Pd-Catalyzed Double Decarbonylative Aryl Sulfide Synthesis through Aryl Exchange between Amides and Thioesters

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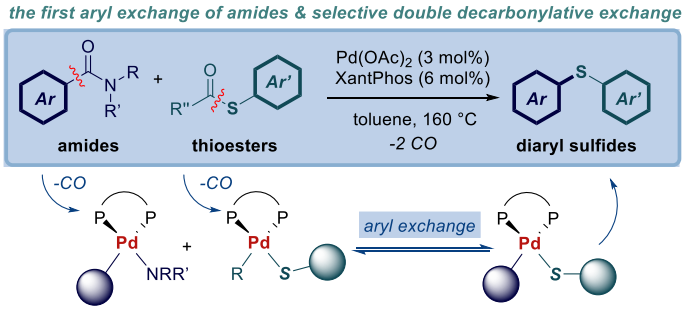


ABSTRACT: We report the palladium-catalyzed double decarbonylative synthesis of aryl thioethers by aryl exchange reaction between amides and thioesters. In this method, amides serve as aryl donors and thioesters are sulfide donors, enabling the synthesis of valuable aryl sulfides. The use of Pd/Xantphos without any additives has been identified as the catalytic system promoting the aryl exchange by C(O)–N/C(O)–S cleavages. The method is amenable to a wide variety of amides and sulfides.

Aryl sulfides represent one of the most important functional groups in organic synthesis due to the lipophilic properties of sulfur, which renders them particularly attractive as key components of bioactive compounds and functional materials.[1-2] Although the most widely utilized approach in organic synthe-sis involves transition-metal-catalyzed C–S bond cross-coupling,[3-5] a major limitation of this method is the use of toxic thiols. As a result, alternative methods for the synthesis of aryl sulfides have been developed, including intramolecular decarbonylation,[6-8] the use of alkyl sulfides as a thiol source[9] and cross-coupling with disulfides;[10] however, compared with other developments, transition-metal-catalyzed thioetherification in the absence of thiols is underdeveloped.[11]

Simultaneously, recent studies have demonstrated transi-tion-metal-catalyzed functional group exchange between two electrophiles (Figure 1A).[12-14] This approach provides valuable alternative to the traditional electrophile-nucleophile cross-coupling as it permits to avoid nucleophilic coupling partners that often result in catalyst poisoning and side processes, while maintaining the classical elementary steps in the catalytic cy-cle. The side reactions and catalyst poisoning are particularly pronounced in the reactions with thiol nucleophiles. The func-tional group exchange approach relies on careful design of the catalytic method and strong driving forces that favor the equi-librium in the appropriate direction. In this context, methods for transition-metal-catalyzed functional group exchange have been reported using Pd catalysis between aroyl chlorides and iodoarenes by Ar–C(O)Cl/Ar'–I exchange.[15-16] Subsequently, Ni-catalyzed aryl exchange between haloarenes/arenols and 3-pyridyl esters was reported by Ar–X/3-py–CO_2Ar' exchange.[17] Most recently, Yamaguchi and co-workers reported Ni-catalyzed aryl sulfide synthesis by aryl exchange between 2-pyridyl sulfides and aromatic esters by 2-py–SR/Ar–CO_2Ar' exchange (Figure 1B).[18]

In light of the report by Yamaguchi[18] and our own work,[11,19-21] we considered it appropriate to disclose our findings on the synthesis of aryl sulfides by Pd-catalyzed double decarbonylative aryl exchange between amides and thioesters (Figure 1C). In contrast to the Ni-catalyzed method,[18] there are three distinct features of our approach: (1) The reaction uses amides as Ar–C(O)X electrophiles (cf. esters), which enables to translate the aryl exchange manifold to amide bonds. Amide bonds represent key motifs in chemistry, biochemistry and biology. (2) The reaction is Pd-catalyzed (cf. Ni) which enables for a comparatively broader scope and functional group tolerance inherent to Pd catalysis.[20a]

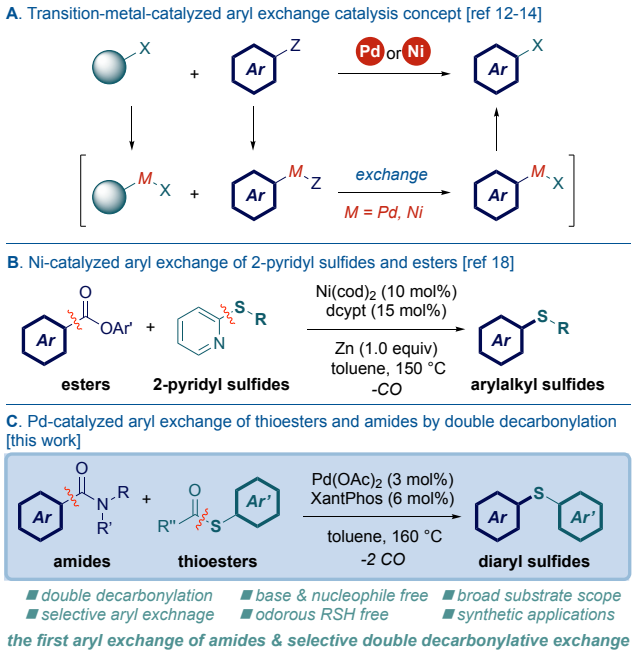


Figure 1. Aryl exchange catalysis: previous and this work.

Furthermore, Pd-catalysis enables to use well-established and broadly available ligands. (3) Finally, the reaction is compatible with various thioesters as sulfide donors (cf. 2-pyridyl sulfides).

In a broader view, the two catalytic systems should be considered in terms of complementary classes of substrates (2-py-SR vs. Ar-COSR), metal catalysts (Ni vs. Pd) and products (diaryl sulfides vs. aryl alkyl sulfides). We hypothesize that the reaction mechanism is similar to that reported by Yamaguchi and coworkers with the key difference that the reaction involves oxidative addition of the C(O)–N bond vs. C(O)–O bond and Pd(0) vs. Ni(0) (Figure 2).

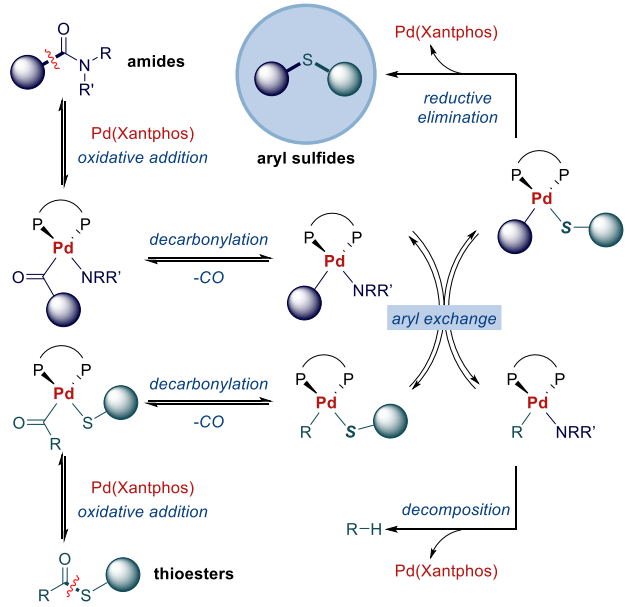
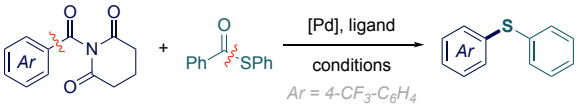


Figure 2. Possible aryl exchange mechanism.

The proposed decarbonylative thioether synthesis was first investigated using 1-(4-(trifluoromethyl)benzoyl)piperidine-2,6-dione (**1a**) and *S*-phenyl benzothioate (**2a**) as modular substrates. The key optimization results are summarized in

Table 1. Optimization of Reaction Conditions[a]



entry	[Pd]	ligand	base	yield (%)
1	$Pd(OAc)_2$	DPPP	Na_2CO_3	48
2	$Pd(OAc)_2$	DPPP	K_2CO_3	26
3	$Pd(OAc)_2$	DPPP	K_3PO_4	<2
4	$Pd(OAc)_2$	DPPP	DMAP	44
5	$Pd(OAc)_2$	DPPP	Et_3N	20
6	$Pd(OAc)_2$	DPPP	-	68
7	$Pd(OAc)_2$	DPPP	-	40
8	$Pd_2(dba)_3$	DPPF	-	56
9	$Pd(OAc)_2$	XantPhos	-	90
10	$Pd(OAc)_2$	DPPE	-	<5
11	$Pd(OAc)_2$	PCy_3	-	<5
12	$Pd(OAc)_2$	PPh_3	-	<5
13[b]	$Pd(OAc)_2$	XantPhos	-	92
14[b,c]	$Pd(OAc)_2$	XantPhos	-	85
15[b,d]	$Pd(OAc)_2$	XantPhos	-	52
16[b,e]	$Pd(OAc)_2$	XantPhos	-	67

[a]Conditions: amide (0.20 mmol), thioester (1.0 equiv), [Pd] (5 mol%), ligand (10 mol%), base (1.5 equiv), toluene (0.20 M), 160 °C, 15 h. [b][Pd] (3 mol%), ligand (6 mol%). [c]140 °C. [d]120 °C. [e]1 h.

Table 1. After extensive exploratory studies, we first discovered that a combination of $Pd(OAc)_2$/DPPP and Na_2CO_3 as a base delivered the desired aryl exchange product in 48% yield (entry 1). Interestingly, compared with conditions with various bases, base-free system provided the exchange product in an improved yield (entries 2-6). The use of additive-free condi-tions is an important consideration from a practical standpoint. Furthermore, by screening of phosphine ligands, XantPhos was identified as the optimal ligand, delivering the product in 90% yield. There is a correlation between phosphine bite angle and the reaction efficiency (Xantphos, β_n = 108°; DPPB, β_n = 94°; DPPP, β_n = 91°; DPPF, β_n = 99°; DPPE, β_n = 86°), with smaller bite angle phosphines such as DPPE completely inef-fective in the reaction (entries 6-10). Likewise, monodentate phosphines, such as PCy_3 or PPh_3 are ineffective (entries 11-12). It is important to note that the catalyst loading could be decreased to 3 mol% (entry 13), while the transformation could be well accomplished at temperature as

low as 120 °C (entries 14-15). Finally, the transformation is facile with 67% conversion achieved within 1 hour under the standard condi-tions (entry 16). Thus, the palladium catalyst can engage both Ar^1–C(O)–NR_2 and Ar^2–(CO)–SR' substrates to form the de-sired aryl exchange product Ar^1–SR' after decarbonylation.

With the optimized conditions in hand, the scope of this novel aryl exchange was investigated. As shown in Figure 3A, the method can accommodate various aromatic as well as ali-

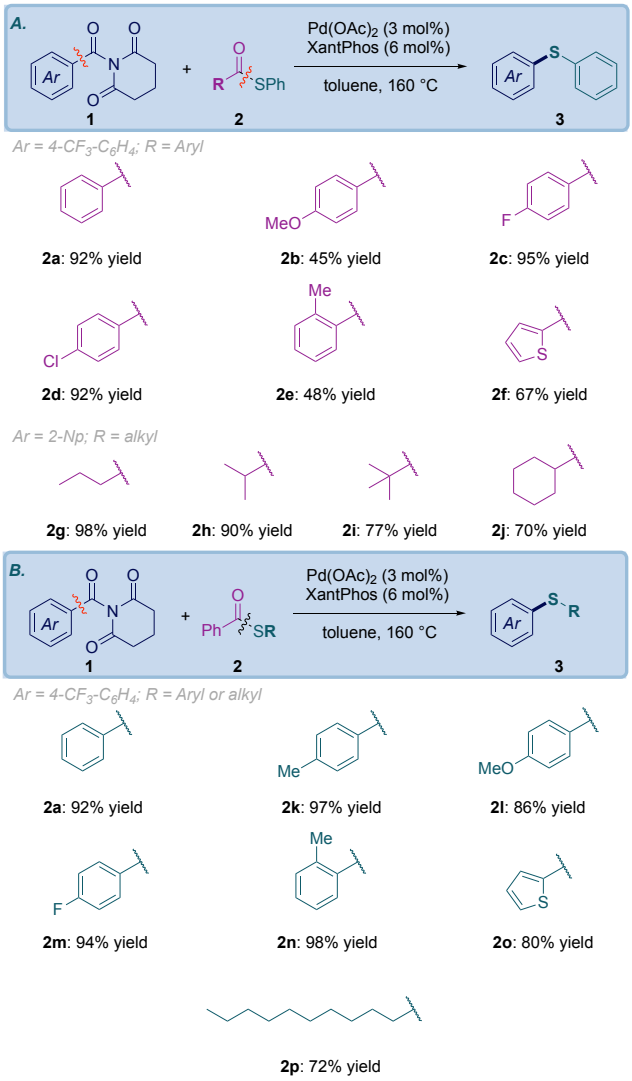


Figure 3. Thioester scope of the aryl exchange.

phatic variation of thioesters in terms of the acyl component. This is a significant difference with the protocol reported by Yamaguchi, which required 2-pyridyl sulfides to drive reduc-tive elimination towards the desired product. Furthermore, the scope of the thioester component accommodates electron-neutral (**3a**), electron-rich (**3c**), electron-deficient (**3d**), sterically-hindered (**3e**), heterocyclic (**3f**) and aliphatic (**3g**) substrates (Figure 3B). This is another difference with the Ni-protocol, which is limited to aliphatic 2-pyridyl sulfides.[18]

Next, we investigated the amide scope in this aryl exchange protocol. As shown in Figure 4A, a range of electronically-varied amides is well-tolerated in this reaction, including elec-tron-neutral (**3h-j**), electron-rich (**3k**) and electron-deficient amides (**3a**). Furthermore, this method tolerates substrates containing sensitive functional groups, such as esters (**3l**), ketones (**3m**) and chlorides (**3o-p**). Moreover, ortho-substituted amides (**3q-r**), het-erocyclic amides (**3s-t**) and even vinyl amides (**3u**) are well com-patible in this method, afford-ing aryl exchange sulfide products in 56-97% yields.

Finally, the scope of amides was investigated (Figure 4B). Var-iation of amide substitution is critically important to control the amide bond resonance ($n_N \rightarrow \pi^*_{C=O}$ conjugation),

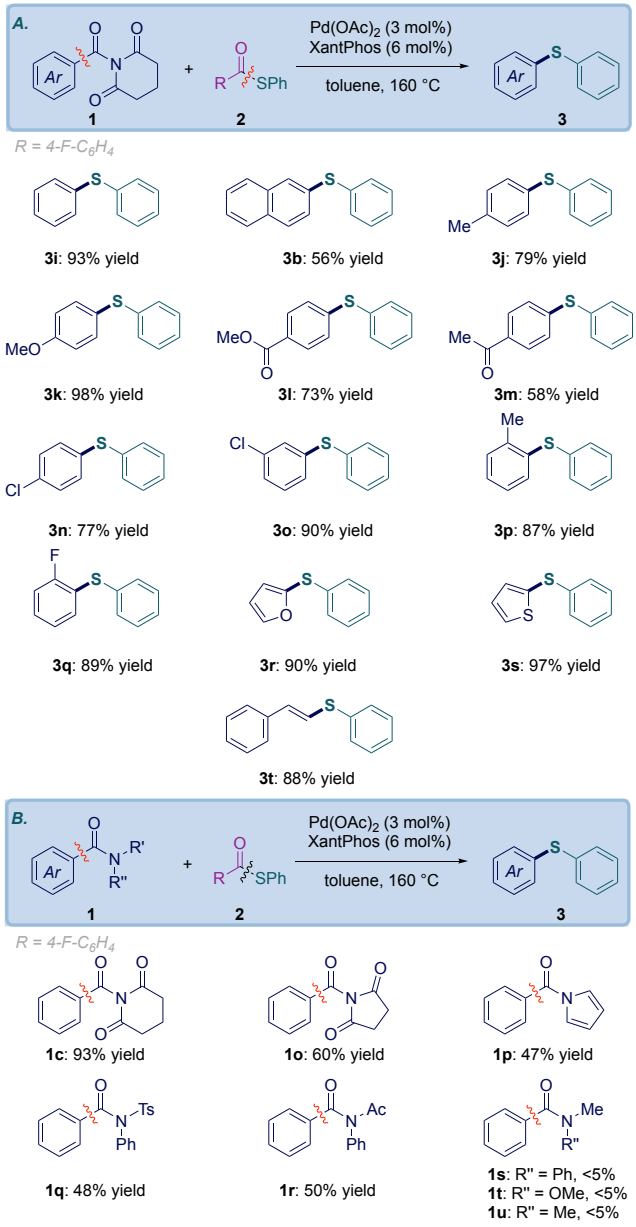


Figure 4. Amide scope of the aryl exchange.

facilitating oxidative addition of the ArC(O)–NR_2 bond to transi-tion metals, while the availability of different amides broadens the scope of reactions available by the historically challenging C(O)–NR_2 disconnection.[19] As such, we were pleased to find that this

aryl exchange reaction is not limited to *N*-acyl-glutarimides and could be extended to an array of amides with varied electronic and steric (twist) properties of the amide bond, including half-twisted *N*-acyl-succinimides (**1c**), electronically-activated *N*-acyl-pyrroles (**1d**), and easily pre-pared from 2° amides, *N*-tosyl-amides (**1e**) and *N*-acyl-amides (**1f**). As expected, unactivated amides, such as anilides (**1g**), *N*-methoxy-amides (**1h**) and dialkyl amides (**1i**) are recovered unchanged from the reaction, highlighting a valuable chemo-differentiation feature of the amide bond activation platform.

Aryl sulfides are widely used in medicinal chemistry re-search.[2] To demonstrate that this aryl exchange method should be attractive in medicinal chemistry programs, we conducted

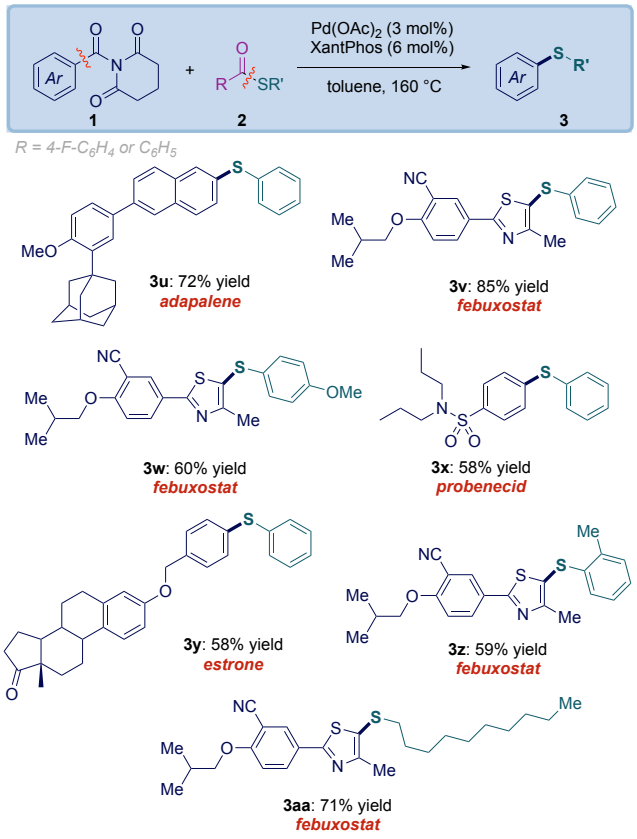


Figure 5. Late-stage aryl exchange of pharmaceuticals.

this double decarbonylative aryl sulfide synthesis in late-stage functionalization of pharmaceuticals (Figure 5). The synthesis of aryl sulfides from amides derived from *adapalene* (**3v**), *febuxostat* (**3w-x**), *probenecid* (**3y**), *estrone* (**3z**) and *febuxo-stat* (**3aa-ab**) highlights the synthetic utility of this strategy, employing readily available amides and thioesters as electro-philes for the synthesis of sulfur-containing products. Overall, this approach exhibits broad substrate scope and excellent functional group tolerance with respect to the reaction partners, including complex sub-strates.

Several additional points should be noted: (1) as expected from related exchange methods,[12-14] substrates are electronically-tuned. Electron-rich amide substrates are inherently more reactive than electron-deficient substrates, while electron-withdrawing thioesters show higher reactivity than electron-donating substrates (see SI). (2) The oxidative addition is likely reversible with the rate-limiting decomposition of ArPd(II)NR_2 intermediate or reductive elimination, while this step is necessary to regenerate Pd(0), it is speculative and no reducing agent can be identified. However, additional mechanistic studies are needed to confirm the individual steps of the reaction mechanism. (3) Further, in select cases direct decarbonylation product of thioester can be detected, however, typically, selectivity is >90:10 in all cases examined (aryl exchange vs. direct decarbonylation). (4) The thioester decomposition to make a thiol that would substitute the activated amide and then undergo decarbonylation is unlikely as control experiments in the absence of Pd indicate that thioesters are stable under these conditions (see SI). (5) At present stage of the reaction development only one representative aliphatic thiol was tested. (6) The reaction does not proceed from a thioether that has undergone decarbonylation. Future studies will be focused on expanding the substrate scope of the method, mechanistic studies, including computational investigation, and expansion to other electrophiles in this decarbonylative platform.

In conclusion, we have reported the first double decarbonylative synthesis of aryl thioethers by aryl exchange reaction between amides and thioesters. This method avoids the use of toxic and nucleophilic thiols for the synthesis of aryl sulfides by engaging amides and thioesters as electrophilic components by C(O)–N/C(O)–S cleavages. The method does not require external bases or other additives and shows broad substrate scope. Applications in the late-stage derivatization of pharma-ceuticals highlight the utility of the method in medicinal chemistry. Mechanistic studies and further investigation of decarbonylative aryl exchange reactions are ongoing and will be reported in due course.

ASSOCIATED CONTENT

Supporting Information

Experimental details, characterization data. This material is available free of charge via the Internet at http://pubs.acs.org.

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REFERENCES

(1) (a) Smith, M. B. *March's Advanced Organic Chemistry: Reactions, Mechanisms, and Structure*. (Wiley, Hoboken, **2013**). (b) Terrier, F. *Modern Nucleophilic Aromatic Substitution* (Wiley, Hoboken, **2013**). (c) Ackermann, L. *Modern Arylation Methods* (Wiley: Hoboken, **2009**).

(2) For leading reviews on sulfur-containing drugs, see: (a) Ilardi, E. A.; Vitaku E.; Njardarson, J. T. Data-Mining for Sulfur and Fluorine: An

Evaluation of Pharmaceuticals To Reveal Opportunities for Drug Design and Discovery, *J. Med. Chem.*, **2014**, *57*, 2832–2842; (b) Feng, M.; Tang, B.; Liang S. H.; Jiang, X. Sulfur Containing Scaffolds in Drugs: Synthesis and Application in Medicinal Chemistry, *Curr. Top. Med. Chem.*, **2016**, *16*, 1200–1216; (c) Beno, B. R.; Yeung, K. S.; Bartberger, M. D.; Pennington L. D.; Meanwell, N. A. A Survey of the Role of Noncovalent Sulfur Interactions in Drug Design, *J. Med. Chem.*, **2015**, *58*, 4383-4438.

(3) (a) Yus, M.; Martinez P.; Guijarro, D. Direct Transformation of Allylic and Benzylic Thiols, Thioethers, and Disulfides into Organolithium Compounds, *Synth. Commun.*, **2003**, *33*, 2365–2376; (b) Hoyle C. E.; Bowman, C. N. Thiol-Ene Click Chemistry, *Angew. Chem., Int. Ed.*, **2010**, *49*, 1540–1573; (c) Lucchi, O.; Miotti U.; Modena, G. The Pummerer Reaction of Sulfinyl Compounds, *Org. React.* **1991**, *40*, 157–184.

(4) For representative reviews of C−S bond formation, see (a) Kondo, T.; Mitsudo, T. Metal-Catalyzed Carbon-Sulfur Bond Formation. *Chem. Rev.* **2000**, *100*, 3205−3220. (b) Beletskaya, I. P.; Ananikov, V. P. Transition-Metal-Catalyzed C-S, C-Se, and C-Te Bond Formation via Cross-Coupling and Atom-Economic Addition Reactions. *Chem. Rev.* **2011**, *111*, 1596−1636.

(5) For selected methods of C−S bond-formation, see (a) Kwong, F. Y.; Buchwald, S. L. A General, Efficient, and Inexpensive Catalyst System for the Coupling of Aryl Iodides and Thiols. *Org. Lett.* **2002**, *4*, 3517−3520. (b) Fernández-Rodríguez, M. A.; Shen, Q.; Hartwig, J. F. A General and Long-Lived Catalyst for the Palladium-Catalyzed Coupling of Aryl Halides with Thiols. *J. Am. Chem. Soc.* **2006**, *128*, 2180−2181. (c) Sayah, M.; Organ, M. G. Carbon-Sulfur Bond Formation of Challenging Substrates at Low Temperature by Using Pd-PEPPSI-IPent. *Chem. - Eur. J.* **2011**, *17*, 11719−11722. (d) Wang, X.; Cuny, G. D.; Noël, T. A Mild, One-Pot Stadler-Ziegler Synthesis of Arylsulfides Facilitated by Photoredox Catalysis in Batch and Continuous-Flow. *Angew. Chem., Int. Ed.* **2013**, *52*, 7860−7864. (e) Uyeda, C.; Tan, Y.; Fu, G. C.; Peters, J. C. A New Family of Nucleophiles for Photoinduced, Copper-Catalyzed Cross-Couplings via Single-Electron Transfer: Reactions of Thiols with Aryl Halides Under Mild Conditions (0 °C). *J. Am. Chem. Soc.* **2013**, *135*, 9548−9552. (f) Saravanan, P.; Anbarasan, P. Palladium Catalyzed Aryl(alkyl)thiolation of Unactivated Arenes. *Org. Lett.* **2014**, *16*, 848-851. (g) Yin, G.; Kalvet, I.; Englert, U.; Schoenebeck, F. Fundamental Studies and Development of Nickel-Catalyzed Tri-fluoromethylthiolation of Aryl Chlorides: Active Catalytic Species and Key Roles of Ligand and Traceless MeCN Additive Revealed. *J. Am. Chem. Soc.* **2015**, *137*, 4164−4172. (h) Oderinde, M. S.; Frenette, M.; Robbins, D. W.; Aquila, B.; Johannes, J. W. Photoredox Mediated Nickel Catalyzed Cross-Coupling of Thiols with Aryl and Heteroaryl Iodides via Thiyl Radicals. *J. Am. Chem. Soc.* **2016**, *138*, 1760−1763. (i) Jouffroy, M.; Kelly, C. B.; Molander, G. A. Thioetherification via Photoredox/Nickel Dual Catalysis. *Org. Lett.* **2016**, *18*, 876−879. (j) Liu, B.; Lim, C.-H.; Miyake, G. M. Visible-Light-Promoted C-S Cross-Coupling via Intermolecular Charge Transfer. *J. Am. Chem. Soc.* **2017**, *139*, 13616−13619.

(6) For representative nickel-catalyzed intramolecular decarbonylation of thioesters, see: (a) Liu, C.; Szostak, M. Decarbonylative Thioetherification by Nickel Catalysis Using Air- and Moisture-Stable Nickel Precatalysts. *Chem. Commun.* **2018**, *54*, 2130−2133. (b) Ishitobi, K.; Isshiki, R.; Asahara, K. K.; Lim, C.; Muto, K.; Yamaguchi, J. Decarbonylative Aryl Thioether Synthesis by Ni Catalysis. *Chem. Lett.* **2018**, *47*, 756−759. (c) Ichiishi, N.; Malapit, C. A.; Wozniak, L.; Sanford, M. S. Palladium- and Nickel-Catalyzed Decarbonylative C−S Coupling to Convert Thioesters to Thioethers. *Org. Lett.* **2018**, *20*, 44−47. (d) Brigham, C. E.; Malapit, C. A.; Lalloo, N.; Sanford, M. S. Nickel-Catalyzed Decarbonylative Synthesis of Fluoroalkyl Thioethers. *ACS Catal.* **2020**, *10*, 8315−8320.

(7) For representative palladium-catalyzed intramolecular decarbonylation of thioesters, see: Cao, H.; Liu, X.; Bie, F.; Shi, Y.; Han, Y.; Yan, P.; Szostak, M.; Liu, C. General and Practical Intramolecular Decarbonylative Coupling of Thioesters via Palladium Catalysis. *Org. Chem. Front.* **2021**, *8*, 1587−1592.

(8) For representative rhodium-catalyzed intramolecular decarbonylation of thioesters, see: Cao, H.; Liu, X.; Bie, F.; Shi, Y.; Han, Y.; Yan, P.; Szostak, M.; Liu, C. Rh(I)-Catalyzed Intramolecular Decarbonylation of Thioesters. *J. Org. Chem.* **2021**, *86*, 10829-10837.

(9) (a) Mao, J.; Jia, T.; Frensch, G.; Walsh, P. J. Palladium-Catalyzed Debenzylative Cross-Coupling of Aryl Benzyl Sulfides with Aryl Bromides: Synthesis of Diaryl Sulfides. *Org. Lett.* **2014**, *16*, 5304-5307. (b) Li, Y.; Bao, G.; Wu, X.-F. Palladium-Catalyzed Intermolecular Transthioetherification of Aryl Halides with Thio- ethers and Thioesters. *Chem. Sci.* **2020**, *11*, 2187-2192.

(10) (a) Taniguchi, N.; Onami, T. Magnesium-Induced Copper-Catalyzed Synthesis of Unsymmetrical Diaryl Chalcogenide Compounds from Aryl Iodide via Cleavage of the Se-Se or S-S Bond. *J. Org. Chem.* **2004**, *69*, 915− 920. (b) Taniguchi, N. Alkyl- or Arylthiolation of Aryl Iodide via Cleavage of the S-S Bond of Disulfide Compound by Nickel Catalyst and Zinc. *J. Org. Chem.* **2004**, *69*, 6904−6906.

(11) (a) Liu, C.; Ji, C. L.; Hong, X.; Szostak, M. Palladium-Catalyzed Decarbonylative Borylation of Carboxylic Acids: Tuning Reaction Selectivity by Computation. *Angew. Chem. Int. Ed.* **2018**, *57*, 16721-16726. (b) Liu, C.; Ji, C. L.; Zhou, T.; Hong, X.; Szostak, M. Bimetallic Cooperative Catalysis for Decarbonylative Heteroarylation of Carboxylic Acids via C-O/C-H Coupling. *Angew. Chem., Int. Ed.* **2021**, *60*, 10690−10699. (c) Liu, C.; Szostak, M. Decarbonylative Sulfide Synthesis from Carboxylic Acids and Thioesters via Cross-Over C–S Activation and Acyl Capture. *Org. Chem. Front.* **2021**, *8*, 4805-4813.

(12) (a) Bhawal, B. N.; Morandi, B. Catalytic Isofunctional Reactions-Expanding the Repertoire of Shuttle and Metathesis Reactions. *Angew. Chem., Int. Ed.* **2019**, *58*, 10074−10103. (b) Bhawal, B. N.; Morandi, B. Shuttle Catalysis-New Strategies in Organic Synthesis. *Chem. Eur. J.* **2017**, *23*, 12004−12013.

(13) (a) Fang, X.; Yu, P.; Morandi, B. Catalytic Reversible Alkene-Nitrile Interconversion Through Controllable Transfer Hydrocyanation. *Science* **2016**, *351*, 832−836. (b) Lian, Z.; Bhawal, B. N.; Yu, P.; Morandi, B. Palladium-Catalyzed Carbon-Sulfur or Carbon-Phosphorus Bond Metathesis by Reversible Arylation. *Science* **2017**, *356*, 1059−1063. (c) Fang, X.; Cacherat, B.; Morandi, B. CO- and HCl-Free Synthesis of Acid Chlorides from Unsaturated Hydrocarbons via Shuttle Catalysis. *Nat. Chem.* **2017**, *9*, 1105−1109. (d) Boehm, P.; Roediger S.; Bismuto, A.; Morandi, B. Palladium-Catalyzed Chlorocarbonylation of Aryl (Pseudo)Halides Through In Situ Generation of Carbon Monoxide. *Angew. Chem., Int. Ed.* **2020**, *59*, 17887−17896. (e) Boehm, P.; Martini, T.; Lee, Y. H.; Cacherat, B.; Morandi, B. Palladium-Catalyzed Decarbonylative Iodination of Aryl Carboxylic Acids Enabled by Ligand-Assisted Halide Exchange. *Angew. Chem., Int. Ed.* **2021**, *60*, 17211-17217.

(14) (a) Jun, C.-H.; Lee, H. Catalytic Carbon-Carbon Bond Activation of Unstrained Ketone by Soluble Transition-Metal Complex. *J. Am. Chem. Soc.* **1999**, *121*, 880−881. (b) Murphy, S. K.; Park, J. W.; Cruz, F. A.; Dong, V. M. Rh-Catalyzed C-C Bond Cleavage by Transfer Hydroformylation. *Science* **2015**, *347*, 56−60. (c) Fan, C.; Lv, X.-Y.; Xiao, L.-J.; Xie, J.-H.; Zhou, Q.-L. Alkenyl Exchange of Allylamines via Nickel(0)-Catalyzed C−C Bond Cleavage. *J. Am. Chem. Soc.* **2019**, *141*, 2889−2893. (d) Kanda, T.; Naraoka, A.; Naka, H. Catalytic Transfer Hydration of Cyanohydrins to α-Hydroxya-mides. *J. Am. Chem. Soc.* **2019**, *141*, 825−830.

(15) Lee, Y. H.; Morandi, B. Metathesis-Active Ligands Enable a Catalytic Functional Group Metathesis Between Aroyl Chlorides and Aryl Iodides. *Nat. Chem.* **2018**, *10*, 1016−1022.

(16) De La Higuera Macias, M.; Arndtsen, B. A. Functional Group Transposition: A Palladium-Catalyzed Metathesis of Ar-X σ-Bonds and Acid Chloride Synthesis. *J. Am. Chem. Soc.* **2018**, *140*, 10140−10144.

(17) Isshiki, R.; Inayama, N.; Muto, K.; Yamaguchi, J. Ester Transfer Reaction of Aromatic Esters with Haloarenes and Arenols by a Nickel Catalyst. *ACS Catal.* **2020**, *10*, 3490−3494.

(18) Isshiki, R.; Kurosawa, M. B.; Muto K.; Yamaguchi, J. Ni-Catalyzed Aryl Sulfide Synthesis through an Aryl Exchange Reaction. *J. Am. Chem. Soc.* **2021**, *143*, 10333−10340.

(19) (a) Liu, C.; Szostak, M. Twisted Amides: From Obscurity to Broadly Useful Transition-Metal-Catalyzed Reactions by N–C Amide Bond Activation. *Chem. Eur. J.* **2017**, *23*, 7157-7173. (b) Takise, R.; Muto, K.; Yamaguchi, J. Cross-Coupling of Aromatic Esters and Amides. *Chem. Soc. Rev.* **2017**, *46*, 5864-5888.

(20) (a) Lu, H.; Yu, T.-Y.; Xu, P.-F.; Wei, H. Selective Decarbonylation via Transition-Metal-Catalyzed Carbon-Carbon Bond Cleavage. *Chem. Rev.* **2021**, *121*, 365−411. (b) Liu, C.; Szostak, M. Decarbonylative Cross-Coupling of Amides. *Org. Biomol. Chem.* **2018**, *16*, 7998-8010. (c) Ji, C. L.; Hong, X. Factors Controlling the Reactivity and Chemoselectivity of Resonance Destabilized Amides in Ni-Catalyzed Decarbonylative and Nondecarbonylative Suzuki-Miyaura Coupling. *J. Am. Chem. Soc.* **2017**, *139*, 15522-15529.

(21) (a) Meng, G.; Szostak, M. General Olefin Synthesis by the Palladium-Catalyzed Heck Reaction of Amides: Sterically Controlled Chemoselective N–C Activation. *Angew. Chem. Int. Ed.* **2015**, *54*, 14518-14522. (b) Shi, S.; Meng, G.; Szostak, M. Synthesis of Biaryls through Nickel-Catalyzed Suzuki-Miyaura Coupling of Amides by Carbon–Nitrogen Bond Cleavage. *Angew. Chem. Int. Ed.* **2016**, *55*, 6959-6963. (c) Liu, C.; Szostak, M. Decarbonylative Phosphorylation of Amides by Palladium and Nickel Catalysis: The Hirao Cross-Coupling of Amide Derivatives. *Angew. Chem. Int. Ed.* **2017**, *56*, 12718-12722.