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Synthesis of Cu_2O coated Cu nanoparticles and their successful applications to Ullmann-type amination coupling reactions of aryl chlorides†

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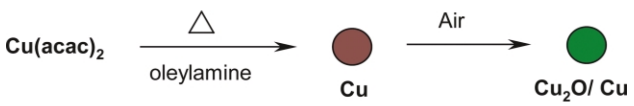
We synthesized uniform Cu_2O coated Cu nanoparticles from the thermal decomposition of copper acetylacetonate followed by air oxidation and used these nanoparticles as catalysts for Ullmann type amination coupling reactions of aryl chlorides

The development of uniform nanometre sized particles has been intensively pursued because of their many technological and fundamental scientific interests.[1] Many colloidal transition metal nanoparticles have been synthesized and applied as catalysts for organic reactions because they have a characteristic high surface area available for catalysis.[2] Ullmann-type aryl amination is one of the most popular reactions not only in the laboratory but also in industry because the reaction products are very useful for the production of many important pharmaceuticals.[3]

Recently, the synthesis of aryl imidazole derivatives has been intensively conducted because of the importance of N-heterocyclic carbene chemistry.[4] Although considerable advances in the Ullmann-type aryl amination reactions using copper catalysts have been achieved, generally the coupling partners of amines were confined to aryl iodides or aryl bromides. There are only a few reports on the coupling reaction using aryl chlorides as coupling partners. In this communication, we report on the synthesis of Cu_2O coated Cu nanoparticles and their catalytic application to Ullmann-type coupling of aryl chlorides and imidazole.

The current synthetic procedure is a modified version of the method developed by our group for the synthesis of various nanoparticles of metals and oxides, which employs the thermal decomposition of metal–surfactant complexes in hot surfactant solution.[5] Recently, several groups reported the synthesis of copper nanoparticles.[6] For example, Fischer and coworkers synthesized monodisperse copper nanoparticles from the thermal decomposition of $Cu(OCH(Me)CH_2NMe_2)_2$.[6a] We synthesized Cu nanoparticles from the thermal decomposition of commercially available copper acetylacetonate in oleylamine (Scheme 1).

The detailed synthetic procedure is as follows. A solution containing 0.1 g of $Cu(acac)_2$ and 10 mL of oleylamine was slowly heated to 230 °C. Then, the solution was kept at this temperature for 6 hours, producing a red-colored colloidal solution. A transmission electron microscopic (TEM) image showed that uniform 15 nm sized copper nanoparticles were produced and the HRTEM image showed the polycrystalline nature of the Cu nanoparticle (Fig. 1(a) and 1(b)). When 0.5 g of precursor was used in the synthesis, smaller 12 nm sized copper nanoparticles were synthesized. When the synthesized Cu nanoparticles were exposed to air, the color of the nanoparticle solution changed to blue, which shows that copper oxide, Cu_2O, was formed (Fig. 1c). The TEM image revealed that the size and shape of the nanoparticles are kept nearly unchanged after the air oxidation. The X-ray diffraction pattern, shown in Fig. 1d, revealed that Cu_2O shell was formed from sacrificing the copper core.



Scheme 1 Synthetic procedure for Cu_2O coated Cu nanoparticles.

We investigated the catalytic performance of the Cu_2O coated copper nanoparticles for Ullmann coupling reactions.[7] When coupling reactions using aryl bromides such as 2-bromopyridine and 4-bromoacetophenone were conducted in DMSO at 150 °C, the reactions proceed to completion. Even though coupling reactions using copper-based catalysts have been intensively studied[8] and applied in many industrial processes for more than 100 years, most of the reported coupling reactions using copper-based catalysts, however, have used expensive aryl iodides and aryl bromides as reactants. Recently, in coupling reactions using palladium-based catalysts, employing cheap aryl chlorides instead of expensive aryl bromides or aryl iodides became a very important issue.[9] As previously described, there are only few reports on the Ullmann coupling reaction using aryl chloride as coupling partners. Recently, Buchwald reported[8d,e] on the Ullmann type amination of aryl chlorides using CuI and 1,2-diaminocyclohexane derivatives. In the case of nanoparticles, Gedanken reported[8l] on the Ullmann coupling reaction of iodobenzene using 50–70 nm sized Cu nanoparticles. As previously described, the Cu nanoparticles are

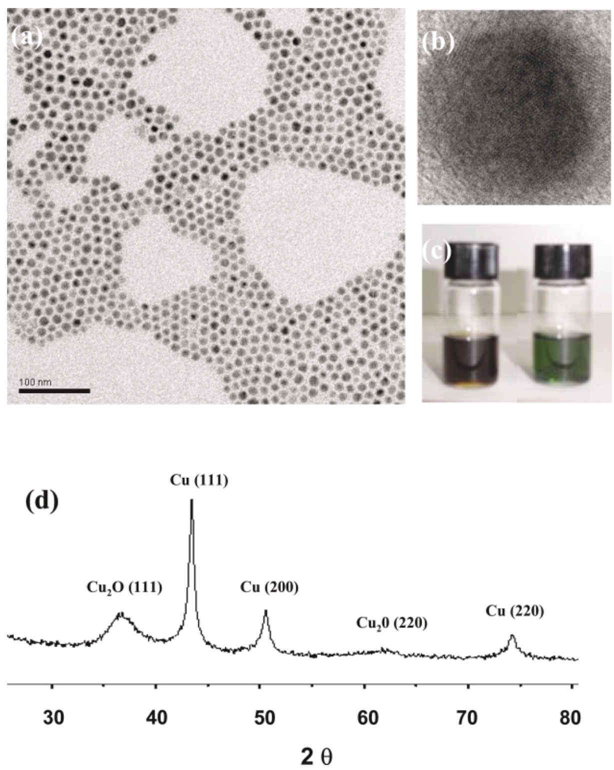


Fig. 1 (a) TEM and (b) HRTEM images of 15 nm Cu_2O coated Cu nanoparticles. (c) Photographs of the colloidal solution containing Cu nanoparticles (left) and Cu_2O coated Cu nanoparticles (right). (d) XRD pattern of Cu_2O coated Cu nanoparticles.

† Electronic supplementary information (ESI) available: detailed experimental procedure for the catalytic reactions. See http://www.rsc.org/suppdata/cc/b3/b316147a/

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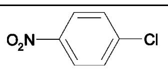
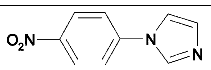
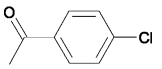
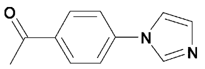
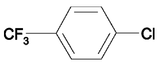
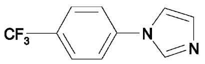
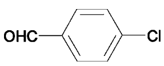
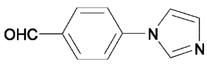
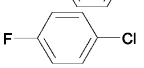
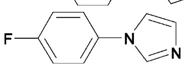
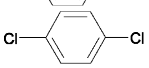
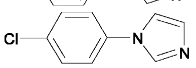
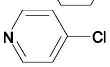
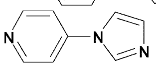
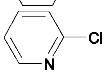
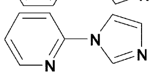
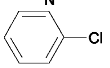
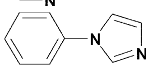
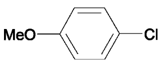
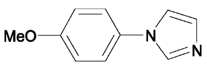
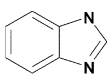
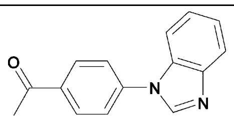
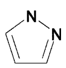
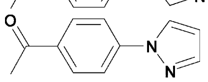
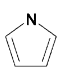
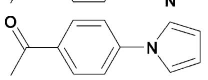
very air-sensitive and easily oxidized to Cu_2O. We used the Cu_2O coated Cu nanoparticles as catalysts. Surprisingly enough, when we conducted Ullmann-type amination reactions of imidazole with various aryl chlorides having electron withdrawing groups using the Cu_2O coated copper nanoparticles as catalysts, the reactions proceeded very well (entries 1–8 in Table 1). This high catalytic activity of the Cu_2O coated Cu nanoparticles seems to result from the high surface area derived from the nanoparticles. In addition, the coordination of oleylamine on the nanoparticles might affect the catalytic activity. The enhancement of the catalytic activity of copper by coordination of a suitable amine ligand was very recently reported by Buchwald and coworkers.[8] It is noteworthy that commercially available bulk Cu_2O powder showed only 16% conversion for 4-chloroacetophenone under same conditions. In the case of un-activated aryl chlorides such as chlorobenzene and 4-methoxychlorobenezene, we failed to isolate any coupled product (entries 9 and 10 in Table 1). Interestingly, we anticipated that in the case of 1,4-dichlorobenzene, only one chloride of 1,4-dichlorobenzene would participate in the coupling reaction because the initial product, 4-chloroimidazolylbenzene can be regarded as an electron-donating chlorobenzene substrate. As expected, the single-imidazole coupled product, 4-chloroimidazolylbenzene, was selectively produced in 69% yield (entry 6 in Table 1). The freshly prepared Cu nanoparticles also showed good activity for this Ullmann type amination (95% isolated yield for 4-chlorofluorobenzene).

Table 1 Catalytic reactions using Cu_2O coated Cu nanoparticles for Ullmann coupling of imidazole with various aryl chlorides[a]

Entry	Reactant	Product	Yield(%)[b]
1			95
2			91
3			90
4			85
5			97
6			69
7			86
8			88
9			0
10			0

[a] 5 mol% Cu_2O coated Cu nanoparticles and 2 eq. imidazole used, Cs_2CO_3, DMSO, 150 °C, 18 h. [b] Isolated yield.

Table 2 Catalytic reactions using Cu_2O coated Cu nanoparticles for Ullmann coupling of 4-chloroacetophenone with various amines[a]

Entry	Reactant	Product	Yield(%)[b]
1			84
2			86
3			63

[a] 5 mol% Cu_2O coated Cu nanoparticles used, Cs_2CO_3, DMSO, 150°C, 18 h. [b] Isolated yield.

Next, we screened various amines to obtain the coupled products with 4-chloroacetophenone (Table 2). In the case of benzimidazole, pyrazole and pyrrole, the yield of product is good to moderate. But when indole was used as substrate, a complex mixture was obtained.

In conclusion, we synthesized uniform Cu_2O coated Cu nanoparticles and successfully used them for the catalyst for Ullmann type amination coupling reactions of aryl chlorides.

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Notes and references

1 (*a*) A. P. Alivisatos, *Science*, 1996, **271**, 933; (*b*) K. J. Klabunde, *Nanoscale Materials in Chemistry*; Wiley-Interscience, New York, 2001; (*c*) T. Hyeon, *Chem. Commun.*, 2003, 927; (*d*) S. Sun, C. B. Murray, D. Weller, L. Folks and A. Moser, *Science*, 2000, **287**, 1989.

2 (*a*) L. N. Lewis, *Chem. Rev.*, 1993, 2693; (*b*) B. F. G. Johnson, *Coord. Chem. Rev.*, 1999, **190–192**, 1269; (*c*) S.-W. Kim, S. U. Son, S. S. Lee, T. Hyeon and Y. K. Chung, *Chem. Commun.*, 2001, 2212; (*d*) S. U. Son, S. I. Lee, Y. K. Chung, S.–W. Kim and T. Hyeon, *Org. Lett.*, 2002, **4**, 277; (*e*) H. Bönnemann, W. Brijoux, K. Siepen, J. Hormes, R. Franke, J. Pollmann and J. Rothe, *J. Appl. Organomet. Chem.*, 1997, **11**, 783; (*f*) M. T. Reetz and E. Westermann, *Angew. Chem., Int. Ed.*, 2000, **39**, 165; (*g*) Y. Li, X. M. Hong, D. M. Collard and M. A. El-Sayed, *Org. Lett.*, 2000, **5**, 385; (*h*) K. S. Weddle, J. D. Aikin and R. G. Finke, *J. Am. Chem. Soc.*, 1998, **120**, 5653; (*i*) N. Toshima, Y. Shiraishi, T. Teranishi, M. Miyake, T. Tominaga, H. Watanabe, W. Brijoux, H. Bönnemann and G. Schmid, *Appl. Organomet. Chem.*, 2001, **15**, 178; (*j*) M. Zhao and R. M. Crooks, *Angew. Chem., Int. Ed.*, 1999, **38**, 364.

3 (*a*) F. Ullmann, *Ber. Dtsch. Chem. Ges.*, 1903, **36**, 2382; (*b*) J. Lindley, *Tetrahedron*, 1984, **40**, 1433; (*c*) K. Kunz, U. Scholz and D. Ganzer, *Synlett*, 2003, 2428.

4 (*a*) W. A. Hermann and C. Kocher, *Angew. Chem., Int. Ed.*, 1997, **36**, 2162; (*b*) W. A. Hermann, *Angew. Chem., Int. Ed.*, 2002, **41**, 1290.

5 (*a*) T. Hyeon, S. S. Lee, J. Park, Y. Chung and H. B. Na, *J. Am. Chem. Soc.*, 2001, **123**, 12798; (*b*) T. Hyeon, Y. Chung, J. Park, S. S. Lee, Y.-W. Kim and B. H. Park, *J. Phys. Chem. B*, 2002, **106**, 6831; (*c*) J. Joo, T. Yu, Y.-W. Kim, H. M. Park, F. Wu., J. Z. Zhang and T. Hyeon, *J. Am. Chem. Soc.*, 2003, **125**, 6553; (*d*) J. Joo, H. B. Na, T. Yu, J. H. Yu, Y. W. Kim, F. Wu, J. Z. Zhang and T. Hyeon, *J. Am. Chem. Soc.*, 2003, **125**, 11100.

6 (*a*) J. Hambrock, R. Becker, A. Birkner, J. Weiß and R. A. Fischer, *Chem. Commun.*, 2002, 68; (*b*) L. Gou and C. J. Murphy, *Nano Lett.*, 2003, **3**, 231; (*c*) B. A. Korgel, K. P. Johnston, R. C. Doty and K. J. Ziegler, *J. Am. Chem. Soc.*, 2001, **123**, 7797; (*d*) M. P. Pileni, *Langmuir*, 1997, **13**, 3266.

7 See Electronic supplementary information†.

8 (*a*) D. Ma and H. Zhang, *Org. Lett.*, 2003, **5**, 2453; (*b*) D. Ma, Y. Zhang, J. Yao, S. Wu and F. Tao, *J. Am. Chem. Soc*, 1998, **120**, 12459; (*c*) D. Ma and C. Xia, *Org. Lett.*, 2001, **3**, 2583; (*d*) A. Klapars, J. Antilla, X. Huang and S. L. Buchwald, *J. Am. Chem. Soc.*, 2001, **123**, 7727; (*e*) A. Klapars, X. Huang and S. L. Buchwald, *J. Am. Chem. Soc.*, 2002, **124**, 7421; (*f*) J. C. Antilla, A. Klapars and S. L. Buchwald, *J. Am. Chem. Soc.*, 2002, **124**, 11684; (*g*) F. Y. Kwong, A. Klapars and S. L. Buchwald, *Org. Lett.*, 2002, **4**, 581; (*h*) F. Y. Kwong and S. L. Buchwald, *Org. Lett.*, 2003, **5**, 793; (*i*) G. Nordman and S. L. Buchwald, *J. Am. Chem. Soc.*, 2003, **125**, 4978; (*j*) D. Gelman, L. Jiang and S. L. Buchwald, *Org. Lett.*, 2003, **5**, 2315; (*k*) C. Enguehard, H. Allouchi, A. Gueiffier and S. L. Buchwald, *J. Org. Chem.*, 2003, **68**, 4367; (*l*) N. A. Dhas, C. P. Raj and A. Gedanken, *Chem. Mater.*, 1998, **10**, 1446.

9 (*a*) J. P. Wolfe, S. Wagaw, J.-F. Marcoux and S. L. Buchwald, *Acc. Chem. Res.*, 1998, **31**, 805; (*b*) R. B. Bedford and M. E. Blake, *Adv. Synth. Catal.*, 2003, **345**, 1107; (*c*) J. P. Stambuli, R. Kuwano and J. F. Hartwig, *Angew. Chem., Int. Ed.*, 2002, **41**, 4746; (*d*) A. F. Littke and G. C. Fu, *Angew. Chem., Int. Ed.*, 2002, **41**, 4176; (*e*) A. Schnyder, A. F. Indolese, M. Studer and H.-U. Blaser, *Angew. Chem., Int. Ed.*, 2002, **41**, 3671; (*f*) B. H. Lipshutz, *Adv. Synth. Catal.*, 2001, **343**, 313; (*g*) A. Zapf, A. Ehrentraut and M. Beller, *Angew. Chem., Int. Ed.*, 2000, **39**, 4153.