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Nickel–NHC-Catalyzed Cross-Coupling of 2-Methylsulfanylbenzofurans with Alkyl Grignard Reagents

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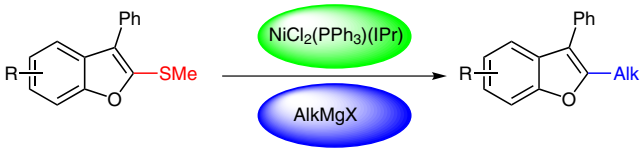

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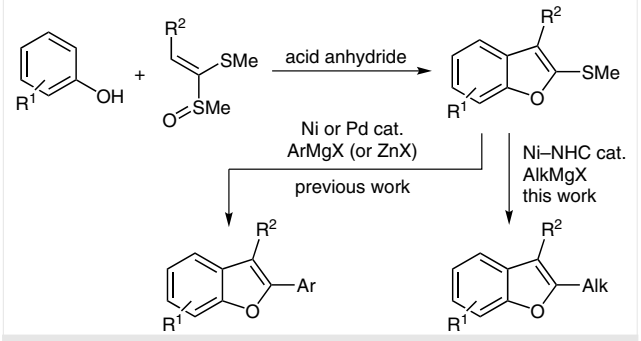
Abstract $NiCl_2(PPh_3)(IPr)$ catalyzes cross-coupling reactions of 2-methylsulfanylbenzofurans with alkyl Grignard reagents. Other nickel complexes such as $NiCl_2(dppe)$ failed to catalyze the same reaction. The alkylation is applicable to the synthesis of a couple of protein tyrosine phosphatase inhibitors, 3-(4-biphenylyl)-2-alkylbenzofurans.

Key words nickel, alkylation, cross-coupling, sulfide, homogeneous catalysis

Cross-coupling reactions of organosulfur compounds date back to 1979, when Takei and Wenkert independently reported the $NiCl_2(PPh_3)_2$-catalyzed arylation of aryl or alkenyl sulfides with Grignard reagents.[1] Despite subsequent extensive studies since then,[2–4] cross-coupling of aryl sulfides still remains in its infancy compared with the mature cross-coupling of aryl halides. The immaturity would be mostly attributable to 1) slow oxidative addition of their rather strong C(sp^2)–S bonds, 2) reluctant transmetalation due to high affinity between a transition metal and sulfur in an oxidative adduct, and 3) catalyst poisoning by sulfur compounds. New reaction conditions for more efficient and robust cross-coupling of aryl sulfides with a sustainable metal catalyst have thus been awaited.

We have been interested in extended Pummerer reactions[5] of ketene dithioacetal monoxides[4g,h,6,7] and recently developed an efficient and modular access to multisubstituted benzofurans through Pummerer annulation[4g,h,6e,f] (Scheme 1). Since our annulation always leads to the formation of 2-methylsulfanyl-substituted benzofurans, transformations of the sulfur moieties should dictate the usefulness of our methodology. Indeed, with state-of-the-art transition-metal catalysis, cross-coupling arylation of the products yielded highly fluorescent compounds[4g,h,6e,f] as well as anticancer agents.[4g,h] Along this line, we report herein that a nickel–NHC (N-heterocyclic carbene) complex is an effective catalyst for cross-coupling alkylation[8] of 2-methylsulfanyl-substituted benzofurans, which was applied to efficient synthesis of protein tyrosine phosphatase (PTP) 1B inhibitors **6**.

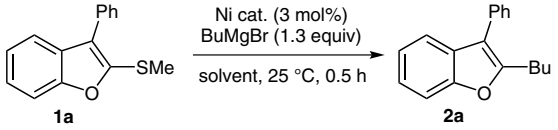


Scheme 1 Pummerer annulation–cross-coupling strategy for tailor-made synthesis of benzofurans

Cross-coupling butylation of benzofuran **1a** was chosen as a model reaction to probe a potent catalytic system. The results of catalyst optimization are summarized in Table 1. Although nickel–phosphine complexes are known to promote cross-coupling of aryl sulfides,[1,2a–e] the transformation of **1a** is not trivial. Attempted butylation with nickel diphosphine complexes resulted in no conversions (Table 1, entries 1–3). As **1a** is regarded as a bulky aryl sulfide due to the neighboring phenyl group, we envisioned a nickel–NHC complex bearing a bulky NHC to be suitable in analogy with the relevant palladium chemistry.[9,10] Indeed, a commercially available nickel complex $NiCl_2(PPh_3)(IPr)$[11] [IPr = 1,3-bis(2,6-diisopropylphenyl)imidazol-2-ylidene] catalyzed the desired alkylation very smoothly to afford **2a** in 95% yield (Table 1, entry 4). Finally, replacing toluene with THF

as a solvent led to quantitative formation of **2a** in 30 minutes (Table 1, entry 5). In the absence of any catalysts, no reaction took place (Table 1, entry 6).

Table 1 Optimization of Catalyst for Alkylation

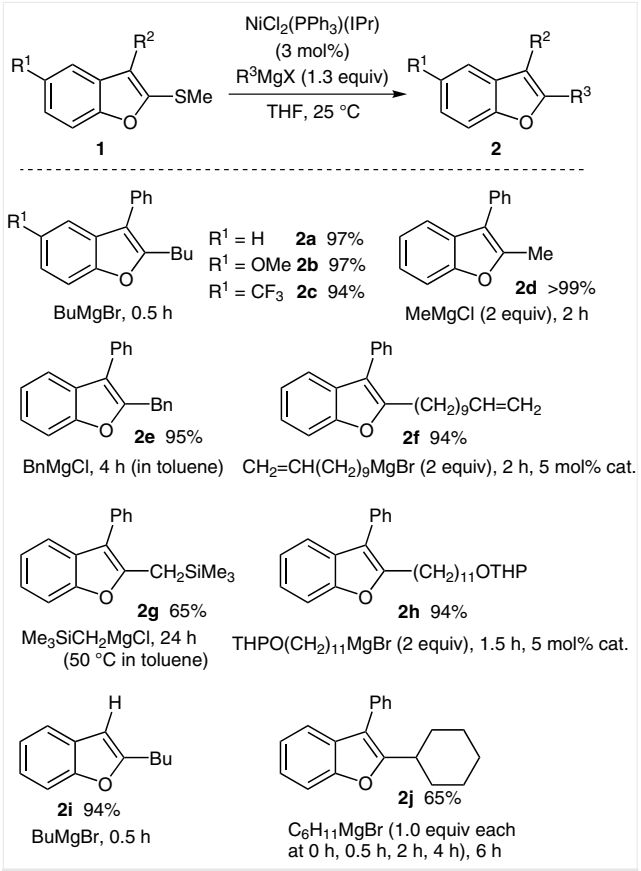


Entry	Catalyst	Solvent	Results[a]
1	$NiCl_2(PPh_3)_2$	toluene	no conversion
2	$NiCl_2$(dppe)	toluene	no conversion
3	$NiCl_2$(dppp)	toluene	no conversion
4	$NiCl_2(PPh_3)$(IPr)	toluene	95% yield of **2a**
5	$NiCl_2(PPh_3)$(IPr)	THF	>99% yield of **2a**
6	none	THF	no conversion

[a] By NMR analyses.

The scope of the alkylation is summarized in Scheme 2.[12] Electronically biased substituents at the 6-position have virtually no influence on the efficiency of the reaction (**2b** and **2c**). The smallest methyl (**2d**), unsaturated 10-undecenyl (**2f**), and THP-protected 11-hydroxyundecyl (**2h**) groups were installed easily. Benzylmagnesium chloride was less reactive and required four hours to reach completion (**2e**). Trimethylsilylmethylmagnesium chloride was much more reluctant to afford **2g** in 24 hours even at 50 °C. It is worth noting that 2-methylsulfanylbenzofuran, which has no substituent at the 3-position, totally resisted alkylation with $NiCl_2$(dppe) but underwent very smooth alkylation with $NiCl_2(PPh_3)$(IPr) to yield **2i**.[13] Secondary alkyl Grignard reagents underwent the cross-coupling with much less efficiency. Cyclohexylation required sequential additions of totally four equivalents of a cyclohexyl Grignard reagent to afford **2j** in 65% yield, along with a reduced byproduct where the SMe was replaced with H atom.

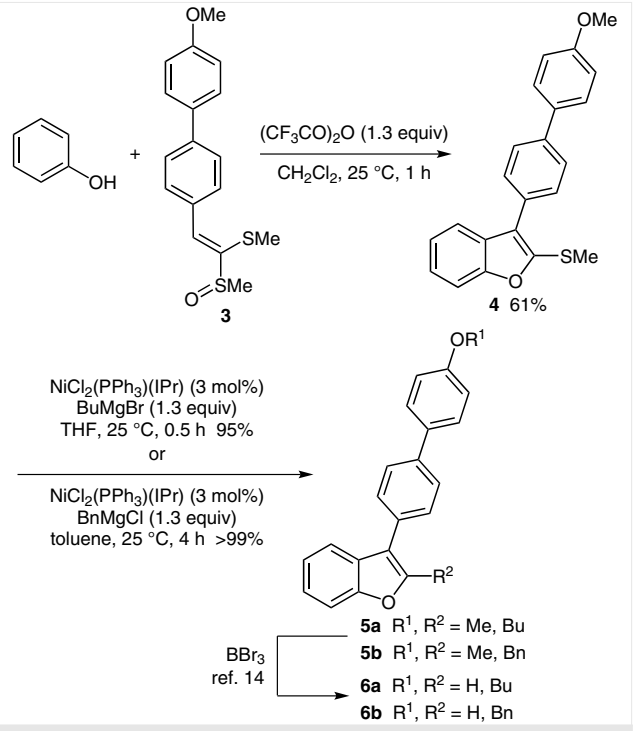
A series of 3-(4-biphenylyl)-2-alkylbenzofurans are attracting significant attention since they serve as potent inhibitors of PTP 1B.[14] In the previous report, each alkylbenzofuran in the library was prepared via a lengthy linear route. Advantageously, our approach to 2-alkylbenzofurans has proved to be more efficient for the synthesis of 3-(4-biphenylyl)-2-alkylbenzofurans bearing variety in the alkyl chain. Ketene dithioacetal monoxide **3** was prepared



Scheme 2 Scope of alkylation

through the Knoevenagel condensation in one step according to the literature procedure.[7a] Phenol underwent the Pummerer annulation[4g,h] with **3** by means of trifluoroacetic anhydride to afford 2-methylsulfanylbenzofuran **4** in 61% yield. The following cross-coupling butylation and benzylation were successful, yielding intermediates **5a** and **5b**, respectively, in a diversity-oriented fashion. Benzofurans **5a** and **5b** are key intermediates that should undergo demethylation as the last step to yield potent PTP 1B inhibitors **6** (Scheme 3).[14]

In summary, we have developed a highly efficient cross-coupling alkylation of benzofuryl sulfides with a nickel–NHC catalyst and applied it to the formal synthesis of PTP 1B inhibitors. Investigations to find efficient transformations of organosulfur compounds with a sustainable transition-metal catalyst are underway in our laboratory.



Scheme 3 Formal synthesis of PTP inhibitors

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Supporting Information

Supporting information for this article is available online at http://dx.doi.org/10.1055/s-0034-1378914.

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(12) **Butylation of 1a – Representative Procedure**
$NiCl_2(PPh_3)(IPr)$ (11.7 mg, 0.015 mmol) was placed in a dry Schlenk tube equipped with a magnetic stir bar and a rubber septum under argon. A solution of methylsulfanylbenzofuran (**1a**, 120 mg, 0.50 mmol) in THF (5.0 mL) was then added. Butylmagnesium bromide (0.60 M in THF, 1.0 mL, 0.60 mmol) was then added to the mixture, and the resulting mixture was stirred for 30 min at 25 °C. The mixture was filtered through a pad of silica gel with copious washings with CH_2Cl_2. The filtrate was evaporated to leave a crude oil. ^{1}H NMR analysis of the oil revealed the yield of **2a** was quantitative. Silica gel column purification (*n*-hexane) afforded butylated benzofuran **2a** (121 mg, 0.48 mmol) in 97% yield as a colorless oil.

2-Butyl-3-phenylbenzo[*b*]furan (2a)
^{1}H NMR (600 MHz, $CDCl_3$): δ = 7.60 (d, 1 H, *J* = 7.8 Hz), 7.54–7.50 (m, 5 H), 7.40 (t, 1 H, *J* = 6.6 Hz), 7.30 (t, 1 H, *J* = 6.6 Hz), 7.25 (t, 1 H, *J* = 7.8 Hz), 2.90 (t, 2 H, *J* = 7.8 Hz), 1.81 (quint, 2 H, *J* = 7.2 Hz), 1.44 (sext, 2 H, *J* = 7.2 Hz), 0.95 (t, 3 H, *J* = 7.2 Hz) ppm. ^{13}C NMR (150 MHz, $CDCl_3$): δ = 155.46, 154.18, 133.07, 129.25, 129.06, 128.86, 127.12, 123.66, 122.68, 119.57, 116.93, 110.97, 30.68, 26.66, 22.61, 13.95 ppm. IR: 2956, 2928, 2871, 1610, 1496, 1454, 1255, 1219, 1174, 1012, 969, 769, 700 cm^{-1}. ESI-HRMS: *m/z* calcd for $C_{18}H_{18}OH$ $[M + H]^+$: 281.1536; found: 281.1538.

(13) The scope of benzofuran substrates in the alkylation seems to be narrower than that in our previous arylation at present. For instance, 3-CF_3-substituted benzofuran resisted the butylation whereas it underwent smooth arylation in ref. 6f.

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