carbon Dioxide Capture: Prospects for New Materials, *Angew. Chem., Int. Ed.*, 2010, **49**, 6058–6082; (b) M. Cokoja, C. Bruckmeier, B. Rieger, W. A. Herrmann and F. E. Kühn, Transformation of Carbon Dioxide with Homogeneous Transition-Metal Catalysts: A Molecular Solution to a Global Challenge?, *Angew. Chem., Int. Ed.*, 2011, **50**, 8510–8537; (c) M. Y. He, Y. H. Sun and B. X. Han, Green Carbon Science: Scientific Basis for Integrating Carbon Resource Processing, Utilization, and Recycling, *Angew. Chem., Int. Ed.*, 2013, **52**, 9620–9633; (d) E. V. Kondratenko, G. Mul, J. Baltrusaitis, G. O. Larrazábal and J. Pérez-Ramírez, Status and perspectives of CO₂ conversion into fuels and chemicals by catalytic, photocatalytic and electrocatalytic processes, *Energy Environ. Sci.*, 2013, **6**, 3112–3135; (e) M. Aresta, A. Dibenedetto and A. Angelini, Catalysis for the Valorization of Exhaust Carbon: from CO₂ to Chemicals, Materials, and Fuels. Technological Use of CO₂, *Chem. Rev.*, 2014, **114**, 1709–1742; (f) K. Sekine and T. Yamada, Silver-catalyzed carboxylation, *Chem. Soc. Rev.*, 2016, **45**, 4524–4532; (g) J. H. Ye, T. Ju, H. Huang, L. L. Liao and D. G. Yu, Radical Carboxylative Cyclizations and Carboxylations with CO₂, *Acc. Chem. Res.*, 2021, **54**, 2518–2531.
- 5 (a) S. F. Cai, H. R. Li and L. N. He, Bifunctionalization of unsaturated bonds via carboxylative cyclization with CO₂: a sustainable access to heterocyclic compounds, *Green Chem.*, 2021, **23**, 9334–9347; (b) X. Yang, L. K. Xu, Y. Q. Zhu, S. J. Zhang, G. W. Jia and J. Du, Efficient fabrication of oxazolidinones for the carboxylative cyclization with carbon dioxide, *J. CO₂ Util.*, 2023, **74**, 102531–102553; (c) Z. Zhang, J. H. Ye, D. S. Wu, Y. Q. Zhou and D. G. Yu, Synthesis of Oxazolidin-2-ones from Unsaturated Amines with CO₂ by Using Homogeneous Catalysis, *Chem. – Asian J.*, 2018, **13**, 2292–2306; (d) C. K. Ran, H. Huang, X. H. Li, W. Wang, J. H. Ye, S. S. Yan, B. Q. Wang, C. Feng and D. G. Yu, Cu-Catalyzed Selective Oxy-Cyanoalkylation of Allylamines with Cycloketone Oxime Esters and CO₂, *Chin. J. Chem.*, 2020, **38**, 69–76; (e) L. Sun, J. H. Ye, W. J. Zhou, X. Zeng and D. G. Yu, Oxy-Alkylation of Allylamines with Unactivated Alkyl Bromides and CO₂ via Visible-Light-Driven Palladium Catalysis, *Org. Lett.*, 2018, **20**, 3049–3052; (f) S. Wang and C. J. Xi, Recent advances in nucleophile-triggered CO₂-incorporated cyclization leading to heterocycles, *Chem. Soc. Rev.*, 2019, **48**, 382–404; (g) M. Yoshida, T. Mizuguchi and K. Shishido, Synthesis of Oxazolidinones by Efficient Fixation of Atmospheric CO₂ with Propargylic Amines by using a Silver/1,8-Diazabicyclo [5.4.0]undec-7-ene (DBU) Dual-Catalyst System, *Chem. – Eur. J.*, 2012, **18**, 15578–15581; (h) R. M. Yuan, B. H. Wei and G. Fu, How the Coordinated Structures of Ag(I) Catalysts Affect the Outcomes of Carbon Dioxide Incorporation into Propargylic Amine: A DFT Study, *J. Org. Chem.*, 2017, **82**, 3639–3647; (i) S. Arshadi, E. Vessally, M. Sobati, A. Hosseini and A. Bekhradnia, Chemical fixation of CO₂ to N-propargylamines: A straightforward route to 2-oxazolidinones, *J. CO₂ Util.*, 2017, **19**, 120–129; (j) X. Xu, Z. T. Li, H. L. Huang, X. Jing and C. Y. Duan, A novel copper metal-organic framework catalyst for the highly efficient conversion of CO₂ with propargylic amines, *Inorg. Chem. Front.*, 2022, **9**, 3839–3844; (k) J. N. Goswami, D. Saha, U. Saha, A. Bera, M. Ouladsmane, N. Bar, S. Biswas, M. Z. Ansari and M. Dolai, Noble metal free double helix binuclear Cu(I) complex as catalyst for carboxylative cyclization of propargylamines with atmospheric carbon dioxide toward oxazolidinones synthesis under mild conditions, *Inorg. Chim. Acta*, 2024, **563**, 121926–121936; (l) F. Chen, Sh. Tao, Q. Q. Deng, D. H. Wei, N. Liu and B. Dai, Binuclear Tridentate Hemilabile Copper (I) Catalysts for Utilization of CO₂ into Oxazolidinones from Propargylic Amines, *J. Org. Chem.*, 2020, **85**, 15197–15212.
- 6 X. T. Gao, C. C. Gan, S. Y. Liu, F. Zhou, H. H. Wu and J. Zhou, Utilization of CO₂ as a C1 Building Block in a Tandem Asymmetric A³ Coupling-Carboxylative Cyclization Sequence to 2-Oxazolidinones, *ACS Catal.*, 2017, **7**, 8588–8593.
- 7 Z. Zhang, Z. H. Zhang, F. Zhou and J. Zhou, Catalytic Enantioselective Transfer Hydrogenation–Carboxylative Cyclization to 4-Fluoroalkyl 2-Oxazolidinone with CO₂ as the C1 Synthon, *Org. Lett.*, 2021, **23**, 2726–2730.
- 8 (a) C. J. Fahrni, Allylic Oxidation Catalyzed by Chiral Dinuclear Copper Complexes, *Tetrahedron*, 1998, **54**, 5465–5470; (b) C. J. Fahrni and A. Pfaltz, Synthesis of Chiral C₂-Symmetric Binucleating Ligands, *Helv. Chim. Acta*, 1998, **81**, 491–506; (c) C. J. Fahrni, A. Pfaltz, M. Neuburger and M. Zehnder, Structure and Properties of Transition-Metal Complexes with Chiral C₂-Symmetric Binucleating Ligands, *Helv. Chim. Acta*, 1998, **81**, 507–524; (d) E. Salvadeo, L. Dubois and J. M. Latour, Trinuclear copper complexes as biological mimics: Ligand designs and reactivities, *Coord. Chem. Rev.*, 2018, **374**, 345–375; (e) R. B. Ferreira and L. J. Murray, Cyclophanes as Platforms for Reactive



- Multimetallic Complexes, *Acc. Chem. Res.*, 2019, **52**, 447–455; (f) A. N. Desnoyer, A. Nicolay, P. Rios, M. S. Ziegler and T. D. Tilley, Bimetallics in a Nutshell: Complexes Supported by Chelating Naphthyridine-Based Ligands, *Acc. Chem. Res.*, 2020, **53**, 1944–1956; (g) R. Mal, N. Mittal, T. J. Emge and D. Seidel, Facile synthesis of a chiral urea bridged bisoxazoline ligand and structural characterization of its bis-copper(II)-chloride complex, *Chem. Commun.*, 2009, 7309–7311.
- 9 (a) J. Gao, J. H. Reibenspies and A. E. Martell, Structurally Defined Catalysts for Enantioselective Oxidative Coupling Reactions, *Angew. Chem., Int. Ed.*, 2003, **42**, 6008–6012; (b) W. J. Li and S. X. Qiu, A Novel D_2 -Symmetrical Chiral Tetraoxazoline Ligand for Highly Enantioselective Hydrosilylation of Aromatic Ketones, *Adv. Synth. Catal.*, 2010, **352**, 1119–1122; (c) L. Zhang, G. Yang, C. Shen, S. Arghib and W. Zhang, Chiral dinuclear phthalazine bridged bisoxazoline ligands: synthesis and application in enantioselective Cu-catalyzed conjugate addition of ZnEt_2 to enones, *Tetrahedron Lett.*, 2011, **52**, 2375–2378; (d) S. F. Zhu, B. Xu, G. P. Wang and Q. L. Zhou, Well-Defined Binuclear Chiral Spiro Copper Catalysts for Enantioselective N-H Insertion, *J. Am. Chem. Soc.*, 2012, **134**, 436–442.
- 10 Q. L. Cai, H. Q. Rao, S. J. Li, Y. Lan, K. L. Ding and X. M. Wang, Well-defined chiral dinuclear copper complexes in enantioselective propargylic substitution: For a long-standing supposition on binuclear mechanism, *Chem*, 2024, **10**, 265–282.
- 11 (a) A. L. Gavrilova and B. Bosnich, Principles of mononucleating and binucleating ligand design, *Chem. Rev.*, 2004, **104**, 349–383; (b) P. A. Vigato, V. Peruzzo and S. Tamburini, Acyclic and cyclic compartmental ligands: recent results and perspectives, *Coord. Chem. Rev.*, 2012, **256**, 953–1114; (c) A. M. Barrios and S. J. Lippard, Phthalazine-based dinucleating ligands afford dinuclear centers often encountered in metalloenzyme active sites, *Inorg. Chem.*, 2001, **40**, 1060–1064; (d) S. Brooker, Some copper and cobalt complexes of Schiff-base macrocycles containing pyridazine head units, *Eur. J. Inorg. Chem.*, 2002, **2002**, 2535–2547; (e) L. Zhang, G. Yang and W. Zhang, *China Patent CN 102464656A*, 2012; (f) R. Connon, B. Roche, B. V. Rokade and P. J. Guiry, Further developments and applications of oxazoline-containing ligands in asymmetric catalysis, *Chem. Rev.*, 2021, **121**, 6373–6521; (g) D. Das, R. Mal, N. Mittal, Z. Zhu, T. J. Emge and D. Seidel, Chiral bisoxazoline ligands designed to stabilize bimetallic complexes, *Beilstein J. Org. Chem.*, 2018, **14**, 2002–2011; (h) G. Desimoni, G. Faita and K. A. Jørgensen, C_2 -symmetric chiral bis(oxazoline) ligands in asymmetric catalysis, *Chem. Rev.*, 2006, **106**, 3561–3651; (i) Y. Z. Zhu, Z. P. Li, J. A. Ma, F. Y. Tang, L. Kang, Q. L. Zhou and A. S. C. Chan, Synthesis of chiral bis(oxazolinyl)bipyridine ligands and related helical metal complexes, *Tetrahedron: Asymmetry*, 2002, **13**, 161–165.
- 12 (a) R. J. Detz, M. M. E. Delville, H. Hiemstra and J. H. van Maarseveen, Enantioselective Copper-Catalyzed Propargylic Amination, *Angew. Chem., Int. Ed.*, 2008, **47**, 3777–3780; (b) G. Hattori, H. Matsuzawa, Y. Miyake and Y. Nishibayashi, Copper-Catalyzed Asymmetric Propargylic Substitution Reactions of Propargylic Acetates with Amines, *Angew. Chem., Int. Ed.*, 2008, **47**, 3781–3783.
- 13 (a) G. Hattori, K. Sakata, H. Matsuzawa, Y. Tanabe, Y. Miyake and Y. Nishibayashi, Copper-Catalyzed Enantioselective Propargylic Amination of Propargylic Esters with Amines: Copper–Allenylidene Complexes as Key Intermediates, *J. Am. Chem. Soc.*, 2010, **132**, 10592–10608; (b) C. Zhang, Y. H. Wang, X. H. Hu, Z. Zheng, J. Xu and X. P. Hu, Chiral Tridentate P,N,N Ligands for Highly Enantioselective Copper-Catalyzed Propargylic Amination with both Primary and Secondary Amines as Nucleophiles, *Adv. Synth. Catal.*, 2012, **354**, 2854–2858; (c) T. Mino, H. Taguchi, M. Hashimoto and M. Sakamoto, Copper-catalyzed asymmetric propargylic amination of propargylic acetates with amines using BICMAP, *Tetrahedron: Asymmetry*, 2013, **24**, 1520–1523; (d) A. Yoshida, G. Hattori, Y. Miyake and Y. Nishibayashi, Copper-Catalyzed Enantioselective Propargylic Amination of Nonaromatic Propargylic Esters with Amines, *Org. Lett.*, 2011, **13**, 2460–2463; (e) S. J. Li, J. Huang, J. Y. He, R. J. Zhang, H. D. Qian, X. L. Dai, H. H. Kong and H. Xu, Highly enantioselective copper-catalyzed propargylic amination to access N-tethered 1,6-enynes, *RSC Adv.*, 2020, **10**, 38478–38483; (f) Z. Zhang, Y. Sun, Y. Gong, D. L. Tang, H. Luo, Z. P. Zhao, F. Zhou, X. Wang and J. Zhou, Enantioselective propargylic amination and related tandem sequences to α -tertiary ethynylamines and azacycles, *Nat. Chem.*, 2024, **16**, 521–532; (g) J. S. Ma, H. Y. Lu, Y. W. Chen, W. C. Zhao, Y. Z. Sun, R. P. Li, H. X. Wang, G. Q. Lin and Z. T. He, Copper-catalysed convergent regio- and enantioselective alkynylallylic substitution, *Nat. Synth.*, 2023, **2**, 37–48; (h) D. Y. Zhang and X. P. Hu, Recent advances in copper-catalyzed propargylic substitution, *Tetrahedron Lett.*, 2015, **56**, 283–295; (i) C. H. Ding and X. L. Hou, Catalytic asymmetric propargylation, *Chem. Rev.*, 2011, **111**, 1914–1937; (j) N. Ljungdahl and N. Kann, Transitionmetal-catalyzed propargylic substitution, *Angew. Chem., Int. Ed.*, 2009, **48**, 642–644; (k) R. J. Detz, H. Hiemstra and J. H. van Maarseveen, Catalyzed propargylic substitution, *Eur. J. Org. Chem.*, 2009, 6263–6276; (l) Y. Miyake, S. Uemura and Y. Nishibayashi, Catalytic propargylic substitution reactions, *ChemCatChem*, 2009, **1**, 342–356.
- 14 During the submission of this manuscript, a similar Cu-catalyzed reaction *via* CO_2 shuttling or CO_2 fixation was independently reported: H. Li, J. S. Ma, H. Y. Lu, G. Q. Lin and Z. T. He, Asymmetric Multicomponent Propargylations *via* Carbon Dioxide Shuttling and Fixation, *ACS Catal.*, 2024, **14**, 11646–11656.
- 15 (a) W. J. Yoo and C. J. Li, Highly Efficient Oxidative Amidation of Aldehydes with Amine Hydrochloride Salts, *J. Am. Chem. Soc.*, 2006, **128**, 13064–13065; (b) S. C. Ghosh, J. S. Y. Ngiam, A. M. Seayad, D. T. Tuan, C. L. L. Chai and A. Chen, Copper-Catalyzed Oxidative Amidation of



Aldehydes with Amine Salts: Synthesis of Primary, Secondary, and Tertiary Amides, *J. Org. Chem.*, 2012, 77, 8007–8015; (c) W. L. Zhang, Y. J. Yao, Y. L. Xu, X. Y. Zhou and G. Wu, Amine hydrochloride salts as bifunctional reagents for the radical aminochlorination of maleimides,

Org. Chem. Front., 2021, 8, 5766–5770; (d) J. Huang, H. H. Kong, S. J. Li, R. J. Zhang, H. D. Qian, D. R. Li, J. Y. He, Y. N. Zheng and H. Xu, Asymmetric copper-catalyzed propargylic amination with amine hydrochloride salts, *Chem. Commun.*, 2021, 57, 4674–4677.

