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Practical Synthesis of Allyl, Allenyl, and Benzyl Boronates through S_N1'-Type Borylation under Heterogeneous Gold Catalysis

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catalysts is described. Au nanoparticles supported on TiO₂ showed high activity under mild conditions employing low catalyst loading conditions without the aid of any additives, such as phosphine and bases. A variety of allyl, propargyl, and benzyl substrates participated in the heterogeneously catalyzed reactions to furnish the corresponding allyl, allenyl, and benzyl boronates in high yields. Besides, Au/TiO2 was also effective for the direct borylation of allylic and benzylic



alcohols. A mechanistic investigation based on a Hammett study and control experiments revealed that sp³ C-O bond borylation over supported Au catalysts proceeded through $S_N 1'$ -type mechanism involving the formation of a carbocationic intermediate. The high activity, reusability, and environmental compatibility of the supported Au catalysts as well as the scalability of the reaction system enable the practical synthesis of valuable organoboron compounds.

KEYWORDS: gold, heterogeneous catalyst, borylation, allylic substitution, allenyl boronate, benzyl boronate, carbocation

1. INTRODUCTION

Organoboron compounds are versatile and essential reagents in organic synthesis for obtaining value-added molecules such as pharmaceuticals, agrochemicals, and functional materials. Particularly, extensive efforts have been devoted to exploit novel protocols for synthesizing allyl and allenyl boronates, which are used as allyl, allenyl, and propargyl sources in transition-metal-catalyzed cross-coupling.^{1e,3} In addition, valuable homoallyl- and homopropargyl alcohols and amines can be synthesized from these organoboron compounds upon treatment with carbon electrophiles such as aldehydes, ketones, and imines.⁴ Catalytic borylation of sp^3 C–X bonds (X = O and halogen) under the influence of transition metals such as Cu,⁵ Ni,⁶ Pd,⁷ and Fe⁸ is the most promising method for preparing allyl, benzyl, and allenylboron compounds, in which reductive elimination from π -allyl boryl metal species (Scheme 1a) or $S_N 2'$ reaction by copper-boryl species (Scheme 1b) result in efficient C-B bond formation. Recent extensive studies on the stereospecific synthesis of chiral organoboron compounds further increased the importance of these protocols in synthetic chemistry. Despite the significant utility of the catalytic C-X bond borylation, major tools are still limited to homogeneous catalyses based on metal complexes which often face the difficulty of separating and recycling catalysts as well as contamination by toxic metals. Moreover, one reason why it is difficult to realize reactions at a scale beyond lab scale is that additives such as phosphines and bases are indispensable in most reported C-X bond borylation under transition-metal catalysis. Although base-catalyzed Scheme 1. Proposed Mechanisms for C-B Bond Formation in Allylic Borylation



Received: August 29, 2020 **Revised:** November 20, 2020 Published: January 1, 2021





borylation of allylic alcohols is also an attractive tool in allylic borylation,⁹ the problem of limited substrate scope is still unresolved. On the other hand, the use of heterogeneous catalysis based on supported metal nanoparticles (NPs) can provide a reliable solution thanks to their high stability, reusability, and ease with which they can be separated from the products. These features make it possible to synthesize valuable chemicals on a practical scale in a green manner. Although Morken and co-workers reported that Pd/C showed activity for the conversion of an allyl chloride to an allyl boronate,^{6a} the development of a novel catalytic system that shows high activity and reusability, as well as a wide substrate scope is still largely unexplored. Meanwhile, in the last decade, supported gold nanoparticles have emerged as efficient heterogeneous catalysts for the synthesis of organoboron compounds,¹⁰ which stimulated us to devise gold-based catalytic system for C-X bond borylation. Herein, we describe the catalytic borylation of sp³ C–O bonds over supported Au catalysts. While the Au-catalyzed borylation of allyl, benzyl, and propargyl esters required no aid of additives, a series of the corresponding allyl, allenyl, and benzyl boronates were obtained in high yields. A detailed investigation on the reaction mechanism elucidated that the formation of C-B bonds over Lewis acidic Au NPs proceeded in the $S_N 1'$ manner involving the formation of a cationic intermediate (Scheme 1c), thereby leading to a high reaction efficiency and broad substrate scope. Furthermore, supported Au catalysts showed excellent reusability, scalability, and environmentally friendly nature, which should be key characteristics for the practical synthesis of organoboron compounds.

2. RESULTS AND DISCUSSION

Initially, we examined the catalytic activity of a series of metal NPs supported on TiO₂ for the borylation of cinnamyl acetate (1a) with bis(pinacolato)diboron (2) (Table 1). The reaction in the presence of supported Au catalyst (2 mol %) at 60 °C completed within only 15 min and delivered a boryl group exclusively at the α -position, to give cinnamyl boronate (3a) in 94% yield (entry 1). In contrast, a supported Pt NP catalyst showed no activity. Although Ni, Cu, and Pd have been

Table	1.	Boryl	lation	of	1a	Over	Sup	ported	Catal	ysts
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Ph	Au/TiO ₂ (2 mol%) → 1,4-Dioxane 1a 2 60 °C, 15 min	Ph Bpin 3a	
entry	variation from the standard condition	yield of $3a (\%)^b$	
1	none	94 (93)	
2	Ni, Cu, Pd, or Pt instead of Au	0	
3	THF instead of 1,4-dioxane	11	
4	toluene instead of 1,4-dioxane	19	
5	1,2-DCE or CH ₃ CN instead of 1,4-dioxane	0	
6	at 30 °C for 1 h	83	
7	$-OCO_2Me$, $-OCO_2^tBu$, or $-OPO(OEt)_2$ as LG instead of $-OAc$, at 30 °C for 1 h	72-83	
8	-Cl as LG instead of -OAc	0	
9	0.02 mol % of Au/TiO $_2$ at 100 $^\circ C$ for 3 h	63 (TON = 3150)	

^{*a*}Reaction condition: **1a** (0.30 mmol), **2** (0.60 mmol), Au/TiO₂ (2 mol %),1,4-dioxane (1.0 mL), 60 °C, 15 min under Ar. ^{*b*}Determined by ¹H NMR with mesitylene as an internal standard. Isolated yield is shown in parentheses.

reported to be effective catalytic components under homogeneous conditions, their metal-NP variants were ineffective (entry 2). A survey to identify the optimal solvent revealed that 1,4-dioxane was the solvent of choice for the present Au NPcatalyzed borylation, while THF, toluene, acetonitrile, and 1,2dichloroethane were unsuitable (entries 3-5). The supported Au catalyst showed high activity, and the reaction, even at 30 °C, gave 3a in 83% yield (entry 6). In addition to an acetoxy (-OAc) group, carbonate $(-OCO_2Me \text{ and } -OCO_2^tBu)$ and phosphate $(-OPO(OEt)_2)$ groups also served as suitable leaving groups to give 3a in comparable yields (entry 7). In contrast, 3a was not obtained at all in the reaction of cinnamyl chloride (entry 8). The high catalytic activity of Au/TiO₂ was further well reflected in the reaction with a low catalyst loading (substrate/Au = 5000), to provide 3a in satisfactory yield. Notably, the turnover number of 3150 was the highest value ever reported in the catalytic borylation of sp³ C-X bonds (entry 9, data for comparison are shown in the Supporting Information).

The scope of allylic substrates in the Au NP-catalyzed C–O bond borylation was investigated (Table 2). The reactions of primary allyl acetates provided the corresponding allyl boronates in good to high yields, and boryl groups were delivered predominantly at terminal positions (entries 2-5). Although the reaction of the simplest allylic acetate required at least 1 h to furnish 3b in moderate yield (entry 1), the installation of substituents on the alkene moiety shortened the time required for full conversion of substrate and increased product yields (entries 2 and 3). The present heterogeneous Au-catalyzed reaction can deliver a boryl group in terpenebased scaffolds to provide 3e in excellent yields (entries 4 and 5). The E/Z configuration of the starting substrates (1e and 1f) did not affect the reaction efficiency, and the E/Zconfigurations at alkene moieties were not transferred to the corresponding allyl boronates. The borylation of secondary and tertiary allyl acetates also proceeded efficiently to give the corresponding allyl boronates in excellent yields (entries 6-15). In the reaction of secondary allyl acetates bearing a terminal alkene moiety (1g-1j), C-B bonds were formed exclusively at the γ -position (entries 6–9). On the other hand, the introduction of a methyl group at the γ -position of secondary allyl acetate led to the formation of a mixture of regioisomers $(3k-\alpha \text{ and } 3k-\gamma)$ (entry 10). In contrast, a substrate containing a phenyl substituent at the γ -position of allyl acetate underwent C-B bond formation selectively at the α -position to afford secondary allyl boronate 31 (entry 11). A methyl substituent at the β -position was also tolerated in the Au NP-catalyzed reaction to give the corresponding boronate (entry 12). Such regiochemistry in the present borylation enables us to envisage that C-O borylation over Au NPs proceeds through reaction mechanism that is different from an $S_N 2'$ mechanism, which is often seen in C–X bond borylations under Cu catalysis.⁵ The terminal chloro group remained intact during the catalytic borylation of 1p (entry 15).

Borylation of cinnamyl acetate (1a) with various diboron compounds (2'-2''') other than bis(pinacolato)diboron (2) was investigated (Scheme 2). Although a higher reaction temperature was required, the reaction of bis-(neopentylglycolato)diboron (2') and bis(hexyleneglycolato)diboron (2'') proceeded to furnish the corresponding cinnamyl boronates (3a' and 3a'') in 63 and 89% yields, respectively. In contrast, tetrahydroxydiboron (2''') was not suitable as a boron source for the Au-catalyzed borylation.

Table 2. Synthesis of Allyl Boronate over Au/TiO₂^{*a,b,cb*}

Entry	Substrate	Product	t/ h	Yield(%)♭	EIZ
10	≫∽ _{OAc} 1b	Spin 3b	1	61 (37)	-
2	JoAc 1c	Bpin 3c	0.25	94 (70)	-
3 ^c	OAc 1d	Bpin 3d	1	(88)	72:28
4	1e OAc	3e Bpin	0.5	92 (83)	81:19
5	1f	3e Bpin	0.5	96 (95)	41:59
6	OAc Ph 1g	Ph Bpin 3g	0.5	(91)	<i>E</i> only
7	OAc 1h	Bpin ^{3h}	0.5	(85)	<i>E</i> only
8	OAc CI	CI Bpin ³ⁱ	0.5	(98)	<i>E</i> only
9	Ph OAc 1j	Ph Bpin 3j	1	(91)	75:25
10	Ph 1k	Bpin Ph 3k-α Ph 3k-γ	1	99 (75) (α:γ=44:56)	<i>E</i> only 68:32
11	Ph Ph Ph 11	Ph Ph 31	1	(75)	<i>E</i> only
12	Ph 1m	Ph ^{ee} Bpin 3m	2	(78)	46:54
13	OAc 1n	Bpin 3n	3	86 (84)	-
14	OAc 10	Bpin 30	1	83 (77)	-
15	CI Ph OAc 1p	Cl Ph Bpin 3p	1	(70)	<i>E</i> only

^aReaction condition: **1** (0.3 mmol), **2** (0.6 mmol), Au/TiO₂ (2 mol %), 1,4-dioxane (1.0 mL), 60 °C under Ar. ^bDetermined by ¹H NMR with mesitylene as an internal standard. Isolated yield is shown in parentheses. ^c0.9 mmol of **2** was used.





^{*a*}Reaction conditions: **1a** (0.30 mmol), **2** (0.60 mmol), Au/TiO₂ (2.0 mol %),1,4-dioxane (1 mL). Isolated yields are given. ^{*b*}Au/TiO₂ (5.0 mol) was used.

 Au/TiO_2 also efficiently catalyzed benzylic borylation without the aid of any additives (Table 3).^{5e,11,12} The reaction



^{*a*}Reaction conditions: **4** (0.30 mmol), **2** (0.60 mmol), Au/TiO₂ (2.0 mol %), 1,4-dioxane (1 mL). Determined by ¹H NMR with tetrachloroethane as an internal standard. Isolated yields are shown in parentheses. ^{*b*}**2** (0.90 mmol). ^{*c*}Reaction at 100 °C.

of benzyl acetate (4a) with 2 furnished the corresponding benzyl boronate (5a) in 69% yield. Electron-donating methoxy and methyl substituents positively affected the yield of the corresponding benzyl boronates (5b, 5c, and 5g). Although a trifluoromethyl group on a phenyl group was not a suitable substituent for the present borylation of a benzylic C–O bond, fluoro and chloro groups were tolerated to afford the corresponding benzyl boronates (5d and 5e) in high yields. Naphthylmethyl and furylmethyl boronates (5h and 5i) were also obtained in 89 and 75% yields, respectively. Notably, the supported Au catalyst was remarkably effective for the borylation of secondary benzyl acetates. Methyl, secondary, and tertiary butyl groups as well as an aryl group were compatible as second substituents at the benzylic position in the substrates to furnish the corresponding secondary benzyl boronates (5j-5m) in good to high yields. Besides, the Au NP-catalyzed reaction allowed the delivery of a boryl group to indene and chromane scaffolds (5n and 5o).

 Au/TiO_2 catalyst was also effective for the synthesis of allenyl boronates (Table 4).^{4a,5e,13,14} The reactions of propargyl carbonates 6 and 2 in the presence of Au/TiO_2 proceeded under mild reaction conditions to deliver a boryl group at the γ -position, thus giving only the corresponding allenyl boronates 7. A characteristic of the Au NP-catalyzed reaction is its broad scope of propargyl substrates. The reaction of both secondary and tertiary propargyl carbonates bearing alkyl substituents gave the corresponding tri- and tetrasubstituted allenyl boronates (7a-7e) in high yields, in which a terminus bulky tert-butyl group was tolerated in the Au-catalyzed borylation. Furthermore, 1-boryl-1-silylallene derivative (7f) could be synthesized via borylation of γ silylated propargyl carbonate. Although Ito^{14a} and Szabó^{14b,c,e} independently demonstrated seminal Cu- and Pd/Cucatalyzed borylation of propargyl carbonates for the synthesis of allenyl boronates, efficient borylation of aryl-substituted substrates has not yet been explored satisfactorily. In this

Table 4. Synthesis of Allenyl Boronates over Au/TiO_2 Catalyst^{*a,b,c*}



^{*a*}Reaction conditions: **6** (0.30 mmol), **2** (0.60 mmol), Au/TiO₂ (2.0 mol %), 1,4-dioxane (1 mL). ¹H NMR yields with mesitylene as an internal standard are given, and the isolated are shown in parentheses. ^{*b*}0.90 mmol of **2** was used. ^{*c*}Reaction by Au/TiO₂ (5.0 mol %) at 70 °C.

regard, the Au/TiO₂ catalyst was remarkably effective for the synthesis of aryl-substituted allenyl boronates. Substrates with an aryl group at the α -position provided allenyl boronates in excellent yields (7g-7i). Moreover, aryl groups at both the α -and γ -positions were compatible to furnish the bisaryl allenyl boronate (7m). The reaction of primary propargyl carbonate proceeded efficiently to provide boronates having a terminal allene moiety (7o). The Au/TiO₂ was also effective for the borylation of a propargyl carbonate bearing a terminal sp C–H bond to give allenyl boronate 7p in good yield.

Allylic alcohols should be used as ideal starting substrates in the catalytic borylation of sp3 C-O bonds in terms of atomeconomic synthesis.^{5d,7h} Au/TiO₂ catalyst significantly promoted the borylation of cinnamyl alcohol (8a) under mild reaction conditions to give 3a in 81% yield (Scheme 3(1)). In the catalytic borylation of 8a, the rapid formation of cinnamyl-OBpin at the initial stage of the reaction and subsequent formation of 3a accompanied by the consumption of cinnamyl-OBpin were observed. This indicates that cinnamyl-OBpin is the intermediate for the borylation of allylic alcohol and OBpin species served as a good leaving group for the Au-catalyzed borylation. Au NP enables us to promote both the formation of an O-B bond and subsequent C-O bond borylation,¹⁵ thereby achieving one-pot substitution of alcohol to a boryl group. Besides, the Au/TiO₂ catalyst was also effective for the borylation of benzylic alcohol (8b) to furnish 5c in 86% yield (Scheme 3(2)).

Scheme 3. Borylation of Allylic and Benzylic Alcohols over Au/TiO2 Catalyst b



The present supported Au catalyst satisfies various essential requirements for realizing the practical synthesis of organoboron compounds. The Au/TiO₂ catalyst exhibited high reusability for the borylation of allyl and propargyl esters, and no significant decreases in product yields were confirmed in four consecutive catalytic runs for both allyl and allenyl boronate synthesis (Figure 1). Furthermore, hot filtration of



Figure 1. Reusability of Au/TiO_2 catalyst for sp³ C–O bond borylation^{a,b}. a Reaction condition for allyl boronate: **1a** (0.5 mmol), **2** (1.0 mmol), Au/TiO_2 (2.0 mol %), 1,4-dioxane (1.6 mL), 60 °C, 15 min. b Reaction condition for allenyl boronate: **6a** (0.5 mmol), **2** (1.0 mmol), Au/TiO_2 (2.0 mol %), 1,4-dioxane (1.6 mL), 60 °C, 1 h. NMR yields are given.

the solid catalyst completely suppressed the further formation of boronate products. Besides, atomic adsorption spectrometry revealed no leaching of Au species into the reaction mixture during the reaction of 1a and 2, proving the supported Au catalysts can realize the environmentally friendly synthesis of organoboron compounds.

The present Au catalytic system is highly scalable. Even at a large scale (10 mmol of 1a) and under a low catalyst loading condition (0.1 mol % as Au), the borylation of 2a proceeded smoothly to afford 3a in 68% GC yield. If we consider the low stability of allyl boronates to heat and acids,¹⁶ the process without any purification such as distillation or silica gel chromatography can avoid the loss of valuable boron reagents. Notably, the in situ formed allyl boronate 3a could be used as an allylating reagent without separating from the solid Au catalyst. The subsequent addition of benzaldehyde and ethanol allowed us to achieve a one-pot synthesis of a homoallylic alcohol 9 at gram scale in a high yield (Scheme 4). The above results demonstrate that the supported Au catalyst possesses substantial potential for the green and practical synthesis of valuable organoboron compounds and their derivatives.

To obtain mechanistic insight, we conducted a Hammett study on the formation rate of benzyl boronates.¹⁷ The

Scheme 4. One-Pot Synthesis of Homoallylic Alcohol from 1a via Au-Catalyzed Borylation under Large-Scale Condition



Hammett plot showed a linear correlation ($R^2 = 0.992$) between log (k_x/k_h) and the σ values of the respective parasubstituents, with a ρ value of -3.03 (Figure 2). Furthermore,



Figure 2. Hammett plot for the rate constants in the benzylic borylation over Au/TiO_2 .

the intermolecular competitive reaction of allyl acetates bearing different aryl groups at α -position (**1h** and **1i**) demonstrated that preferential conversion of the substrate with an electron-donating substituent (Scheme 5). These facts allowed us to postulate that C–O borylation over supported Au catalysts proceeds through an S_N1 or S_N1' mechanism involving the formation of cationic (benzyl, allyl, and propargyl) intermediates.

Accordingly, we examined the chiral transfer of (R)-4chromanyl acetate [(R)-4o] to the corresponding benzyl boronate **50** over Au/TiO₂ catalyst. The reactions at both 60 and 30 °C resulted in the formation of **50** with a significantly decreased optical purity (Scheme 6(1)). These results also support the notion that racemization, probably due to the formation of a planar carbocation, is involved in C–O bond borylation. On the other hand, in the partial conversion of benzyl acetate, its ee was maintained, indicating that the C–O bond-cleaving step is irreversible. Note that the constant optical purity of product **50** during the catalytic reaction means that no racemization of **50** took place over the Au/TiO₂ catalyst. Nolan and co-workers reported that the cationic Au(I) complex promoted the catalytic rearrangement of allylic Scheme 6. Control Experiments on Borylation of sp 3 C–O Bonds over Au/TiO₂ Catalyst



acetates¹⁸ as well as Mayer–Schuster rearrangement of propargylic acetates,¹⁹ in which the formation of carbocationic intermediates was proposed. Conversely, Au/TiO₂ catalyst showed no activity for the rearrangement of **1g** to **1a** under conditions identical to those for standard C–O bond borylations (Scheme 6(2)). Furthermore, thermal treatment of (R)-40 with Au/TiO₂ in the absence of diboron **2** resulted in no decrease in its optical purity (Scheme 6(3)). These facts suggest that C–O bond cleavage is unlikely to be taken place through simple oxidative addition, which are often seen in allylic substitution under Pd or Ni catalysis, but rather that Au NPs and diboron would work in concert to form an allyl cation as a key intermediate in the present borylation.

Based on these results, we propose a reaction mechanism for sp³ C–O bond borylation through an $S_N 1'$ pathway over supported Au catalysts (Scheme 7). Initially, diboron 2 adsorbs onto the surface of Au NPs, where the interaction of O atom at boronate with Lewis acidic Au NPs would increase the Lewis acidity of B atom.²⁰ Subsequently, the ester and alkene moieties in allyl esters coordinate to boronate and the Au surface, respectively. This triggers cleavage of the C–O bond to generate allyl cation with the simultaneous formation of tetra-coordinated borate.²¹ Fernández, Szabó, and co-workers reported that diborane-base adducts could liberate nucleophilic

Scheme 5. Intermolecular Competitive Allylic Borylation



Scheme 7. Possible Mechanism for Borylation of Allyl Acetate over Au/TiO₂ Catalyst



boryl species, thus enabling the attack to electrophilic carbon to form a C–B bond.²² The addition of such activated boron species to an alkene moiety and subsequent bond isomerization give allyl boronates.

This catalytic borylation should include the isomerization of less stable allyl cations to a more stable structure, e.g., a primary to secondary or a secondary to benzylic structure. The sequences of allylic borylation of 1j-1l are summarized in Scheme 8 as examples for explaining the regioselectivity of the products in Table 1. As for the reaction of 1j, secondary allyl cation directly formed via C-O bond cleavage is more stable than possible primary allyl cation, which results in delivery of the boryl group predominantly to the γ -position via nucleophilic attack of borate in $S_N 1'$ manner to form 3j (Scheme 8(1)). The introduction of a methyl group to alkene moiety can form two possible secondary allyl cations with comparable stability that consequently produce the mixture of two regioisomers (Scheme 8(2)). In contrast, phenyl substituent allows us to produce a benzylic cation, which is much more stable than cinnamyl cation. Therefore, the reaction of 11 selectively undergoes C-B bond formation at the α -position of allyl acetate (Scheme 8(3)).

Additionally, the fact that electron-donating substituents and an extended π -system stabilize carbocationic intermedia-tes^{12b,23} can explain the higher formation rates of electronrich arylmethyl boronate (5b, 5c, and 5g), naphthylmethyl boronate (5h), and bisarylmethyl boronate (5m) than those of electron-poor arylmethyl boronates (5d–5f) and simple benzyl boronate 5a (see Table 3). These considerations also support the notion that the present sp³ C–O bond borylations proceed in an S_N1' manner. In this mechanism, we surmise that Au NPs activate boronate to enhance its Lewis acidity¹⁰ and stabilize carbocations generated from allyl electrophiles, thereby achieving significantly high reaction efficiency and wide substrate scope. The high stability of byproduct RO-Bpin due to the high dissociation energy of the O-B bond allows us to deduce that the reaction is energetically downhill and has an early transition state. We are currently carrying out a detailed kinetic and theoretical study to elucidate the regioselectivitydetermining step and transition energies in each elemental step. Besides, the fact that the complete loss of ee was not confirmed in the borylation of chiral benzylic acetate (R)-40

Scheme 8. Consideration on the Regioselectivity for Au-Catalyzed Allylic Borylation of 1j, 1k, and 1l



(Scheme 6(1)) forces us to anticipate that the reaction consists of a competition of stereoablative and stereoretentive pathway. A detailed mechanistic investigation on the stereospecific borylation over supported Au catalysts is also currently ongoing in our laboratory.

3. CONCLUSIONS

An efficient and versatile sp³ C–O bond borylation with a Au/ TiO₂ catalyst was demonstrated. A variety of allyl, benzyl, and propargyl substrates participated in the heterogeneous Aucatalyzed reaction without any additives such as ligands and bases to give the corresponding allyl, benzyl, and propargyl boronates in high yields. In addition, Au/TiO₂ catalyzed the direct borylation of allylic and benzylic alcohols. The catalysis by supported Au NPs has various important features related to activity, reusability, environmental compatibility, and scalability, which should be advantageous for the practical synthesis of valuable organoboron compounds. A mechanistic investigation including a Hammett study and control experiments revealed that the borylation over a Au NP catalyst proceeds through S_N1'-type mechanism involving the formation of a cationic intermediate, thereby leading to a high reaction efficiency and broad substrate scope. Further applications of supported Au catalysts toward the chiral synthesis of organoboron compounds and other synthetic reactions as well as a theoretical study on the detailed reaction mechanism are currently underway in our laboratory.

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge at https://pubs.acs.org/doi/10.1021/acscatal.0c03771.

Optimization of reaction conditions for C–O bond borylation, characterization of supported Au catalysts, and ¹H NMR and ¹³C NMR spectra of the substrates and products (PDF)

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Notes

The authors declare no competing financial interest.

ACKNOWLEDGMENTS

This study was supported in part by the Program for Element Strategy Initiative for Catalysts & Batteries (ESICB) (Grant JPMXP0112101003), Grants-in-Aid for Scientific Research (B) (Grant 17H03459), Early-Career Scientists (Grant 19K15362), and Scientific Research on Innovative Areas (Grant 17H06443) commissioned by MEXT of Japan. The XAFS experiment at SPring-8 was carried out under the approval (Proposal No. 2019A1131) of the Japan Synchrotron Radiation Research Institute (JASRI). The authors thank Ono of Tokyo Metropolitan University for providing valuable technical support during the HAADF-TEM observations.

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