Organometallic Chemistry Laboratory（2024）

Chief Scientist: Zhaomin Hou (D.Eng.)

(0) Research fields

CPR Subcommittee**:** Chemistry

Keywords: asymmetric catalysis, C-H functionalization, carbon dioxide fixation, Dinitrogen Activation, Olefin Polymerization

(1) Long-term goal of laboratory and research background

"New Catalysts, New Reactions, New Materials" -this is the main research theme at the Organometallic Chemistry Laboratory. The discovery of novel catalysts can lead to the development of unprecedented chemical reactions and the creation of innovative functional materials that cannot be synthesized by traditional methods. Our research interests cover broad areas of organometallic chemistry, which include the synthesis of new organometallic complexes having novel structures, the development of more efficient, selective catalysts for olefin polymerization and organic synthesis, and the activation and efficient utilization of small molecules. Much of our work lies at the interfaces between inorganic, organic, polymer, and materials chemistry, with an emphasis being placed on the development of our original catalysts for applications in efficient, selective chemical synthesis.

(2) Current research activities (FY2024) and plan

(A) Regio-selective polymerization via C-H activation catalyzed by organo rare-earth catalysts

Aiming towards the creation of novel high-performance polymer materials, a part of our research programs focuses on developing highly active and selective polymerization catalysts based on the unique characteristics of rare-earth metal complexes. We have achieved for the first time the synthesis of a new class of rigid stepladder polymers featuring unique spirodihydroquinoline skeletons (Fig. 1). Under the catalysis of a half-sandwich scandium catalyst, quinoline compounds bearing both an aryl substituent (e.g., phenyl or naphthyl) and an alkynyl group (e.g., $C\equiv CSiMe_3$) selectively undergo dearomative polyspiroannulation between the quinoline skeleton and the alkyne unit via ortho-C−H activation of the aryl group. This reaction efficiently yields rigid step-ladder polymers comprising a spirodihydroquinoline skeleton with a quaternary carbon stereocenter and an unprotected N–H group. Treatment of the N–H-containing polymers with an alkyl lithium reagent followed by methyl iodide leads to quantitative formation of the corresponding N-methylated polymers, which exhibit enhanced thermal stability and porosity compared to their N–H counterparts.

Future plan: We will continue to design and synthesize new organo rare-earth alkyl complexes bearing various types of monoanionic ancillary ligands and develop catalyst-controlled sequence-regular copolymerization of different olefins for the creation of novel functional polymers.

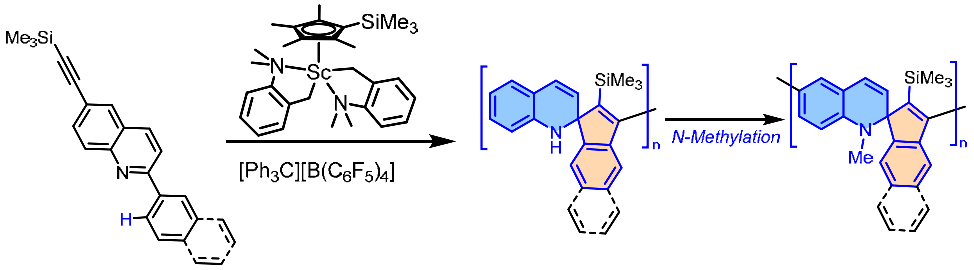

Fig. 1 Scandium-catalyzed dearomative polyspiroannulation of a quinoline skeleton and an alkyne unit via C-H activation

(B) Novel chemical transformations via C-H activation catalyzed by organo rare-earth catalysts

Chiral 1-aminoindenes are important structural components in a wide array of natural products, bioactive molecules, and functional materials. Although the [3+2] annulation of aldimines via C–H activation represents a straightforward and atom-efficient route to these scaffolds, the enantioselective version with alkynes has remained undeveloped due to the lack of suitable chiral catalysts. By using half-sandwich rare-earth catalysts, we have achieved for the first time the enantioselective [3+2] annulation of readily accessible aromatic aldimines with internal alkynes (Fig. 2). This protocol enables the synthesis of diverse multi-substituted chiral 1-aminoindene derivatives with 100% atom-efficiency, broad functional group compatibility, and excellent regio- and enantioselectivity (up to 98:2 e.r.). Specifically, a scandium catalyst, bearing a tert-butyl-substituted cyclopentadienyl (Cp) ligand, exhibited superior performance over its trimethylsilyl-substituted analog. DFT analyses revealed that an attractive noncovalent C-H···π interaction between the catalyst's tert-butyl group and the phenyl ring of the aldimine plays a crucial role in achieving high enantioselectivity, offering a new perspective beyond traditional steric-repulsion models. This work provides an efficient route to a new family of chiral 1-aminoindenes and unprecedented insights into stereocontrol for chiral Cp-ligated metal catalysts.

The regio- and stereoselective hydroalkynylation of internal alkynes with terminal alkynes is of much interest and importance as an atom-efficient route to multi-substituted 1,3-enynes but has remained rarely explored for electronically unbiased unsymmetrical substrates. In particular, the catalytic hydroalkynylation of internal homopropargyl ethers, thioethers, and tertiary amines has remained a challenge to date due to weak coordination or potential catalyst poisoning. By using half-sandwich rare-earth catalysts, we have achieved for the first time the regio- and syn-stereoselective hydroalkynylation of a wide range of such heteroatom-functionalized internal alkynes with terminal alkynes (Fig. 3). This novel synthetic protocol offers a selective and efficient route for the construction of a new family of functionalized 1,3-enynes, featuring 100% atom efficiency, broad substrate scope, and high regio- and syn-stereoselectivity (>19:1 r.r. and syn/anti). Mechanistic investigations reveal that the coordination of the substrate′s heteroatom (O, S, or N) to the rare-earth metal center is critically important for achieving high reactivity and selectivity. Remarkably, the reaction proceeds via a unique dimeric half-sandwich scandium tetraalkynyl active species, which can be recovered and reused, thus constituting the first example of a recyclable catalyst system for the hydroalkynylation of internal alkynes.

Future plan: We will continue to develop regio-, stereoselective and atom-efficient reactions based on our original rare-earth catalysts by making use of the unique activity of rare-earth alkyl species toward C−H activation and C=X insertion (X = C, O, N, S, etc.) together with the unique interaction between rare-earth metal and heteroatom.

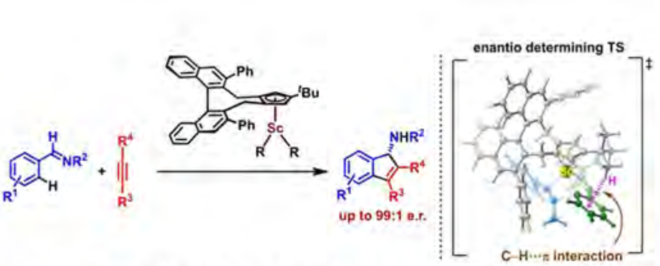

Fig. 2 Enantioselecive [3+2] Annulation of Aldimines with Alkynes

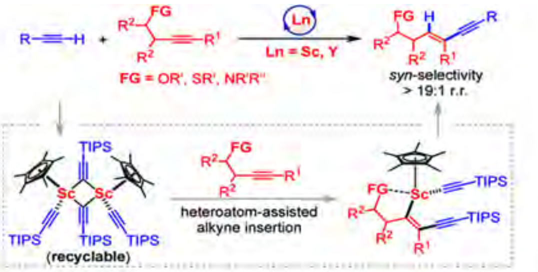

Fig. 3 Regi- and Stereoselective Hydroalkynylation Alkynes

(C) Activation and transformation of dinitrogen using metal hydride clusters

An ideal synthesis of alkyl amines would be the direct use of abundant and easily accessible molecules such as dinitrogen (N_2) and feedstock alkenes. However, this ambition remains a great challenge as it is usually difficult to simultaneously activate both N_2 and a simple alkene and combine them together through carbon–nitrogen (C–N) bond formation. Currently, the synthesis of alkyl amines relies on the use of ammonia produced through the Haber–Bosch process and prefunctionalized electrophilic carbon sources. By employing a trititanium hydride cluster bearing bulky $C_5Me_4SiMe_3$ ligands, we successfully synthesized alkylamines directly from N_2 and readily available simple alkenes (Fig. 4). This work demonstrates a new strategy for the transformation of N_2 and simple hydrocarbons into nitrogen-containing organic compounds mediated by a multinuclear hydride framework.

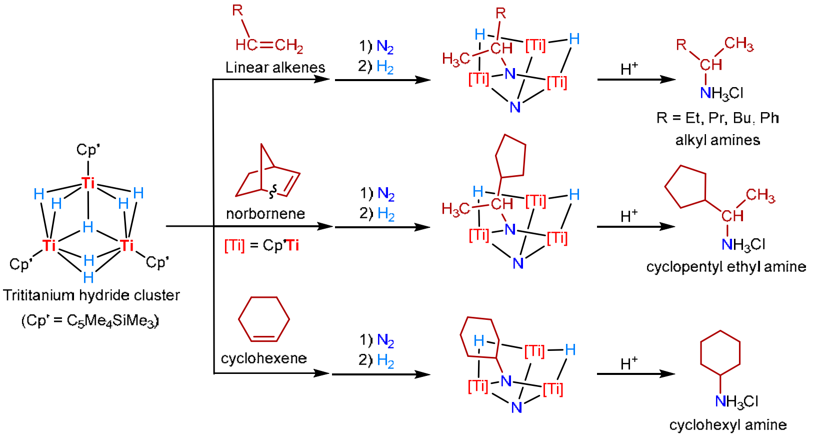

Fig.4 Alkylamine synthesis from alkenes and N_2 mediated by a trititanium hydride cluster

Future plan: We will continue to explore the potential of metal hydride clusters for the activation and transformation of various readily accessible small molecules and develop new synthetic methodologies.

(3) Members

as of March, 2024

(Chief Scientist)
Zhaomin Hou
(Senior Research Scientist)
Masayoshi Nishiura, Takanori Shima, Masanori Takimoto, Liang Zhang, Satoshi Kamiguchi

(Special Postdoctoral Researcher)
Xiaoxi Zhou
(Assistant)
Yuka Cowart
(Part-time Worker)
Keiko Nakamura

(4) Representative research achievements

1. Q. Zhuo, J. Yang, X. Zhou, T. Shima, Y. Luo, Z. Hou, "Dinitrogen Cleavage and Multicoupling with Isocyanides in a Dititanium Dihydride Framework", ***J. Am. Chem. Soc.***, *146*, 10984–10992 (2024).
2. T. Shima, Q. Zhuo, X. Zhou, P. Wu, R. Owada, G. Luo, Z. Hou, "Hydroamination of alkenes with dinitrogen and titanium polyhydrides", ***Nature***, *632*, 307-312 (2024).
3. X. Zhou, Q. Zhuo, T. Shima, X. Kang, Z. Hou, "Denitrogenative Ring-Contraction of Pyridines to a Cyclopentadienyl Skeleton at a Dititanium Hydride Framework", ***J. Am. Chem. Soc.***, *146*, 31348-31355 (2024).
4. J. Shao, L. Huang, S. Lou, A. Ohno, Y. Yamada, M. Nishiura, T. Murahashi, Z. Hou, "Synthesis of Rigid Stepladder Polymers via Scandium-Catalyzed Polyspiroannulation of Quinoline with Alkyne", ***J. Am. Chem. Soc.***, *147*,1416–1420 (2025).
5. A. Mishra, J. Hu, X. Cong, Q. Zhuo, M. Nishiura, G. Luo, Z. Hou, "Enantioselective [3+2] Annulation of Aldimines with Alkynes by Scandium-Catalyzed C−H Activation", ***Angew. Chem. Int. Ed.***, *64*, e202419567 (2025).
6. N. Hao, T. Jiao, Z. Sun, A. Mishra, Q. Zhuo, M. Nishiura, Z. Hou, X. Cong, "Regio- and Stereoselective Hydroalkynylation of Internal Alkynes with Terminal Alkynes by Half-Sandwich Rare-Earth Catalysts", ***J. Am. Chem. Soc.***, *147*, 6149–6161 (2025).

Supplementary
Laboratory Homepage
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