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Highly Enantioselective Construction of Trifluoromethylated All-Carbon Quaternary Stereocenters via Nickel-Catalyzed Friedel–Crafts Alkylation Reaction

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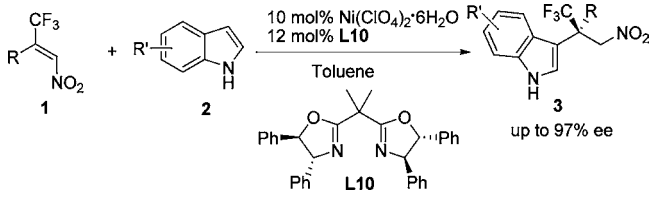
Supporting Information

ABSTRACT: A highly enantioselective Friedel–Crafts alkylation reaction of indoles with β-CF_3-β-disubstituted nitroalkenes was achieved using a $Ni(ClO_4)_2$–bisoxazoline complex as a catalyst, which afforded indole-bearing chiral compounds with trifluoromethylated all-carbon quaternary stereocenters in good yields with excellent enantioselectivities (up to 97% ee). The transformation of one of the products into first a trifluoromethylated tryptamine and then a trifluoromethylated tetrahydro-β-carboline by sequential nitro reduction and Pictet–Spengler cyclization were realized with complete preservation of enantiopurity.

Trifluoromethylated organic compounds of pharmaceutical and agrochemical importance have received increasing attention because of the unique impact of the CF_3 group on the enhancement and modification of their original biological activities.[1] Consequently, the development of reliable synthetic approaches to CF_3-bearing organic compounds has been a topic of focus.[2] To date, methods for the formation of CF_3-substituted tertiary or heteroquaternary stereogenic centers have been successfully developed. Recent examples include direct asymmetric trifluoromethylations based on the use of nucleophilic, electrophilic, and radical trifluoromethylation reagents as well as enantioselective transformations of prochiral trifluoromethylated substrates.[3] In spite of these notable advances, the enantioselective construction of trifluoromethylated all-carbon quaternary stereocenters has been much less exploited and remains a very important and extremely challenging task in asymmetric catalysis.[4] Only a few examples of this have been documented, including electrophilic trifluoromethylation of β-keto esters and conjugate addition of cyanide to β-aryl-β-CF_3 enones.[5] Hence, the development of novel and efficient methods to meet this challenge is highly valuable.

Recently, the Michael-type asymmetric Friedel–Crafts alkylation reaction of electron-deficient olefins has been established as an important route to chiral benzylic stereocenters.[6] However, applications of this methodology for the synthesis of all-carbon quaternary stereocenters are conspicuously limited. To date, only two examples with modest ee's have been reported, involving LUMO activation of β,β-disubstituted enaldehydes and enones by iminium catalysis.[7] The success was limited by the intrinsic steric hindrance and poor reactivity of these substrates. β-Monosubstituted nitroalkenes have turned out to be active substrates in asymmetric Friedel–Crafts alkylations of indoles,[8] pyrroles,[9] furans,[10] and phenols.[11] Utilization of the corresponding β,β-disubstituted nitroalkenes as substrates has not yet been disclosed in this field, although a few reports on enantioselective conjugate additions using dialkylzinc reagents, thiols, and oximes as nucleophiles have appeared.[12] Herein we present the first report of an asymmetric Friedel–Crafts alkylation reaction with β,β-disubstituted nitroalkenes as alkylating reagents. This reaction between indoles and β-CF_3-β-disubstituted nitroalkenes is efficiently catalyzed by a $Ni(ClO_4)_2$–bisoxazoline complex[13] and forms trifluoromethylated all-carbon quaternary stereocenters with excellent enantioselectivities (Scheme 1).[14]

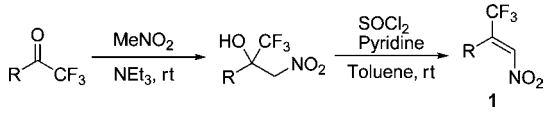
Scheme 1



Notably, one of the resulting adducts was further transformed by sequential nitro reduction and Pictet–Spengler cyclization to give first a trifluoromethylated tryptamine and then a trifluoromethylated tetrahydro-β-carboline as potentially biologically active molecules.

Initially, the nitroalkenes were synthesized according to the procedure illustrated in Scheme 2.[15] Henry reaction of

Scheme 2



trifluoromethylated ketones with nitromethane gave the corresponding nitroalcohols. Subsequent elimination of the nitroalcohols in the presence of $SOCl_2$ and pyridine produced (E)-β-CF_3-β-disubstituted nitroalkenes (**1**)[16] in modest yields. (E)-1-Phenyl-1-trifluoromethyl-2-nitroethene (**1a**) and indole (**2a**) were then chosen as model substrates to study the Friedel–Crafts reaction. Primary results showed that bisoxazo-

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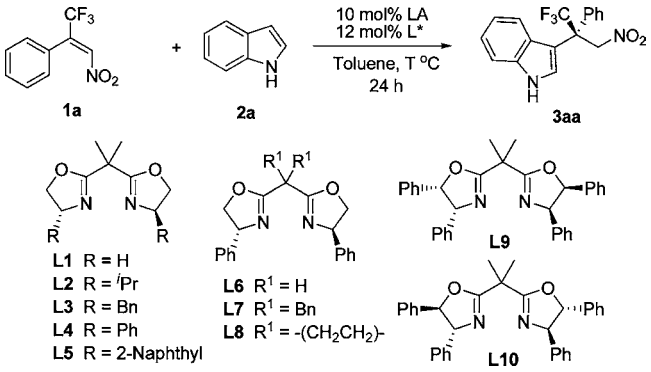
line ligands could efficiently promote the reaction.[17] With achiral bisoxazoline **L1** as the ligand and 10 mol % $Ni(ClO_4)_2{\cdot}6H_2O$ as the catalyst in toluene at 100 °C for 24 h, the desired product was isolated in 75% yield (Table 1, entry 1). Our attention was then moved to chiral bisoxazoline ligands **L2**–**L5** bearing substituents at the C4 positions of the oxazoline rings. Good enantioselectivities were obtained with **L4** and **L5** (entries 2 and 3), while **L2** and **L3** led to very poor enantioselectivity (4% ee for **L2** and 7% ee for **L3**). Other ligands were examined, including **L6**–**L8** with different linkers between the two oxazoline rings and **L9** and **L10** containing additional phenyl groups (entries 4–8). Ligand **L10** bearing *trans*-diphenyl groups gave the highest enantioselectivity. The effect of the Lewis acid was subsequently screened. Zn-$(ClO_4)_2{\cdot}6H_2O$ and $Ni(OTf)_2$ proved to be efficient catalysts, while the reaction did not proceed in the presence of $Cu(ClO_4)_2{\cdot}6H_2O$ (entries 9–11). When the temperature was lowered to 60 °C, both the yield and enantioselectivity obviously increased, although a longer reaction time was required (entry 12). The enantioselectivity was further increased to 97% ee at 50 °C, but the yield decreased (entry 13). Solvent screening showed that the reaction was fully suppressed in tetrahydrofuran (THF) and methanol. It is worth noting that no detrimental effect on the enantioselectivity was observed when the reaction was carried out under air or at a catalyst loading of 5 mol %, although longer reaction times were required to ensure good yields (entries 14 and 15).

Table 1. Optimization of the Reaction Conditions[a]

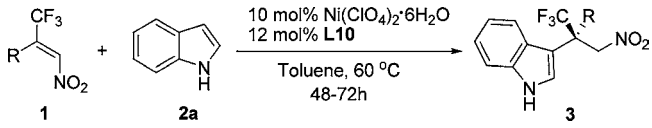


entry	LA	L*	T (°C)	yield (%)[b]	ee (%)[c]
1	$Ni(ClO_4)_2{\cdot}6H_2O$	**L1**	100	75	–
2	$Ni(ClO_4)_2{\cdot}6H_2O$	**L4**	100	85	90
3	$Ni(ClO_4)_2{\cdot}6H_2O$	**L5**	100	84	86
4	$Ni(ClO_4)_2{\cdot}6H_2O$	**L6**	100	86	91
5	$Ni(ClO_4)_2{\cdot}6H_2O$	**L7**	100	87	71
6	$Ni(ClO_4)_2{\cdot}6H_2O$	**L8**	100	80	87
7	$Ni(ClO_4)_2{\cdot}6H_2O$	**L9**	100	88	90
8	$Ni(ClO_4)_2{\cdot}6H_2O$	**L10**	100	89	93
9	$Zn(ClO_4)_2{\cdot}6H_2O$	**L10**	100	80	84
10	$Cu(ClO_4)_2{\cdot}6H_2O$	**L10**	100	<5	–
11	$Ni(OTf)_2$	**L10**	100	85	89
12[d]	$Ni(ClO_4)_2{\cdot}6H_2O$	**L10**	60	95	96
13[e]	$Ni(ClO_4)_2{\cdot}6H_2O$	**L10**	50	87	97
14[f]	$Ni(ClO_4)_2{\cdot}6H_2O$	**L10**	60	72	96
15[g]	$Ni(ClO_4)_2{\cdot}6H_2O$	**L10**	60	82	96

[a]Conditions: **1a** (0.4 mmol), **2a** (0.6 mmol), Lewis acid (LA) (10 mol %), and chiral ligand (L*) (12 mol %) in toluene (4.0 mL) at temperature T for 24 h, unless otherwise noted. [b]Isolated yields. [c]Determined by chiral HPLC. [d]For 48 h. [e]For 72 h. [f]Under air for 72 h. [g]5 mol % $Ni(ClO_4)_2{\cdot}6H_2O$ and 6 mol % **L10** for 96 h.

Under the optimal reaction conditions, a wide range of nitroalkenes (**1a**–**n**) were investigated (Table 2). Nitroalkenes bearing para or meta substituents on the phenyl ring were well-tolerated, and their reactions with indole smoothly afforded the corresponding products with excellent enantioselectivities (>90% ee in most cases; entries 1–15). Relatively lower yields were obtained for products **3ia** and **3la**, showing that electron-withdrawing substituents at the para position have a negative effect on the reactivity (entries 10 and 13). The yields were also influenced unfavorably by the steric effect of the substrate. For example, modest yields were obtained for the products **3ga**, **3ha**, and **3na**, containing 3,5-disubstituted phenyl and 2-naphthyl groups (entries 8, 9, and 15). Moreover, no reaction took place with nitroalkene **1d** containing an *o*-tolyl group (entry 5). It is noteworthy that the heteroaromatic-substituted product **3ma** and the multifluorinated products **3ja**–**3la** were isolated in good yields with excellent enantioselectivities (entries 11–14). The reaction was also successfully extended to alkylated substrates. Good to excellent enantioselectivities were generally obtained for the reactions of substrates **1p**–**s** (entries 17–20). The exception was substrate **1o** bearing a benzyl group, which gave a significantly low ee (entry 16).

Table 2. Nitroalkene Substrate Scope[a]



entry	R	product	yield (%)[b]	ee (%)[c]
1	Ph (**1a**)	**3aa**	95	96
2[d]	Ph (**1a**)	**3aa**	88	96
3	3-MePh (**1b**)	**3ba**	87	95
4	4-MePh (**1c**)	**3ca**	91	96
5	2-MePh (**1d**)	**3da**	n.d.[e]	–
6	3-MeOPh (**1e**)	**3ea**	82	92
7	4-MeOPh (**1f**)	**3fa**	96	96
8	3,4-$(MeO)_2$Ph (**1g**)	**3ga**	78	88
9	3,5-Me_2Ph (**1h**)	**3ha**	72	93
10	4-ClPh (**1i**)	**3ia**	72	92
11	3-FPh (**1j**)	**3ja**	87	95
12	3-CF_3Ph (**1k**)	**3ka**	86	95
13	4-CF_3Ph (**1l**)	**3la**	80	95
14	3-thienyl (**1m**)	**3ma**	96	96
15	2-naphthyl (**1n**)	**3na**	69	95
16	benzyl (**1o**)	**3oa**	78	33
17	2-phenylethyl (**1p**)	**3pa**	88	97
18	3-phenylpropyl (**1q**)	**3qa**	84	88
19	4-phenoxybutyl (**1r**)	**3ra**	97	87
20	1-octyl (**1s**)	**3sa**	96	89

[a]Conditions: **1** (0.4 mmol), **2a** (0.6 mmol), $Ni(ClO_4)_2{\cdot}6H_2O$ (10 mol %), and **L10** (12 mol %) in toluene (4.0 mL) at 60 °C for 48–72 h. [b]Isolated yields. [c]Determined by chiral HPLC. [d]**1a** (4.0 mmol) and **2a** (6.0 mmol) in 30 mL toluene. [e]Not detected

The effect of indole substituents was examined next (Table 3). Excellent enantioselectivities were achieved with indoles bearing either electron-withdrawing or electron-donating groups at C4–C7 (entries 1–7). The reaction of 5-Br-indole was slow, and the product **3ae** was isolated in only 42% yield (entry 4). Gratifyingly, running the reaction at 80 °C improved

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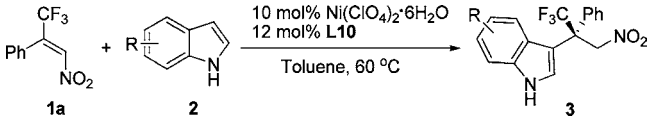
Table 3. Indole Substrate Scope[a]

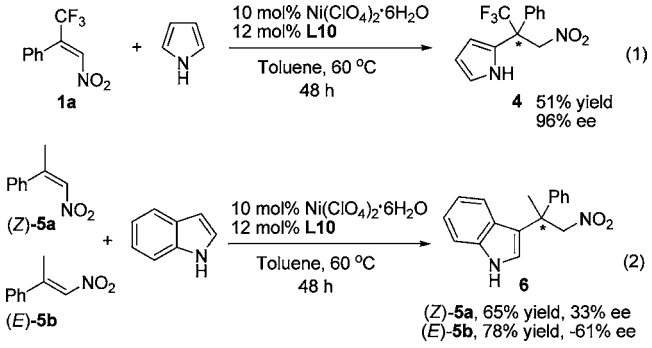


entry	R	product	yield (%)[b]	ee (%)[c]
1	4-MeO (**2b**)	**3ab**	92	97
2	5-MeO (**2c**)	**3ac**	92	96
3	5-Me (**2d**)	**3ad**	89	97
4	5-Br (**2e**)	**3ae**	42	96
5[d]	5-Br (**2e**)	**3ae**	85	96
6[d]	6-Cl (**2f**)	**3af**	86	90
7	7-Me (**2g**)	**3ag**	95	96
8	1-Me (**2h**)	**3ah**	trace	–
9	2-Me (**2i**)	**3ai**	85	15

[a]Conditions: **1a** (0.4 mmol), **2** (0.6 mmol), $Ni(ClO_4)_2·6H_2O$ (10 mol %), and **L10** (12 mol %) in toluene (4.0 mL) at 60 °C for 48 h. [b]Isolated yields. [c]Determined by chiral HPLC. [d]At 80 °C for 72 h.

the yield to 85% with the same ee (entry 5). 1-Me-indole and 2-Me-indole proved to be inferior substrates (entries 8 and 9): product **3ai** was obtained with 15% ee in the reaction of **2**-Me-indole with **1a**, and only a trace amount of product **3ah** was observed in the case of 1-Me-indole.

Pyrrole was also tested as substrate in this Friedel–Crafts reaction. As shown in eq 1, in the presence of 10 mol % $Ni(ClO_4)_2·6H_2O$ and 12 mol % **L10**, the reaction of pyrrole with **1a** proceeded smoothly to afford **4** in 51% yield with 96% ee. In addition, the reactions of indole with the β-methylnitrostyrene isomers (*Z*)-**5a** and (*E*)-**5b**, which are structurally similar to nitroalkene **1a**, were carried out under the identical reaction conditions (eq 2). Significantly lower ee values of 33% and −61%, respectively, were detected, revealing the unique fluorine effect of the CF_3-bearing substrate on the enantioselectivity.[18]



The absolute configuration of product **3ae** was determined to be *R* on the basis of its single-crystal X-ray structure. A possible model for asymmetric induction was then developed (Figure 1). The nitroalkene coordinates to Ni(II) in a 1,3-binding fashion,[8c,d] and the *Re*-face attack of indole at the β-position of the nitroalkene is favored.[13c]

We next examined the transformations of **3aa** to the corresponding trifluoromethylated tryptamine and tetrahydro-β-carboline as potentially biologically active compounds. Nitro reduction of **3aa** using $NaBH_4/NiCl_2·6H_2O$ in methanol at room temperature afforded tryptamine **7** in 92% yield with 96% ee (Scheme 3). Through a CF_3CO_2H-mediated Pictet–Spengler cyclization of **7** with benzaldehyde, trifluoromethylated tetrahydro-β-carboline **8**, an important structural motif in biologically active alkaloids, was isolated in 78% yield with a diastereomeric ratio of 1:2 and 96% ee for both isomers.

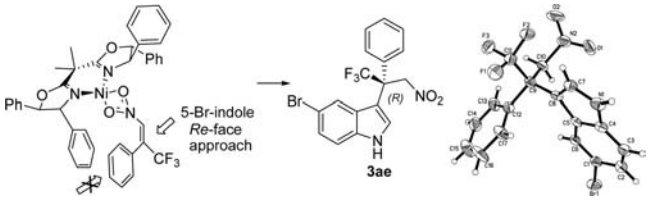
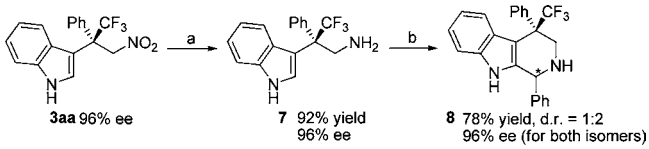


Figure 1. Proposed model for asymmetric induction.

Scheme 3. Synthetic Transformations of Product 3aa[a]



[a]Conditions: (a) $NaBH_4$ (5.0 equiv), $NiCl_2·6H_2O$ (1.0 equiv), MeOH, rt, 30 min. (b) PhCHO (1.2 equiv), CF_3CO_2H (2.0 equiv), $MgSO_4$, CH_2Cl_2, rt, 4 days.

In conclusion, we have developed a highly enantioselective Michael-type Friedel–Crafts alkylation reaction of indoles with β-trifluoromethyl-β-disubstituted nitroalkenes catalyzed by a $Ni(ClO_4)_2$–bisoxazoline complex. This is the first highly enantioselective Friedel–Crafts alkylation reaction to enable the construction of all-carbon quaternary stereocenters, and it provides a reliable strategy for the synthesis of trifluoromethyl-substituted chiral benzylic compounds. Further extension of this methodology in organic synthesis is currently underway in our laboratory.

■ ASSOCIATED CONTENT

Supporting Information

Full experimental procedures and characterization data, including ^1H, ^{13}C, and ^{19}F NMR spectra for all new compounds, chiral HPLC traces for the products, and crystal data. This material is available free of charge via the Internet at http://pubs.acs.org.

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Notes

The authors declare no competing financial interest.

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Y.-X.J. dedicates this work to Professor Qi-Lin Zhou on the occasion of his 55th birthday and to Professor E. Peter Kündig on the occasion of his retirement. We are grateful for the generous financial support by the National Natural Science Foundation of China (21002089) and Young Scholarship for the Doctoral Program of Higher Education (20103317120001).

■ REFERENCES

(1) (a) Kirsch, P. *Modern Fluoroorganic Chemistry: Synthesis, Reactivity, Applications*; Wiley-VCH: Weinheim, Germany, 2004. (b) Müller, K.; Faeh, C.; Diederich, F. *Science* **2007**, *317*, 1881. (c) Bégué, J.-P.; Bonnet-Delpon, D. *Bioorganic and Medicinal Chemistry of Fluorine*; Wiley-VCH: Weinheim, Germany, 2008. (d) Hagmann, W. K. *J. Med. Chem.* **2008**, *51*, 4359. (e) Filler, R.;

Saha, R. *Future Med. Chem.* **2009**, *1*, 777. (f) *Fluorine in Medicinal Chemistry and Chemical Biology*; Ojima, I., Ed.; Wiley: Chichester, U.K., 2009. (g) *Chiral Drugs: Chemistry and Biological Action*; Lin, G.-Q., You, Q.-D., Cheng, J.-F., Eds.; Wiley: Hoboken, NJ, 2011.

(2) For recent reviews, see: (a) Lundgren, R. J.; Stradiotto, M. *Angew. Chem., Int. Ed.* **2010**, *49*, 9322. (b) Furuya, T.; Kamlet, A. S.; Ritter, T. *Nature* **2011**, *473*, 470. (c) Qing, F.-L.; Zheng, F. *Synlett* **2011**, 1052. (d) Roy, S.; Gregg, B. T.; Gribble, G. W.; Le, V.-D.; Roy, S. *Tetrahedron* **2011**, *67*, 2161. (e) Tomashenko, O. A.; Grushin, V. V. *Chem. Rev.* **2011**, *111*, 4475. (f) Besset, T.; Schneider, C.; Cahard, D. *Angew. Chem., Int. Ed.* **2012**, *51*, 5048.

(3) For reviews, see: (a) Mikami, K.; Itoh, Y.; Yamanaka, M. *Chem. Rev.* **2004**, *104*, 1. (b) Shibata, N.; Mizuta, S.; Kawai, H. *Tetrahedron: Asymmetry* **2008**, *19*, 2633. (c) Ma, J.-A.; Cahard, D. *Chem. Rev.* **2008**, *108*, PR1. (d) Nie, J.; Guo, H.-C.; Cahard, D.; Ma, J.-A. *Chem. Rev.* **2011**, *111*, 455. (e) Valero, G.; Companyo, X.; Rios, R. *Chem.—Eur. J.* **2011**, *17*, 2018.

(4) For reviews of catalytic asymmetric construction of all-carbon quaternary stereocenters, see: (a) Corey, E. J.; Guzman-Perez, A. *Angew. Chem., Int. Ed.* **1998**, *37*, 388. (b) Douglas, C. J.; Overman, L. E. *Proc. Natl. Acad. Sci. U.S.A.* **2004**, *101*, 5363. (c) Christoffers, J.; Baro, A. *Adv. Synth. Catal.* **2005**, *347*, 1473. (d) Trost, B. M.; Jiang, C. *Synthesis* **2006**, 369. (e) Hawner, C.; Alexakis, A. *Chem. Commun.* **2010**, *46*, 7295.

(5) (a) Deng, Q.-H.; Wadepohl, H.; Gade, L. H. *J. Am. Chem. Soc.* **2012**, *134*, 10769. (b) Kawai, H.; Okusu, S.; Tokunaga, E.; Sato, H.; Shiro, M.; Shibata, N. *Angew. Chem., Int. Ed.* **2012**, *51*, 4959.

(6) For a book, see: (a) *Catalytic Asymmetric Friedel-Crafts Alkylations*; Bandini, M., Umani-Ronchi, A., Eds.; Wiley-VCH: Weinheim, Germany, 2009. For reviews, see: (b) Poulsen, T. B.; Jørgensen, K. A. *Chem. Rev.* **2008**, *108*, 2903. (c) You, S.-L.; Cai, Q.; Zeng, M. *Chem. Soc. Rev.* **2009**, *38*, 2190. (d) Bandini, M.; Eichholzer, A. *Angew. Chem., Int. Ed.* **2009**, *48*, 9608. (e) Terrasson, V.; Figueiredo, R. M.; Campagne, J. M. *Eur. J. Org. Chem.* **2010**, 2635.

(7) (a) Banwell, M. G.; Beck, D. A. S.; Willis, A. C. *ARKIVOC* **2006**, No. iii, 163. (b) Lyzwa, D.; Dudzinski, K.; Kwiatkowski, P. *Org. Lett.* **2012**, *14*, 1540.

(8) For selected examples, see: (a) Zhuang, W.; Hazell, R. G.; Jørgensen, K. A. *Org. Biomol. Chem.* **2005**, *3*, 2566. (b) Herrera, R. P.; Sgarrzani, V.; Bernardi, L.; Ricci, A. *Angew. Chem., Int. Ed.* **2005**, *44*, 6576. (c) Jia, Y.-X.; Zhu, S.-F.; Yang, Y.; Wang, L.-X.; Zhou, Q.-L. *J. Org. Chem.* **2006**, *71*, 75. (d) Lu, S.-F.; Du, D.-M.; Xu, J. *Org. Lett.* **2006**, *8*, 2115. (e) Ganesh, M.; Seidel, D. *J. Am. Chem. Soc.* **2008**, *130*, 16464. (f) Itoh, J.; Fuchibe, K.; Akiyama, T. *Angew. Chem., Int. Ed.* **2008**, *47*, 4016. (g) Yokoyama, N.; Arai, T. *Chem. Commun.* **2009**, 3285. (h) McKeon, S. C.; Müller-Bunz, H.; Guiry, P. J. *Eur. J. Org. Chem.* **2009**, 4833. (i) Liu, H.; Du, D.-M. *Adv. Synth. Catal.* **2010**, *352*, 1113. (j) Kim, H. Y.; Kim, S.; Oh, K. *Angew. Chem., Int. Ed.* **2010**, *49*, 4476. (k) Guo, F.; Lai, G.; Xiong, S.; Wang, S.; Wang, Z. *Chem.—Eur. J.* **2010**, *16*, 6438. (l) Takenaka, N.; Chen, J.; Captain, B.; Sarangthem, R. S.; Chandrakumar, A. *J. Am. Chem. Soc.* **2010**, *132*, 4536. (m) Wu, J.; Li, X.; Wu, F.; Wan, B. *Org. Lett.* **2011**, *13*, 4834.

(9) (a) Trost, B. M.; Müller, C. *J. Am. Chem. Soc.* **2008**, *130*, 2438. (b) Liu, H.; Lu, S.-F.; Xu, J.; Du, D.-M. *Chem.—Asian J.* **2008**, *3*, 1111. (c) Sheng, Y.-F.; Gu, Q.; Zhang, A.-J.; You, S.-L. *J. Org. Chem.* **2009**, *74*, 6899. (d) Sheng, Y.-F.; Li, G.-Q.; Kang, Q.; Zhang, A.-J.; You, S.-L. *Chem.—Eur. J.* **2009**, *15*, 3351. (e) Zhang, G. *Org. Biomol. Chem.* **2012**, *10*, 2534.

(10) Liu, H.; Xu, J.; Du, D.-M. *Org. Lett.* **2007**, *9*, 4725.

(11) (a) Liu, T.-Y.; Cui, H.-L.; Chai, Q.; Long, J.; Li, B.-J.; Wu, Y.; Ding, L.-S.; Chen, Y.-C. *Chem. Commun.* **2007**, 2228. (b) Sohtome, Y.; Shin, B.; Horitsugi, N.; Takagi, R.; Nagasawa, K. *Angew. Chem., Int. Ed.* **2010**, *49*, 7299.

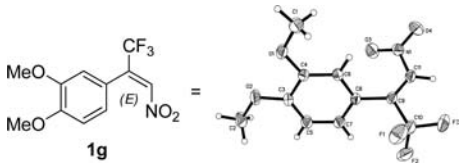
(12) (a) Wu, J.; Mampreian, D. M.; Hoveyda, A. H. *J. Am. Chem. Soc.* **2005**, *127*, 4584. (b) Lu, H.-H.; Zhang, F.-G.; Meng, X.-G.; Duan, S.-W.; Xiao, W.-J. *Org. Lett.* **2009**, *11*, 3946. (c) Zhang, F.-G.; Yang, Q.-Q.; Xuan, J.; Lu, H.-H.; Duan, S.-W.; Chen, J.-R.; Xiao, W.-J. *Org. Lett.* **2010**, *12*, 5636.

(13) $Ni(ClO_4)_2$ has proved to be an efficient catalyst in asymmetric catalysis. For a review, see: (a) Dalpozzo, R.; Bartoli, G.; Sambri, L.; Melchiorre, P. *Chem. Rev.* **2010**, *110*, 3501. For selected examples, see: (b) Kanemasa, S.; Oderaotoshi, Y.; Tanaka, J.; Wada, E. *J. Am. Chem. Soc.* **1998**, *120*, 12355. (c) Kanemasa, S.; Oderaotoshi, Y.; Sakaguchi, S.; Yamamoto, H.; Tanaka, J.; Wada, E.; Curran, D. P. *J. Am. Chem. Soc.* **1998**, *120*, 3074. (d) Kanemasa, S.; Oderaotoshi, Y.; Wada, E. *J. Am. Chem. Soc.* **1999**, *121*, 8657. (e) Kanemasa, S.; Kanai, T. *J. Am. Chem. Soc.* **2000**, *122*, 10710. (f) Kennosuke, I.; Kanemasa, S. *J. Am. Chem. Soc.* **2002**, *124*, 13394. (g) Sibi, M. P.; Ma, Z.; Jasperse, C. P. *J. Am. Chem. Soc.* **2005**, *127*, 5764. (h) Shibata, N.; Kohno, J.; Takai, K.; Ishimaru, T.; Nakamura, S.; Toru, T.; Kanemasa, S. *Angew. Chem., Int. Ed.* **2005**, *44*, 4204. (i) Suga, H.; Funyu, A.; Kakehi, A. *Org. Lett.* **2007**, *9*, 97. (j) Lifchits, O.; Charette, A. B. *Org. Lett.* **2008**, *10*, 2809. (k) Shi, J.-W.; Zhao, M.-X.; Lei, Z.-Y.; Shi, M. *J. Org. Chem.* **2008**, *73*, 305. (l) Suga, H.; Furihata, Y.; Sakamoto, A.; Itoh, K.; Okumura, Y.; Tsuchida, T.; Kakehi, A.; Baba, T. *J. Org. Chem.* **2011**, *76*, 7377. (m) Zhou, Y.-Y.; Wang, L.-J.; Li, J.; Sun, X.-L.; Tang, Y. *J. Am. Chem. Soc.* **2012**, *134*, 9066.

(14) For the latest examples of asymmetric Friedel–Crafts reactions with β-CF_3-β,α-unsaturated systems as substrates to form tertiary trifluoromethylated stereocenters, see: (a) Huang, Y.; Tokunaga, E.; Suzuki, S.; Shiro, M.; Shibata, N. *Org. Lett.* **2010**, *12*, 1136. (b) Blay, G.; Fernandez, I.; Munoz, M. C.; Pedro, J. R.; Vila, C. *Chem.—Eur. J.* **2010**, *16*, 9117. (c) Lin, J.-H.; Xiao, J.-C. *Eur. J. Org. Chem.* **2011**, 4536. (d) Wang, W.; Lian, X.; Chen, D.; Liu, X.; Lin, L.; Feng, X. *Chem. Commun.* **2011**, *47*, 7821. (e) Wen, L.; Shen, Q.; Wan, X.; Lu, L. *J. Org. Chem.* **2011**, *76*, 2282. (f) Shibatomi, K.; Narayama, A.; Abe, Y.; Iwasa, S. *Chem. Commun.* **2012**, *48*, 7380.

(15) Wahed, A. R.; Norbert, M. T.; Tesuya, M. PCT Int. Appl. 2011128299, Oct 20, 2011.

(16) The configuration of nitroalkene **1g** was determined to be *E* by single-crystal X-ray analysis, and those of the other substrates were determined by analogy.



1g

(17) No reaction occurred in the absence of a ligand or with 2,2′-bipyridine as the ligand.

(18) Liu, Y.-L.; Shi, T.-D.; Zhou, F.; Zhao, X.-L.; Wang, X.; Zhou, J. *Org. Lett.* **2011**, *13*, 3826.