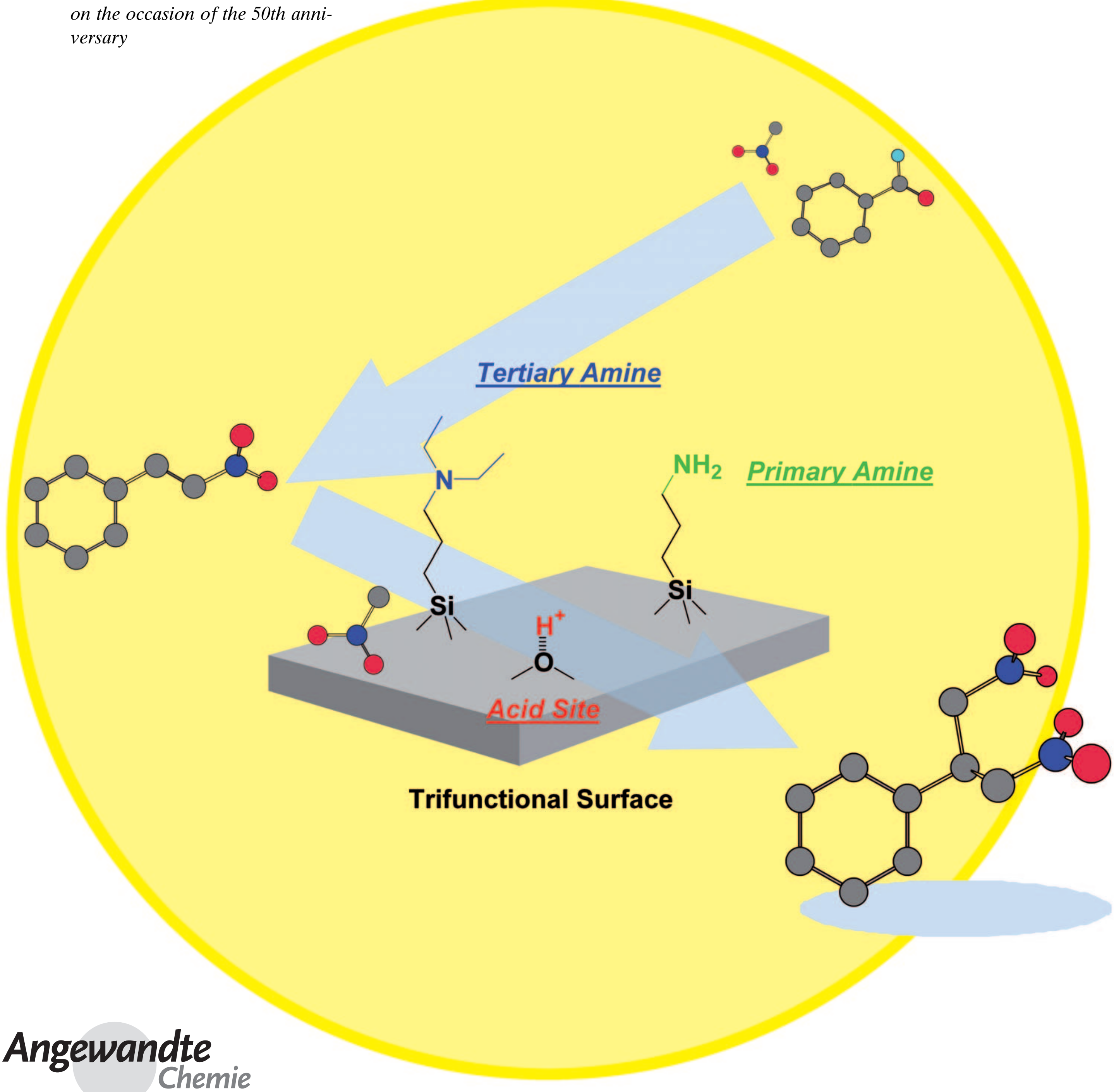
Heterogeneous Catalysis

DOI: 10.1002/anie.200802515

Cooperative Catalysis of Primary and Tertiary Amines Immobilized on Oxide Surfaces for One-Pot C–C Bond Forming Reactions**

*Ken Motokura, Mizuki Tada, and Yasuhiro Iwasawa**

Dedicated to the Catalysis Society of Japan on the occasion of the 50th anniversary

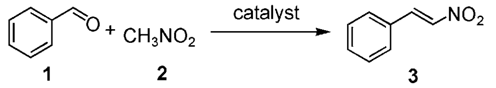


The development of multicatalytic functions enables highly efficient organic syntheses in both homogeneous and heterogeneous catalyst systems.[1] Recently, supported catalysts with chemically designed surfaces have received much attention, not only as recoverable reagents, but also as multifunctional surface materials.[2,3] These multifunctional catalysts can enable one-pot reaction sequences[2] and cooperatively promote single-reaction steps.[3] There are several reports of heterogeneous catalysts having multifunctional sites on their surfaces, which promote organic synthesis.[4,5] Nevertheless, clear examples of cooperative multifunctional catalysis at surfaces for carbon–carbon bond-forming reactions are still required, to understand the synthetic strategy of efficient multifunctional catalysis at surfaces from fundamental and industrial points of view.

Tertiary amines act as Lewis and Brønsted bases for the activation of nucleophiles. Conversely, supported primary amines efficiently catalyze condensation reactions of carbonyl compounds, such as nitro-aldol reactions,[6] in which the primary amines are thought to activate the carbonyl compounds through formation of imine intermediates.[4c,6] These facts suggest that the immobilization of both tertiary and primary amines onto the same solid surface can create an efficient heterogeneous catalyst for organic C−C bond-forming reactions by activation of both nucleophiles and electrophiles. In an organized ensemble of the immobilized system, surface acid sites may also contribute to promotion of the surface reactions. Herein, we report the first example of a heterogeneous combined tertiary and primary amine catalyst, immobilized on silica–alumina (SA), with tremendous efficiency for the one-pot synthesis of 1,3-dinitroalkanes.

We examined the reaction between benzaldehyde (**1**) and nitromethane (**2**) in the presence of various heterogeneous and homogeneous amines, as shown in Table 1. In almost all cases, 2-nitrostyrene (**3**) was obtained as a main product. The double-amine catalysts (SA–NH_2–NEt_2-**A**–**D**, see Experimental Section) showed high initial conversion rates of **1** compared with other amine catalysts (Table 1, entries 1 and 2). A homogeneous solution containing a mixture of the primary and tertiary amines (*n*-hexylamine and triethylamine), in equivalent amounts to NH_2 and NEt_2 in SA–NH_2–NEt_2-**B**, was much less active than SA-supported heterogeneous catalyst (Table 1, entry 11). The low activity was slightly improved by the addition of SA into the solution (Table 1, entry 9). The reactions using SA–NH_2 and SA–NEt_2 with similar amine loadings to those in the SA–NH_2–NEt_2-**B** proceeded at very low conversion rates (Table 1, entries 7 and 8). In the case of a physical mixture of SA–NH_2 and SA–NEt_2, the reaction was not enhanced by the coexistence of both amines (Table 1, entry 6). We also examined the performances of SA–NH_2–NEt_2 with various ratios of the primary and tertiary amines (Table 1, entries 1–4). The initial reaction rate increased with increasing primary amine content, which suggests that **1** is activated mainly by the primary amine immobilized at the SA surface.[7] Notably, the performances of the double-amine immobilized catalysts were much higher than those for typical solid bases, such as MgO and CaO (Table 1, entries 15 and 16).

Table 1: Reaction of benzaldehyde (**1**) and nitromethane (**2**) on various supported and unsupported amines.[a]



Entry	Catalyst	Conversion Rate of **1** [$mmol\,h^{-1}$][b]
1[c]	SA–NH_2–NEt_2-**A** (85/15 NH_2/NEt_2)	1.87
2	SA–NH_2–NEt_2-**B** (60/40 NH_2/NEt_2)	1.45
3[c]	SA–NH_2–NEt_2-**C** (30/70 NH_2/NEt_2)	0.62
4[c]	SA–NH_2–NEt_2-**D** (10/90 NH_2/NEt_2)	0.43
5	SA–NH_2–NEt_2-**B**-cap[d]	0.40
6	SA–NH_2 + SA–NEt_2	0.13
7	SA–NH_2	0.03
8	SA–NEt_2	0.08
9[e]	SA + *n*-hexylamine + triethylamine	0.31
10[f]	HCl + *n*-hexylamine + triethylamine	0.38
11	*n*-hexylamine + triethylamine	0.26
12	*n*-hexylamine	0.08
13	triethylamine	0.09
14[e]	SA	<0.01
15[e,g]	MgO	0.66
16[e,g]	CaO	0.45

[a] Reaction conditions unless otherwise stated: **1** (5 mmol), **2** (2 mL), catalyst (-NH_2: 0.015 mmol, NEt_2: 0.012 mmol), 100 °C. [b] Determined by GC and ^1H NMR spectroscopy. [c] 0.027 mmol of total amines was used. [d] Catalyst was treated with hexamethyldisilazane. [e] Solid catalyst (0.034 g). [f] Triethylamine hydrochloride (0.012 mmol) was used. [g] The main product on MgO and CaO was nitroalcohol.

It is noteworthy that 1,3-dinitro-2-phenylpropane (**5**) formed at 7 % selectivity (after 2 h) along with the main product **3** and a small amount of nitroalcohol (**4**) on the catalyst SA–NH_2–NEt_2-**B** (Table 1, entry 2), whereas, with SA–NH_2, **3** formed with > 99 % selectivity, although the conversion rate was low (2–6 h; Table 1, entry 7). The 1,3-dinitroalkane synthesis may proceed through nitro-aldol reaction, followed by 1,4-addition of **2** to **3**.[8] Recently, many synthetic methods have been reported, which utilize 1,3-dinitroalkanes as a key building block toward a variety of functional organic compounds, including biologically active substances.[9] Because of the synthetic usefulness of 1,3-dinitroalkanes, a further investigation for optimal reaction conditions was conducted to develop the SA–NH_2–NEt_2 catalytic system for 1,3-dinitroalkane synthesis. Remarkably, the synthesis of **5** with 93 % selectivity and 100 % conversion of **1** was achieved after 8 h in the presence of SA–NH_2–NEt_2-**B** (Table 2, entry 2). A sample of SA–NEt_2 possessing a full loading of NEt_2 (SA–NEt_2-f, NEt_2 0.90 $mmol\,g^{-1}$) showed an improved catalytic activity (Table 2, entry 7) compared with a

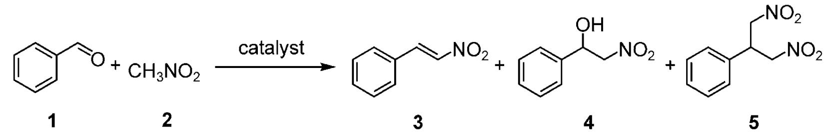
---

[*] Dr. K. Motokura, Dr. M. Tada, Prof. Dr. Y. Iwasawa
Department of Chemistry, Graduate School of Science
The University of Tokyo
Hongo, Bunkyo-ku, Tokyo 113-0033 (Japan)
Fax: (+81) 3-5800-6892
E-mail: iwasawa@chem.s.u-tokyo.ac.jp

[**] This work was supported by the JSPS (19760541) and the Global COE Program for Chemistry Innovation.

Supporting information for this article is available on the WWW under http://dx.doi.org/10.1002/anie.200802515.

Table 2: Performances of the amine-immobilized catalysts for 1,3-dinitroalkane (**5**) synthesis.[a]



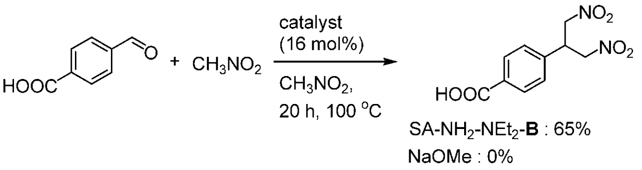
Entry	Catalyst	Yield of **3** [%][b]	Yield of **4** [%][b]	Yield of **5** [%][b]
1[c]	SA–NH_2–NEt_2-**A** (85/15 NH_2/NEt_2)	6	4	90
2	SA–NH_2–NEt_2-**B** (60/40 NH_2/NEt_2)	3	4	93
3[c]	SA–NH_2–NEt_2-**C** (30/70 NH_2/NEt_2)	2	13	77
4[c]	SA–NH_2–NEt_2-**D** (10/90 NH_2/NEt_2)	1	18	64
5	SA–NH_2-f	60	<1	39
6	SA–NH_2	71	<1	29
7	SA–NEt_2-f	2	30	30
8	SA–NEt_2	68	7	8

[a] Reaction conditions unless otherwise stated: **1** (1 mmol), **2** (2 mL), catalyst (-NH_2: 0.044 mmol, -NEt_2: 0.036 mmol), 100 °C, 8 h. [b] Determined by ^{1}H NMR spectroscopy, based on **1**. [c] 0.08 mmol of total amine groups was used.

SA–NEt_2 of a similar amine NEt_2 loading to that in SA–NH_2–NEt_2-**B** (Table 2, entry 8); however, the yield of **5** was only 30 %. The SA–NH_2 and SA–NH_2-f were also less active and unselective (Table 2, entries 5 and 6) for the synthesis of **5**.

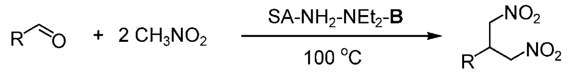
The generality of the SA–NH_2–NEt_2-**B**-catalyzed 1,3-dinitroalkane synthesis was examined with the use of various aldehyde substrates (Table 3). Electron-donating groups in the *para*-position of benzaldehyde enhanced the reactivity of the aldehyde with **2**, and the corresponding 1,3-dinitroalkanes formed in excellent yields (Table 3, entries 2–4, 91–93 %). Conversely, low product selectivities were detected for benzaldehydes with electron-withdrawing groups (Table 3, entries 5 and 6). This reaction also proceeded successfully with piperonal, 3,4-dimethoxybenzaldeyde, and the heteroaromatic aldehyde 2-thiophenecarboxyaldehyde (Table 3, entries 7, 8, and 10). It should be noted that 4-carboxybenzaldehyde also reacted with **2** in the presence of the SA–NH_2–NEt_2-**B** catalyst, affording a 65 % yield of the corresponding 1,3-dinitroalkane product (Scheme 1). This reaction scarcely proceeded with sodium methoxide as a base, as a result of neutralization by the carboxylic acid group. To our knowledge, this is the first report of a catalytic addition reaction of a nitroalkane to an aldehyde with a strong acidic group.

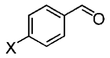
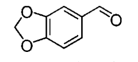
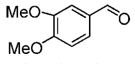
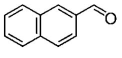
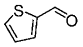
Usually, the direct synthesis of **5** from **1** and **2** requires high reaction temperatures around 100–120 °C.[8] It is noteworthy that the SA–NH_2–NEt_2-**A** catalyst efficiently promoted the reaction of **2** with **1** at 50 °C, giving an 82 % yield of **5** (Scheme 2), whereas, in the MgO-promoted reaction at 50 °C, the yield of **5** was just 5 %. The supported double-amine catalyst provides an economical reaction process to synthesize nitro compounds with thermally unstable groups.



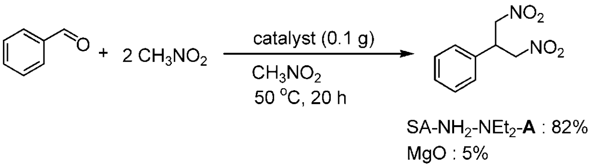
Scheme 1. Reaction of **2** with 4-carboxybenzaldehyde.

Table 3: 1,3-dinitroalkane synthesis from various aldehydes.[a]



Entry	Aldehyde	t [h]	Conversion [%][b]	Yield [%][b]
	 X			
1	X=H	8	>99	93
2	X=Me	5	99	93
3	X=OMe	5	99	91
4	X=OH	5	>99	91
5	X=Cl	8	98	83 (8)[c]
6	X=NO_2	8	95	48 (36)[c]
7		5	97	89
8	 MeO MeO	5	99	88
9		5	99	89
10	 S	8	94	80

[a] Reaction conditions: aldehyde (1 mmol), **2** (2 mL), SA–NH_2–NEt_2-**B** (0.1 g, NH_2: 0.044 mmol, NEt_2: 0.036 mmol), 100 °C. [b] Determined by ^{1}H NMR spectroscopy, based on aldehyde. [c] Yield of nitroalcohol.



Scheme 2. Comparison of 1,3-dinitroalkane synthesis catalyzed by SA–NH_2–NEt_2-**A** or MgO under mild reaction conditions.

The initial rate of SA–NH_2–NEt_2-catalyzed reaction of **1** and **2** is also much higher than those for SA–NH_2, SA–NEt_2, and the mixture of SA–NH_2 and SA–NEt_2 (Table 1). These results suggest a cooperative catalysis of the neighboring primary and tertiary amine groups on the SA surface. After treatment of the SA–NH_2–NEt_2-**B** with **1**, new signals in solid-state ^{13}C magic-angle spinning (MAS) NMR spectrum appeared at $\delta = 159$ ppm (Figure 1 a, b′: N=CH), $\delta = 135$–120 ppm (Figure 1 a, a′: phenyl), and $\delta = 63$ ppm (Figure 1 a, c′: N-CH_2), indicating the formation of a benzyl imine intermediate by dehydration.[6b,10,11] To examine the interaction between the immobilized amines and the substrates in

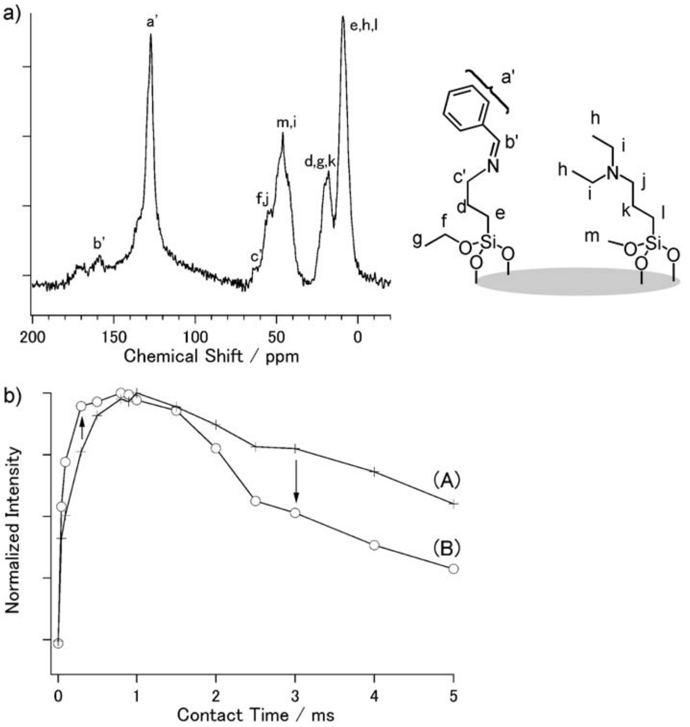


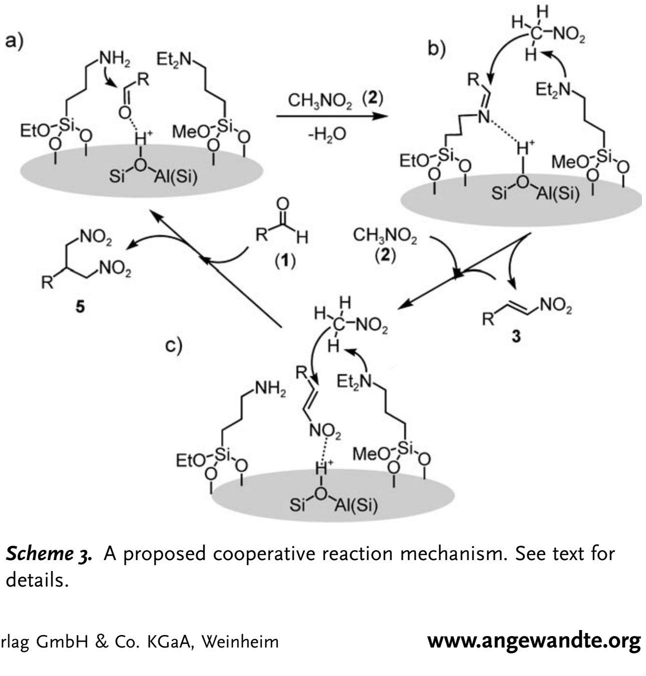
Figure 1. a) Solid-state ^{13}C CP/MAS NMR spectrum (6 kHz) for SA–NH_2–NEt_2-**B** treated with benzaldehyde, and atom-labeling scheme. b) Dependence of the normalized intensity of variable-contact-time ^{13}C CP/MAS NMR spectra at $\delta \approx 9.5$ ppm on contact time: A) fresh SA–NH_2–NEt_2-**B** (+), and B) SA–NH_2–NEt_2-**B** treated with benzaldehyde in nitromethane solution (○). The arrows indicate the change from before (A) to after (B) the treatment of SA–NH_2–NEt_2 with substrates.

the nitro-aldol reaction, variable-contact-time ^{13}C cross-polarization (CP)/MAS NMR spectra of SA–NH_2–NEt_2-**B** were measured, before and after the interaction with both nitromethane and benzaldehyde (see Supporting Information, Figure 2S). Variable-contact-time ^{13}C CP/MAS NMR spectroscopy is a technique used to determine the molecular motion of solid materials.[12] As CP is a measure of the efficiency of magnetization transfer by the dipolar coupling from ^1H to ^{13}C, it is most efficient for static ^1H–^{13}C dipolar interactions. As a result, the less-mobile carbon groups exhibit a faster CP rate, and the NMR signal intensity becomes stronger with relatively short CP contact times. This signal intensity becomes weak with prolonged contact time, as a result of attenuation of the transferred magnetization. Conversely, the signal intensity of a molecule with high mobility is strong with relatively long contact times.[12] The ^{13}C NMR signal of SA–NH_2–NEt_2-**B** at $\delta \approx 9.5$ ppm is due mainly to the terminal carbon atoms of the immobilized tertiary amine group (h), whose molecular motion is strongly affected by interactions of the substrate with the tertiary amine. Comparison of the normalized intensities of NMR signals around $\delta = 9.5$ ppm with contact times revealed that signals for the catalyst SA–NH_2–NEt_2-**B** when interacting with substrates showed relatively higher intensity with the shorter contact times (≤ 0.5 ms) and lower intensity with longer contact times (≥ 2.0 ms) than those for the parent SA–NH_2–NEt_2-**B** (Figure 1 b). These results indicate that the molecular motion of the tertiary amines in SA–NH_2–NEt_2-**B** is restricted by interaction with the substrates,[12] probably by formation of a reaction intermediate (primary amine–aldehyde(imine intermediate), nitromethane–tertiary amine) (Scheme 3 b).

The cooperative catalysis of primary and tertiary amines was enhanced by acid addition (Table 1, entries 9 and 10 cf. entry 11). In addition, the activity of SA–NH_2–NEt_2-**B** was significantly decreased by the capping of surface OH groups with hexamethyldisilazane (Table 1, entry 5).[13] These results suggest that the surface acid site on SA enhances the SA–NH_2–NEt_2-catalyzed nitro-aldol reaction. The supported catalyst showed higher performances than those for the homogeneous amine–acid mixture (Table 1, entry 2 cf. entries 9 and 10) because undesired acid–base neutralization is suppressed at the immobilized surfaces.[4b,e,5]

Si–OH groups on a primary-amine-immobilized SiO_2 surface promote two steps in the nitro-aldol reaction: a) imine formation from the primary amine and the aldehyde, and b) the addition of the nitroalkane to the resultant imine.[4c] We also prepared a SiO_2-supported double amine catalyst, which gave similar results to SA–NH_2–NEt_2, suggesting that, not only strong acid sites (Si-O(H^+)-Al), but also weak acid sites (Si-OH) contribute to the nitro-aldol reaction.[14] However, amine immobilization occurred at higher rate and to a higher degree on SA than on SiO_2 (nitrogen content; SA–NH_2–NEt_2-**B**: 1.10 wt %, SiO_2–NH_2–NEt_2: 0.52 wt %). As a result, the activity of the SiO_2-supported catalyst based on weight was half that for the SA–NH_2–NEt_2.

A reaction mechanism for the 1,3-dinitroalkane synthesis on the SA–NH_2–NEt_2 including the effect of the acid support is illustrated in Scheme 3 (for full version, see Supporting Information, Figure S1): a) the aldehyde is activated by a surface acid site and reacts with an amino group to form an imine intermediate,[6] b) the α-proton of **2** is abstracted by a tertiary amine group, accompanied by the

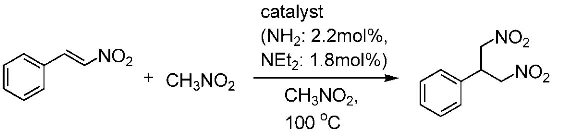


Scheme 3. A proposed cooperative reaction mechanism. See text for details.

nucleophilic attack of the deprotonated **2** on the imine, which is also assisted by surface acid site, resulting in the product **3**, before, c) another molecule of **2** is activated by the tertiary amine group and the Michael reaction with **3** occurs to give the desired product **5**.[15] Nitrostyrene (**3**) might also be activated by surface acid sites.[16]

In a separate experiment, the Michael reaction of **2** with **3**, affording **5**, was examined with a range of amine catalysts. SA–NH_2–NEt_2-**B** and SA–NEt_2-f both showed high activities, but SA–NH_2-f was found to be much less active(Scheme 4), providing further indication that the Michael addition is promoted by tertiary amine groups. In addition, SA–NEt_2-f showed double the activity of homogeneous triethylamine (Scheme 4).

Full-coverage SA–NH_2-f was active for the condensation reaction to afford **3**, whereas the full-coverage SA–NEt_2-f gave nitroalcohol **4** by aldol reaction (Table 2). This formation of **4** and the subsequent dehydration of **4** to form **3** are considered as a minor reaction pathway (see Supporting Information, Scheme S1 (a) and (b)). Nucleophilic attack of **2** on benzaldehydes with electron-withdrawing groups at the *para*-position might easily occur without the formation of imine intermediates, resulting in lower selectivity to 1,3-dinitrocompounds in favor of nitroalcohol formation (Table 3).[17]



Catalyst	Rate (mmol/h)
SA-NH_2-NEt_2-**B**	0.24
SA-NH_2-f	0.02
SA-NEt_2-f	0.18
Triethylamine	0.09

Scheme 4. The amine-catalyzed Michael reaction of **2** and **3**.

In summary, a silica–alumina-supported double-amine catalyst (SA–NH_2–NEt_2) was found to be highly active for the production of 1,3-dinitroalkanes, whereas the supported single amines and the corresponding amines in solution exhibited almost no significant activity in this reaction. The SA–NH_2–NEt_2 catalyst has two notable properties, owing to the multifunctional catalyst surface: a) acceleration of a single reaction by cooperative catalysis and b) promotion of one-pot reaction sequences. The design of more precisely controlled surface structures and further extensions to a variety of organic syntheses are currently under investigation.

Experimental Section

Silica–alumina-supported double-amine catalysts (SA–NH_2–NEt_2-**A**–**D**) were prepared by treatment of amorphous aluminosilicate (SA) with a toluene solution involving given amounts (1.7 mmol of total amine) of 3-aminopropyltriethoxysilane and 3-(diethylamino)propyltrimethoxysilane under reflux. The solid was removed by filtration, washed with dichloromethane, and dried under reduced pressure, affording the catalyst SA–NH_2–NEt_2. The amine groups in SA–NEt_2, SA–NH_2, and SA–NH_2–NEt_2 were characterized by solid-state ^{13}C CP/MAS NMR spectroscopy (Figure 2); the NMR signals derived from primary and tertiary amines in SA–NH_2–NEt_2 showed no significant changes compared to those for SA–NH_2 and SA–NEt_2.

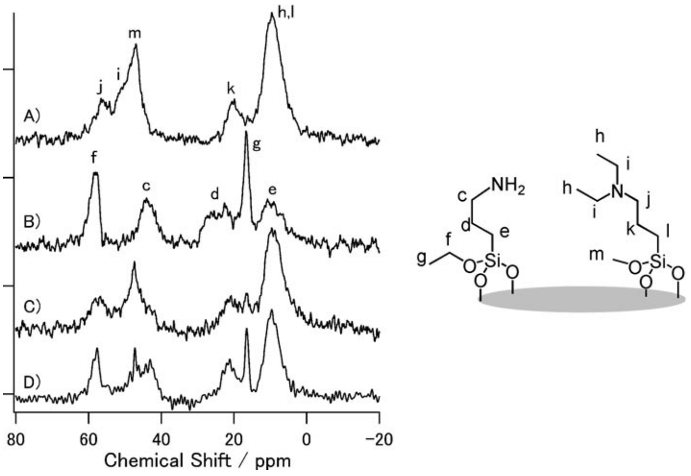


Figure 2. Solid-state ^{13}C CP/MAS NMR spectra (4 kHz) and atom-labeling scheme: A) SA–NEt_2-f, B) SA–NH_2-f, C) SA–NH_2–NEt_2-**B**, and D) SA–NH_2–NEt_2-**A**.

Received: May 29, 2008
Revised: July 25, 2008

Keywords: C–C coupling · cooperative effects · immobilization · nitroalkanes · supported catalysts

---

[1] a) H. Gröger, *Chem. Eur. J.* **2001**, *7*, 5246; b) M. Kanai, N. Kato, E. Ichikawa, M. Shibasaki, *Pure Appl. Chem.* **2005**, *77*, 2047; c) S. Kanemasa, K. Ito, *Eur. J. Org. Chem.* **2004**, 4741; d) J. A. Ma, D. Cahard, *Angew. Chem.* **2004**, *116*, 4666–4683; *Angew. Chem. Int. Ed. Engl.* **2004**, *43*, 4566–4583; e) Y. Wang, H. Li, Y. Q. Wang, Y. Liu, B. M. Foxman, L. Deng, *J. Am. Chem. Soc.* **2007**, *129*, 6364.

[2] a) B. M. Choudary, N. S. Chowdari, S. Madhi, M. L. Kantam, *J. Org. Chem.* **2003**, *68*, 1736; b) K. Motokura, N. Fujita, K. Mori, T. Mizugaki, K. Ebitani, K. Jitsukawa, K. Kaneda, *Chem. Eur. J.* **2006**, *12*, 8228; c) G. Torres, C. R. Apesteguía, J. I. Di Cosimo, *Appl. Catal. A* **2007**, *317*, 161.

[3] a) P. Barbaro, C. Bianchini, V. D. Santo, A. Meli, S. Moneti, R. Psaro, A. Scaffidi, L. Sordelli, F. Vizza, *J. Am. Chem. Soc.* **2006**, *128*, 7065; b) A. Dahan, M. Portnoy, *J. Am. Chem. Soc.* **2007**, *129*, 5860.

[4] a) S. Huh, H. T. Chen, J. W. Wiench, M. Pruski, V. S.-Y. Lin, *Angew. Chem.* **2005**, *117*, 1860; *Angew. Chem. Int. Ed.* **2005**, *44*, 1826; b) R. K. Zeidan, S.-J. Hwang, M. E. Davis, *Angew. Chem.* **2006**, *118*, 6480; *Angew. Chem. Int. Ed.* **2006**, *45*, 6332; c) J. D. Bass, A. Solovyov, A. J. Pascall, A. Katz, *J. Am. Chem. Soc.* **2006**, *128*, 3737; d) T. Takahashi, T. Watahiki, S. Kitazume, H. Yasuda, T. Sakakura, *Chem. Commun.* **2006**, 1664; e) R. K. Zeidan, M. E. Davis, *J. Catal.* **2007**, *247*, 379.

[5] a) K. Motokura, M. Tada, Y. Iwasawa, *J. Am. Chem. Soc.* **2007**, *129*, 9540; b) K. Motokura, M. Tomita, M. Tada, Y. Iwasawa, *Chem. Eur. J.* **2008**, *14*, 4017.

[6] a) X. Wang, K. S. K. Lin, J. C. C. Chan, S. Cheng, *J. Phys. Chem. B* **2005**, *109*, 1763; b) G. Sartori, F. Bigi, R. Maggi, R. Sartorio, D. J. Macquarrie, M. Lenarda, L. Storaro, S. Coluccia, G. Martra,

J. Catal. **2004**, *222*, 410; c) G. Demicheli, R. Maggi, A. Mazzacani, P. Righi, G. Sartori, F. Bigi, *Tetrahedron Lett.* **2001**, *42*, 2401.

[7] Because imine-intermediate formation from **1** and primary amines is generally very fast, the rate determining step in the nitro-aldol reaction is the addition of **2** to the imine intermediate including proton abstraction from **2** by the tertiary amine.

[8] For other reports on synthetic procedures incorporating 1,3-dinitroalkanes, see: a) A. Ferro, M. C. Rezende, S. Sepulveda-boza, M. Reyes-Parada, B. K. Cassels, *J. Chem. Res.* **2001**, *7*, 294; b) R. Ballini, G. Bosica, D. Fiorini, A. Palmieri, *Synthesis* **2004**, 1938; c) T. Hara, S. Kanai, K. Mori, T. Mizugaki, K. Ebitani, K. Jitsukawa, K. Kaneda, *J. Org. Chem.* **2006**, *71*, 7455.

[9] a) R. Ballini, L. Barboni, D. Fiorini, G. Giarlo, A. Palmieri, *Chem. Commun.* **2005**, 2633; b) R. Ballini, L. Barboni, D. Fiorini, G. Giarlo, A. Palmieri, *Green Chem.* **2005**, *7*, 828; c) R. Ballini, L. Barboni, C. Femoni, G. Giarlo, A. Palmieri, *Tetrahedron Lett.* **2006**, *47*, 2295; d) D. Y. Park, K. Y. Lee, J. N. Kim, *Tetrahedron Lett.* **2007**, *48*, 1633.

[10] R. Sayah, K. Glegoła, E. Framery, V. Dufaud, *Adv. Synth. Catal.* **2007**, *349*, 373.

[11] I. L. Lagadic, *Microporous Mesoporous Mater.* **2006**, *95*, 226.

[12] a) S. K. Sahoo, D. W. Kim, J. Kumar, A. Blumstein, A. L. Cholli, *Macromolecules* **2003**, *36*, 2777; b) H.-M. Kao, T.-T. Hung, G. T. K. Fey, *Maclomolecule* **2007**, *40*, 8673.

[13] The performance of SA–NH$_2$–NEt$_2$-**B**-cap (Table 1, entry 5) was higher than that for the homogeneous amine mixture (Table 1, entry 11) because a part of silanol groups still remained, as suggested by IR spectroscopy.

[14] Strong acid sites on SA (Si-O(H$^+$)-Al) effectively activate the acceptor substrates. However, they also show a buffering effect on the basic amines. We envisage this effect is the reason for the similar catalytic activity for SA and SiO$_2$ supports.

[15] After collecting the solid catalyst by filtration, the reaction did not occur in the filtrate under similar reaction conditions, indicating an absence of homogeneous contributions. The catalyst was reusable, but the catalytic activity decreased; for example, in the nitroaldol reaction of **1** and **2**, 93 % yield after 2 h, however when the catalyst is reused the yield is 86 % after 5 h. The primary-amine-immobilized catalyst was reusable with similar reaction conditions,[5] indicating that the tertiary amine groups are less stable than primary amines at such high temperatures. Nevertheless, the significance of the immobilized double-amine catalyst is not reduced, owing to tremendous performances for the one-pot bifunctional catalysis.

[16] C. Palomo, S. Vera, A. Mielgo, E. Gómez-Bengoa, *Angew. Chem.* **2006**, *118*, 6130; *Angew. Chem. Int. Ed.* **2006**, *45*, 5984.

[17] Electron-withdrawing groups would also prevent the dehydration reaction of nitroalcohols.