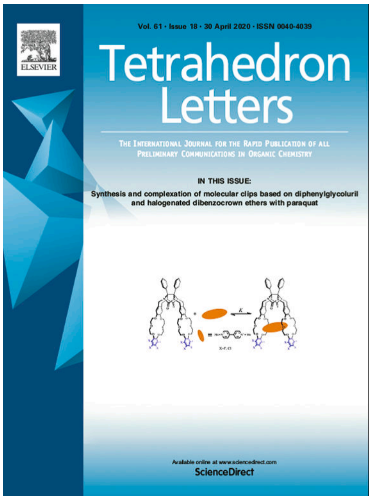

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Efficient aerobic cross-dehydrogenative coupling of tertiary amines over NiGa layered double oxide

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Abstract: An efficient and convenient heterogeneous catalytic system has been developed for the aerobic cross-dehydrogenative coupling over NiGa layered double oxide (Ni_3Ga-LDO) without any additives. The results indicated that the catalytic system could tolerate various tetrahydroquinoline derivatives and nucleophiles using molecular oxygen as a sustainable oxidant. The catalyst could be recycled four times without significantly decrease of activity or change of XRD pattern, indicating that Ni_3Ga-LDO was catalytically and structurally stable in the cross-coupling reaction.

Keywords: cross-dehydrogenative coupling; NiGa layered double oxide; molecular oxygen; C–H activation; *N*-phenyltetrahydroisoquinoline

Cross-dehydrogenative coupling (CDC) reaction has been an attractive strategy for constructing C–C bonds under oxidative conditions, because it avoids prefunctionalization of the coupling partners [1]. During the past decade, considerable progress has been achieved in oxidative CDC reactions and various homogeneous catalytic systems based on Cu [2], Fe [3], Ru [4], Au [5], Rh [6], Co [7], and metal-free systems [8], have been developed using molecular oxygen or peroxides as the oxidant. Even so, it is hard for homogeneous systems to achieve high catalytic efficiency, sustainability and cost-effectiveness. Some heterogeneous catalysts originated from Au [9], Ru [10] and some photocatalyzed systems [11] have been developed for CDC reactions. However, precious metals applied for these catalysts will limit their wide application to some extent.

Some noble-metal-free materials have been introduced into CDC reactions. Hudson et al. [12] reported that $CuFe_2O_4$ nanoparticles could effectively catalyze the coupling reaction of two sp^3 carbons using DDQ (2,3-dichloro-5,6-dicyanobenzoquinone) as the oxidant. Liu et al. developed a SBA-15-support iron terpyridine [13] catalyst, which exhibited excellent catalytic activity for the C–C cross-coupling reactions in the presence of TBHP (*tert*-butyl hydroperoxide). Marset et al. [14] developed a magnetite supported copper(II) oxide catalyst for the synthesis of different tetrahydroisoquinolines via CDC reaction using choline chloride/ethylene glycol as

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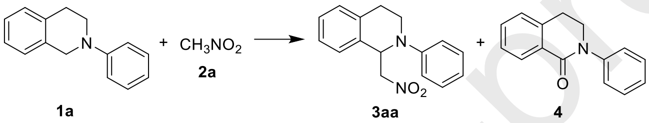
a deep eutectic solvent, but the efficiency was quite low. Sharma et al. [15] found that CeO_2 could efficiently catalyze the C–H functionalization of *N*-aryltetrahydroisoquinolines via CDC reactions. Recently, Dutta et al. [16] disclosed a heterogeneous catalytic approach for selective coupling of C1 of *N*-aryltetrahydroisoquinolines with C3 of indoles over mesoporous manganese oxides using molecular oxygen as the oxidant. Still and all, some of the above systems required complicated preparation methods for catalysts, or were only investigated in limited substrate scope. In addition, peroxides were always introduced as the oxidant, which are corrosive and unstable at room temperature, making them less suitable for large scale industrial reactions. In view of the principles of green and practical chemistry, developing efficient heterogeneous catalytic system based on readily available materials using molecular oxygen without any additives for the CDC reaction is still highly desirable.

In our study on the heterogeneous catalytic materials for the aerobic CDC reactions, we found that NiGa layered double oxide (Ni_3Ga-LDO) could efficiently accelerate the transformation using molecular oxygen as the sole oxidant without any additives. Although nickel has emerged as a good choice to replace precious transition metals for the C−H bond activation, including various CDC reactions [17], heterogeneous catalyst based on nickel has rarely been reported. Henceforth, we report a facile and operationally convenient catalytic system for the aerobic oxidative coupling of tertiary amines with various pro-nucleophiles based on Ni-containing material under mild conditions.

Initially, the cross-coupling between *N*-phenyltetrahydroisoquinoline **1a** and nitromethane **2a** was chosen as a model reaction to optimize the reaction conditions (Table 1). Various solvents were firstly screened in the model reaction. It is observed that all the selected solvents could give good selectivity to the desired product except acetonitrile and toluene (entries 1-8), suggesting that polar environment might benefit to the coupling reaction. The main byproduct was 2-phenyl-3,4-dihydroisoquinolin-1(2H)-one (4), which should be produced from over-oxidation, in consistent with reported results [7,17a]. The low selectivity might also imply that the rate of over-oxidative amide formation was higher than that of enamine nucleophilic attack under acetonitrile or toluene. However, the conversions were generally unsatisfactory under the selected solvents (entry 2), and the highest conversion of **1a** was observed using dioxane as the solvent with a satisfied selectivity. Concerning the reaction temperature, decreasing the temperature to 60 °C resulted in significantly reduced 52% conversion of **1a** and 32% selectivity of **3aa** (entry 9). When the reaction performed under an increased temperature of 100 °C, the selectivity of **3aa** was 68% (entry 10), which should be due to the over-oxidation of the substrate. Decreasing the ratio of **2a**/**1a** to 2 or 4, reduced conversion and selectivity were observed, whilst further increasing the value to 8 only gave slightly improved yield of **3aa** (etnries 11-13). Prolonging the reaction time to 16 h led to full conversion and an increased 92% selectivity of **3aa**. Further increasing the time could not improve the result significantly. According to the proposed reaction path for the CDC reaction of *N*-aryltetrahydroisoquinolines [2g,11c,11d], it is generally believed that iminium cation is firstly formed via oxidative dehydrogenation, and a nucleophile attacks the intermediate to afford the coupled products. In the present catalytic aerobic CDC reactions, the fact that the selectivity increased with the reaction time should be related to the formation of iminium intermediate. These observations also suggested that the nucleophilic attack reaction was slower than the oxidative dehydrogenation. Summary, an efficient heterogeneous catalytic system based on Ni_3Ga-LDO has been developed for the CDC reaction between *N*-phenyltetrahydroisoquinoline and nitromethane using molecular oxygen as the sole oxidant.

Table 1 Optimization of the reaction conditions.[a]



Entry	Solvent	Temp. /°C	**2a**/**1a**	Conv. (Sel.)[b] /%
1	acetonitrile	80	6	12 (67)
2	1,4-dioxane	80	6	93 (85)
3	trifluorotoluene	80	6	21 (98)
4	mesitylene	80	6	18 (93)
5	DCE	80	6	13 (92)
6	toluene	80	6	32 (71)
7	H_2O	80	6	43 (98)
8	DMSO	80	6	18 (95)
9	1,4-dioxane	60	6	52 (32)
10	1,4-dioxane	100	6	>99 (68)
11	1,4-dioxane	80	2	89 (72)
12	1,4-dioxane	80	4	91 (75)
13	1,4-dioxane	80	8	94 (86)
14[c]	1,4-dioxane	80	6	>99 (92)
15[d]	1,4-dioxane	80	6	>99 (93)

[a] Reaction conditions: **1a** 0.5 mmol, Ni_3Ga-LDO 0.2 g, solvent 2 mL, 12 h, O_2 atmosphere (1 atm).

[b] Based on the ^1H-NMR analysis.

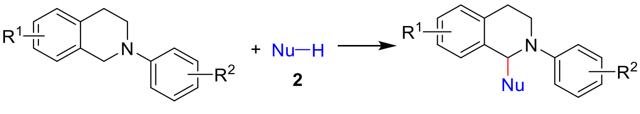
[c] 16 h.

[d] 20 h.

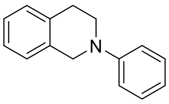
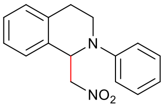
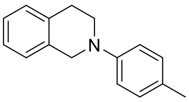
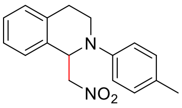
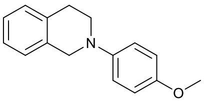
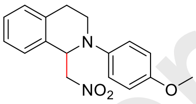
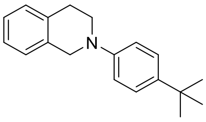
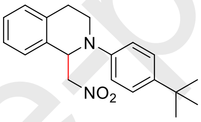
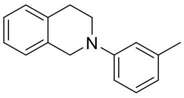
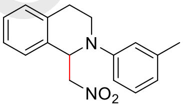
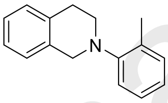
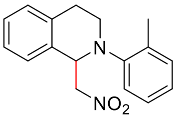
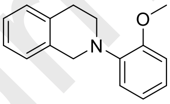
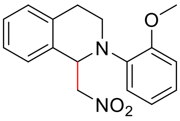
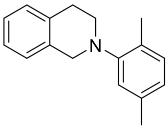
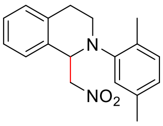
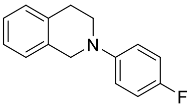
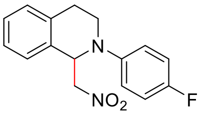
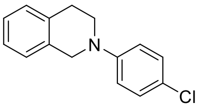
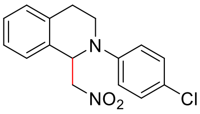
With the optimized reaction conditions have been obtained, various substrates have been tested in the CDC reaction under analogous reaction conditions (Table 2). A variety of *N*-phenyltetrahydroquinoline derivatives with different substituents were firstly introduced into the Ni_3Ga-LDO-catalyzed aerobic cross-coupling reaction. It can be observed that substrates with electron-donating substituents on the *para*-site of the aromatic rings could be well tolerated by the catalytic system, and good to excellent yields of the coupled product were obtained (entries 2-4), comparable with the reported Fe-based catalytic systems [3a]. When groups on the *meta*-or/and ortho-sites of the aromatic rings, prolonged reaction time were required for the full conversion of the substrates (entries 5-8), indicating the existence of steric effect. Delightedly, *N*-(3-methylphenyl)-1,2,3,4-tetrahydroisoquinoline gave an excellent 88% isolated yield of the corresponding CDC product (**3ea**) with a longer reaction time. On the other hand, for the substrates with electron-withdrawing groups locating on the *para*-sites of aromatic rings, significantly longer reaction times were required to finish the reaction and relatively lower yields of the corresponding coupled products were obtained (entries 9-11). These observations indicated that electron-withdrawing groups suppressed the CDC reactivity, and the electronic effect existed in the catalytic system. For the compound **1l** with two methoxyl groups on 6- and 7-sites, it could also give a good yield for the target product (entry 12), and methoxyl group activated the substrate. On the contrary, electron-withdrawing substituent, such as Br on the 7-site reduced the reactivity, and longer reaction time was required (entry 13). Even though, a good 75% yield of the coupling product was obtained. On the whole, moderate to good yields of the products could be obtained under the selected conditions for these substrates. *N*-phenylpiperidine was also tested in the present catalytic system. Only a 23% yield of the corresponding coupled product could be obtained (entry 14), which might be due to its low reactivity in the formation of iminium intermediate, because it is not stable in the case [18].

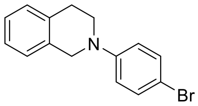
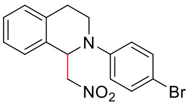
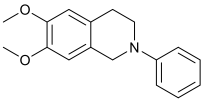
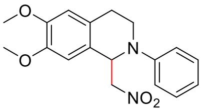
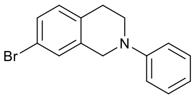
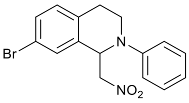
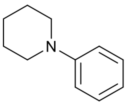
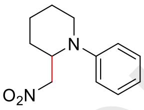
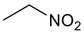
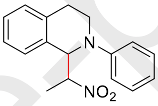
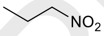
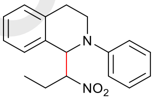
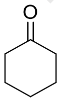
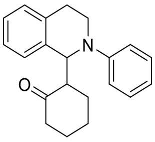
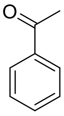
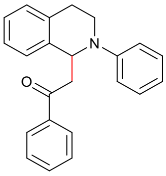
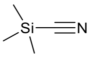
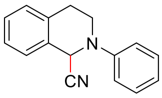
In addition, some other nucleophiles with C_{sp3}–H have also been tested. Nitroalkanes with different carbon atoms could be well tolerated in the catalytic system (**3ab** and **3ac**), and good yields were obtained, behaving comparably performance with the homogeneous Cu systems [2a]. The reactivity discernibly decreased as the carbon atom increase, which was probably due to the steric hindrance effect (entries 15-16). For the carbonyl compounds with α-C–H, cyclohexanone and acetophenone could not gave satisfied yield of the coupled product (entry 17), which was possibly ascribed to their steric hindrance and the lower nucleophilicity. Trimethylsilyl cyanide, as a typical cyanide source, was also investigated in the catalytic system, and a good 73% yield was obtained (entry 19). It can be concluded from the above results that *N*-phenyl-1,2,3,4-tetrahydroisoquinoline and its derivatives and some nucleophiles were compatible in the Ni_3Ga-LDO -catalyzed aerobic CDC reaction. They could uniformly provide the corresponding products in good to excellent isolated yields in appropriate reaction times.

Table 2 Reaction scope for the Ni$_3$Ga-LDO-catalyzed aerobic CDC reaction.[a]



1 3

Entry	1	2	3	Time /h	Yield[b] /%
1	 **1a**	CH_3NO_2 **2a**	 **3aa**	16	84
2	 **1b**	**2a**	 **3ba**	16	78
3	 **1c**	**2a**	 **3ca**	16	72
4	 **1d**	**2a**	 **3da**	16	69
5	 **11** **e**	**2a**	 **3ea**	24	88
6	 **1f**	**2a**	 **3fa**	24	72
7	 **1g**	**2a**	 **3ga**	36	76
8	 **1h**	**2a**	 **3ha**	24	62
9	 **1i**	**2a**	 **3ia**	24	59
10	 **1j**	**2a**	 **3ja**	24	62

11	 **1k**	**2a**	 **3ka**	24	68
12	 **1l**	**2a**	 **3la**	20	69
13	 **1m**	**2a**	 **3ma**	36	75
14	 **1n**	**2a**	 **3na**	48	23
15	**1a**	 **2b**	 **3ab**	24	78
16	**1a**	 **2c**	 **3ac**	24	73
17	**1a**	 **2d**	 **3ad**	36	46
18	**1a**	 **2e**	 **3ae**	36	40
19	**1a**	 **2f**	 **3af**	24	73

[a] Reaction conditions: **1** 0.5 mmol, **2** 3 mmol, Ni_3Ga-LDO 0.2 g, 1,4-dioxane 2 mL, 80 °C, O_2 atmosphere (1 atm).

[b] Isolated yield.

To confirm the heterogeneity of Ni_3Ga-LDO-catalyzed system, a hot filtration experiment has been conducted under the standard conditions. After 4 h (～38% conversion of **1a**), the filtrate afforded only slight additional conversion for another 8 h under the same conditions (Fig. 1). These observations implied that Ni_3Ga-LDO was a true heterogeneous catalyst in the reaction, and leaching of active metals could be ignored. The catalytic stability of Ni_3Ga-LDO was also tested in the research. After the reaction, the catalyst was filtrated, washed with ethyl acetate and dried at 120 °C for 4 h to recycle the catalyst. The results showed that only slight reduction of activity and selectivity were observed for the catalyst even after four runs (Fig. S1). XRD pattern for the recycled catalyst indicates that the structure of the NiGa hydrotalcite double oxide was basically preserved after several reuses (Fig. S2).

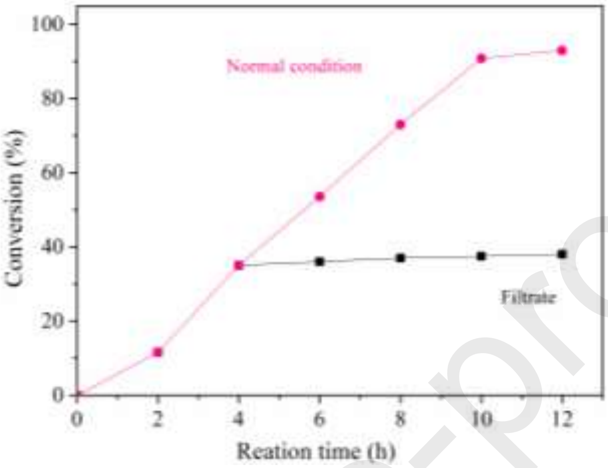
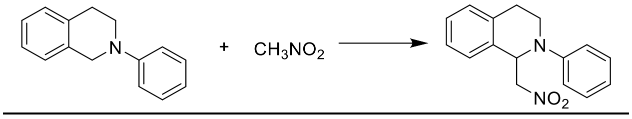


Fig. 1. The hot-filtration experiment. Reaction conditions: **1a** 0.5 mmol, **2a** 3 mmol, Ni_3Ga-LDO 0.2 g, 1,4-dioxane 2 mL, 80 °C, O_2 atmosphere (1 atm).

To validate the possible reaction pathways, some controlled experiments have been conducted under the standard reaction conditions (Table 3). In the absence of catalyst, Only a 45% selectivity could be obtained with a significantly lower conversion, implying the catalytic activity of Ni_3Ga-LDO for the CDC reaction (entry 2). When oxygen was replaced by air, markedly decreased catalytic activity was observed, indicating that molecular O_2 was important for the Ni_3Ga-LDO-catalyzed CDC reaction. In addition, performing the reaction under nitrogen atmosphere still led to a 20% conversion of **1a**, implying that oxygen was not necessary at the initial stage of the reaction. In all cases with catalyst, the selectivity for the coupled product were significantly higher than that without catalyst (entries 1-4), indicating that Ni_3Ga-LDO was effective for the coupling reaction, which might be related to the surface acidity of catalyst [19]. To further elucidate the catalytic performance of Ni_3Ga-LDO, Mg_3Ga-LDO and Ni_3Al-LDO were subjected into the reaction as comparisons. Under the standard reaction conditions, lower conversion of **1a** was observed in the case of Mg_3Ga-LDO, while Ni_3Al-LDO could gave full conversion, suggesting that Ni might be the catalytic active site. However, quite lower selectivity to **3aa** was obtained in both cases, which might be related to the varied surface property of these catalysts, which is affected mainly by the compositions of layered double oxide [20].

When the reaction was conducted with 2,6-di-*tert*-butyl-4-methylphenol (BHT) or CCl_3Br as a radical scavenger, quite lower conversion of the substrate and selectivity to **3aa** were obtained (entry 6), although only a slight decrease of conversion was observed in the case of CCl_3Br. These results implied that a radical pathway was probably involved in the Ni_3Ga-LDO-catalyzed aerobic CDC reaction of *N*-aryl tetrahydroisoquinolines.

Table 3 The results of some controlled experiments.[a]



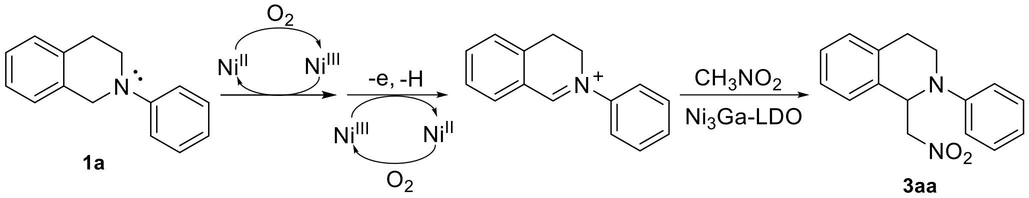
Entry	Catalyst	Reaction conditions	Conv.[b] /%	Sel.[b] /%
1	Ni_3Ga-LDO	O_2	>99	92
2	-	O_2	79	45
3	Ni_3Ga-LDO	air	67	84
4	Ni_3Ga-LDO	N_2	20	80
5	Ni_3Al-LDO	O_2	>99	51
6	Mg_3Ga-LDO	O_2	92	62
7	Ni_3Ga-LDH	O_2	97	65
8	Ni_3Ga-LDO	O_2/BHT[c]	56	76
9	Ni_3Ga-LDO	O_2/CCl_3Br[c]	97	48

[a] Reaction conditions: **1a** 0.5 mmol, **2a** 3 mmol, Ni_3Ga-LDO 0.2 g, 1,4-dioxane 2 mL, 80 °C, 16 h, O_2 atmosphere (1 atm).

[b] Based on the ^{1}H-NMR analysis.

[c] 2 Equiv. of substrate.

The possibly formed iminium intermediate was also examined in the CDC reactions by analysing the reaction mixture performed without a nucleophile [2,3]. The iminium could be obviously observed at 208.1 apart from the substrate peak (210.1) (Fig. S3), confirming the formation of iminium ion. The controlled experiment has shown that both of the conversion and selectivity decreased without catalyst (Table 3, entries 1-2), implying that Ni_3Ga-LDO might accelerate not only the transform of the substrate, but also the nucleophilic attack of the formed iminium. On the basis of the obtained and reported results [2,3,7,17b,17c], we believe that *N*-aryl tetrahydroisoquinoline (**1a**) is oxidized to iminium ion intermediate (**II**) in the catalytic system (Scheme 1). Subsequently, the intermediate reacts nucleophilic species to furnish the desired coupled product **3aa** with the catalysis of Ni_3Ga-LDO.



Scheme 1. A possible reaction path for the Ni_3Ga-LDO-catalyzed aerobic CDC reaction of *N*-phenyltetrahydroisoquinolines with nitromethane

In summary, a green and sustainable catalytic system based on NiGa layered double oxide for the aerobic CDC reaction has been developed. Various substrates could be tolerated by the present protocol, and it provides an alternative synthetic strategy to achieve CDC reaction for the *α*-functionalization of *N*-aryl tetrahydroisoquinolines via heterogeneous catalysis. Further studies on the application of the protocol to other substrates and the detailed catalytic mechanism are under way in our laboratory.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgment

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Supplementary data

Supplementary data (general experimental information, and ^{1}H and ^{13}C NMR spectral data for all compounds) associated with this article can be found, in the online version, at doi:0000000.

References

[1] (a) P. Anastas, N. Eghbali, Chem. Soc. Rev. 39 (2010) 301-312;
(b) Z. Li, C.J. Li, J. Am. Chem. Soc. 127 (2005) 6968-6969;
(c) G. Wang, J.T. Wang, B. Zhao, et al., Tetrahedron Lett. 61 (2020) 151426;
(d) X.L. Zhang, G.F. Pan, X.Q. Zhu, et al., Org. Lett. 21 (2019) 2731-2735;
(e) D.Y. Wang, S.H. Guo, G.L. Pan, et al., Org. Lett. 20 (2018) 1794-1797.

[2] Some selected examples:
(a) Z.P. Li, C.J. Li, J. Am. Chem. Soc. 126 (2004) 11810-11811;
(b) Z.P. Li, C.J. Li, Eur. J. Org. Chem. 44 (2005) 3173-3176;
(c) Z.P. Li, C.J. Li, Org. Lett. 6 (2004) 4997-4999;
(d) Z.P. Li, C.J. Li, J. Am. Chem. Soc. 127 (2005) 3672-3673;

(e) O. Baslé, C.J. Li, Chem. Commun. 27 (2009) 4124-4126;

(f) O. Baslé, C.J. Li, Green Chem. 9 (2007) 1047-1050;

(g) E. Boess, C. Schmitz, M. Klussmann, J. Am. Chem. Soc. 134 (2012) 5317-5325;

(h) W. Zhang, S.P. Yang, Z.M. Shen, Adv. Synth. Catal. 358 (2016) 2392-2397;

(i) T. Wang, M. Schrempp, A. Berndhäuser,et al., Org. Lett. 17 (2015) 3982-3985;

(j) G. Zhang, Y.X. Ma, S.L. Wang, et al., J. Am. Chem. Soc. 134 (2012) 12334-12337;

(k) Z.P. Li, D.S. Bohle, C.J. Li, Proc. Natl. Acad. Sci. 103 (2006) 8928-8933;

(l) X.Z. Shu, X.F. Xia, Y.F. Yang, et al., J. Org. Chem. 74 (2009) 7464-7469;

(m) M. Ghobrial, M. Schnürch, M.D. Mihovilovic, J. Org. Chem. 76 (2011) 8781-8793;

(n) Y.X. Liu, C. Wang, D. Xue,et al., Chem. Eur. J. 23 (2017) 3051-3061.

[3] (a) M. Brzozowski, J.A. Forni, G.P. Savage, et al., Chem. Commun. 51 (2015) 334-337;

(b) M.O. Ratnikov, X.F. Xu, M.P. Doyle, J. Am. Chem. Soc. 135 (2013) 9475-9478;

(c) T.Y. Huang, X.H. Liu, J.W. Lang, et al., ACS Catal. 135 (2017) 5654-5660.

[4] (a) M.Z. Wang, C.Y. Zhou, M.K. Wong, et al., Chem. Eur. J. 16 (2010) 5723-5735;

(b) A.H. Yu, Z. Gu, D. Chen, et al., Catal. Commun. 11 (2009) 162-166;

(c) P. Rana, R. Gaur, R. Gupta, et al., Chem. Commun. 55 (2019) 7402-7405.

[5] J. Xie, H.M. Li, J.C. Zhou, et al., Angew. Chem. Int. Ed. 51 (2012) 1252-1255.

[6] M.O. Ratnikov, M.P. Doyle, J. Am. Chem. Soc. 135 (2013) 1549-1557.

[7] M.R. Patil, N.P. Dedhia, A.R. Kapdi,et al., J. Org. Chem. 83 (2018) 4477-4490.

[8] (a) H. Ueda, K. Yoshida, H. Tokuyama, Org. Lett. 16 (2014) 4194-4197;

(b) K. Alagiri, P. Devadig, K.R. Prabhu, Chem. Eur. J. 18 (2012) 5160-5164;

(c) R.A. Kumar, G. Saidulu, K.R. Prasad, et al., Adv. Synth. Catal. 354 (2012) 2985-2991;

(d) X.H. Pan, X.G. Liu, S.T. Sun, et al., Chin. J. Chem. 36 (2018) 1187-1190;

(e) M. Cao, Y. Mao, J.C. Huang, et al., Tetrahedron Lett. 60 (2019) 1075-1078;

(f) M.L. Deb, C.D. Pegu, P.J. Borpatra, et al., Tetrahedron Lett. 57 (2016) 5479-5483.

[9] (a) H.E. Ho, Y. Ishikawa, N. Asao, et al., Chem. Commun. 51 (2015) 12764-12767;

(b) W.S. Yang, L. Wei, T. Yan, et al., Catal. Sci. Technol. 7 (2017) 1744-1755.

[10] Q.Y. Meng, Q. Liu, J.J. Zhong, et al., Org. Lett. 14 (2012) 5992-5995.

[11] (a) Z. Li, Y.X. Pi, D.Y. Xu, et al., Appl. Catal. B: Environ. 213 (2017) 1-8;

(b) D.Y. Shi, C. He, B. Qi, et al., Chem. Sci. 6 (2015) 1035-1042;

(c) Q. Yang, L. Zhang, C. Ye, et al., Angew. Chem. Int. Ed. 56 (2017) 3694-3698;

(d) J.J. Zhong, Q.Y. Meng, G.X. Wang, et al., Chem. Eur. J. 19 (2013) 6443-6450;

(e) W.T. Liu, Q. Su, P.Y. Ju, et al., ChemSusChem 10 (2017) 664-669;

(f) G. Pandey, S.K. Tiwari, B. Singh, Tetrahedron Lett. 57 (2016) 4480-4483;

(g) J.X. Jiang, Y.Y. Li, X.F. Wu, et al., Macromolecules 46 (2013) 8779-8783.

[12] R. Hudson, S. Ishikawa, C.J. Li, A. et al., Synlett 24 (2013) 1637-1642.

[13] P. Liu, C.Y. Zhou, S. Xiang, et al., Chem. Commun. 46 (2010) 2739-2741.

[14] X. Marset, J.M. Pérez, D.J. Ramón, Green Chem. 18 (2016) 826-833.

[15] S. Kumud, B. Ashwini, N. Kashmiri, et al., ChemistrySelect 1 (2016) 4620-4623.

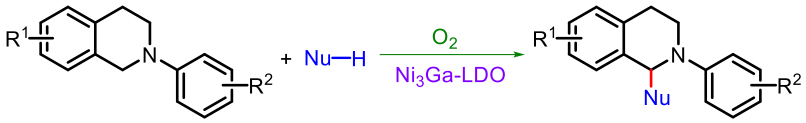
[16] B. Dutta, V. Sharma, N. Sassu, et al., Green Chem. 19 (2017) 5350-5355.

[17] (a) S.B. Zhou, J. Wang, D.Z. Lin, et al., J. Org. Chem. 78 (2013) 11204-11212;
(b) L.K. Jin, L. Wan, J. Feng, et al., Org. Lett. 17 (2015) 4726-4729;
(c) Z.L. Li, K.K. Sun, C. Cai, Org. Lett. 20 (2018) 6420-6424;
(d) P. Kumar, A.K. Sharma, R. Singh, et al., Adv. Synth. Catal. 360 (2018) 1786-1789;
(e) Z.L. Li, P.Y. Wu, K.K. Sun, et al., New J. Chem. 43 (2019) 12152-12158;
(f) A.M. Whittaker, V.M. Dong, Angew. Chem. Int. Ed. 54 (2015) 1312-1315;
(g) X. Wang, P.P. Xie, R.H. Qiu, et al., Chem. Commun. 53 (2017) 8316-8319;
(h) T. Kawasaki, N. Ishida, M. Murakami, J. Am. Chem. Soc. 142 (2020) 3366-3370;
(i) T. Verheyen, L.V. Turnhout, J.K. Vandavasi, et al., J. Am. Chem. Soc. 141 (2019) 6869-6874.

[18] A.S.K. Tsang, A.S.K. Hashmi, et al., Chem. Eur. J. 23 (2017) 9313-9318.

[19] B. Hanna, E. Anna, K. Burkhard, et al., J. Am. Chem. Soc. 138 (2016) 11860-11871.

[20] (a) G. Wojciech, Appl. Surf. Sci. 257 (2011) 2875-2880;
(b) Y. Zhao, J.E. Wang, G.X. Song, et al., Catal. Lett. 146 (2016) 1934-1942;
(c) G.D. Souza, N.R. Marcilio, O.W. Perez-Lopez, J. Therm. Anal. Calorim. 128 (2017) 735-744.



-heterogeneous catalysis

Up to 88% yield

-readily available material

-simple and mild conditions

1. NiGa layered double oxide can catalyze the aerobic oxidative cross-dehydrogenative coupling.
2. A convenient heterogeneous catalytic procedure is developed for the CDC reaction.
3. The catalyst can tolerate various substrates.
4. Good catalytical and structural stable in the coupling reaction have been observed.