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Nano-$BF_3.SiO_2$: A reusable and eco-friendly catalyst for thioacetalization and trans-thioacetalization reactions

Bi Bi Fatemeh Mirjalili[*a], Abdolhamid Bamoniri[b], Ali Akbari[a]

[a]*Department of Chemistry, College of Science, Yazd University, Yazd. P.O.Box 89195-741, Iran*
[b]*Department of Organic Chemistry, Faculty of Chemistry, University of Kashan, Kashan, I. R Iran*

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ABSTRACT

Nano-silica supported boron trifluoride ($BF_3.SiO_2$) is an efficient, reusable and eco-friendly catalyst for chemoselective thioacetalization of aldehydes and ketones. So, this catalyst was applied for transthioacetalization of acetals and acylals into their corresponding 1,3-dithiolanes or 1,3-dithianes in good to excellent yields. The reactions were carried out at room temperature under solvent free and grinding conditions in 1.5-2.5 minutes.

Keywords: *$BF_3.SiO_2$, Nano-$BF_3.SiO_2$, Thioacetal, Thioacetalization, Trans-thioacetalization, Protecting group*

1. Introduction

In modern organic synthesis, thioacetals are utilized as masked acyl anions or methylene functions in carbon–carbon bond formation *via* conjugate addition of lithiated 1,3-dithianes or 1,3-dithiolanes to a carbon electrophile [1,2]. So, thioacetals are very important protecting groups for aldehydes and ketones due to their stability under both basic and mildly acidic conditions [1]. Generally, thioacetals can be formed *via* condensation of thiols or dithiols with aldehydes or ketones in the presence of an acidic catalyst. Most recently, some catalysts such as $LiBF_4$ [3], I_2/NP [4], $In(OTf)_3$ [5], NBS [6], $Sc(OTf)_3$ [7], $NiCl_2$ [8], $CoCl_2$ [9], $Y(OTf)_3$ [10], $VO(OTf)_2$ [11], selenium ionic liquid [12], I_2/molecular sieve [13], PhSeBr [14] and silica functionalized sulfonic acid [15] were used in the formation of thioacetals. Although some of these catalysts produce good to high yields, some of them have certain disadvantages such as long reaction times [3,5-9,12], tedious work-up or purification with chromatography [5-8,12], moisture sensitivity [10,11], high price [5,7,10-15] and toxicity [5,7,10,11] or non chemoselectivity [12].Therefore, there is still a need to developing a versatile, cheap, simple, mild, and efficient method for the chemoselective protection of aldehydes with easy work-up.

2. Experimental

* Corresponding author: E-mail: fmirjalili@yazduni.ac.ir
Fax: 0351-8210644

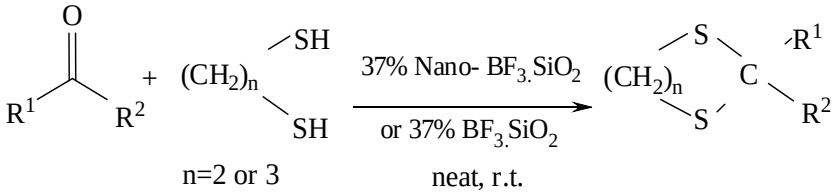
The products were characterized by, ATR of FT-IR, ^{1}H NMR, and ^{13}C NMR spectra. IR spectra were run on a Bruker, Eqinox 55 spectrometer. ^{1}H-NMR and ^{13}C-NMR spectra were obtained by a Bruker Avans 400 and 500 MHz spectrometers (DRX). Melting points were determined by a Buchi melting point B-540 B.V.CHI apparatus and are uncorrected.

2.1. Preparation of 37% nano $BF_3.SiO_2$ and 37% $BF_3.SiO_2$

0.37 g of BF_3 (0.7 ml of $BF_3.Et_2O$) was added drop-wise to a mixture of 0.63 g of silica gel or nano-silica gel and 5 ml of chloroform. The mixture was stirred for 1 h at room temperature. The resulted suspension was filtered. The obtained solid was washed with chloroform and dried at room temperature.

2.2. General procedure for conversion of aldehydes, ketones, acetals and acylals to thioacetals

A mixture of aldehyde, ketone, acetal, or acylal (1 mmol), 1,2-ethanedithiol or 1,3-peropandithiol (1.2 mmol) and 37% $BF_3.SiO_2$ (0.3 g) or 37% nano-$BF_3.SiO_2$ (0.07 g) was ground in a pestle at an ambient temperature. The progress of reaction was monitored by TLC. After the completion of the reaction, the product was dissolved to $CHCl_3$ and filtered to recover the catalyst. The solvent was evaporated and the crude product recrystallized from ethanol and water. With catechol form substrates, initially, the products were dissolved in ethanol, filtered, and the solvent was evaporated. The obtained solid was recrystallized in chloroform.



Scheme 1. Thioacetalization in the presence of $BF_3.SiO_2$

The selected spectral data:

2-(3,4-dihydroxyphenyl)-1,3-dithiolane (Table 2, entry 10). IR (KBr) cm^{-1}: 3411, 3263, 2955, 2909, 1606, 1519, 1467, 1385, 1342, 1296, 1262, 1108, 962, 881, 755, 717. ^{1}H NMR (500MHz, $CDCl_3$, ppm) δ: 7.14 (1H, d, *J* = 2 Hz), 6.96 (1H, dd, *J* = 8.15 and 2 Hz), 6.82 (1H, d, *J* = 8.15 Hz), 5.61 (1H, s), 3.48–3.54 (2H, m), 3.33–3.39 (2H, m).^{13}C NMR (125 MHz, $CDCl_3$, ppm) δ: 40.54, 56.64, 115.47, 115.50, 120.82, 132.76, 144.26, 144.40.

2-(3,4-dihydroxyphenyl)-1,3-dithiane (Table 2, entry 20). IR (KBr) cm^{-1}: 3479, 3441, 3306, 2929, 2891, 1622, 1607, 1532, 1520, 1454, 1428, 1352, 1299, 1248, 1112, 961, 873, 817, 763. ^{1}H NMR (500 MHz, $CDCl_3$, ppm) δ: 6.86 (1H, d, *J* = 1.7 Hz), 6.7 (1H, d, *J* = 1.7 Hz), 6.67 (1 H, s), 4.94 (1 H, s), 2.92 (2H, td, *J* = 13.3 and 1.7 Hz), 2.76 (2H, dt, *J* = 14 and 3.5 Hz). 2.02-2.05 (1 H, m), 1.71–1.80 (1 H, m).^{13}C NMR (125 MHz, $CDCl_3$, ppm) δ: 25.49, 32.49, 51.41, 115.47, 115.390, 115.69, 119.69, 131.17, 145.08, 145.36.

2-(2,3-dihydroxyphenyl)-1,3-dithiane (Table 2, entry 21). IR (KBr) cm^{-1}: 3378, 3348, 2955, 2899, 1624, 1595, 1508, 1477, 1359, 1336, 1284, 1272, 1244, 979, 827, 754. ^{1}H NMR (500 MHz, $CDCl_3$, ppm) δ: 6.66 (1H, d, *J*=7.8 Hz), 6.47 (1H, d, *J* = 7.8 Hz), 6.38 (1H, t, *J* = 7.8 Hz), 5.37 (1H, s), 2.92 (2H, t br, *J* = 12.62 Hz), 2.56 (2H, dt, *J* = 14.2 and 3.1 Hz), 1.85-1.89 (1 H, m), 1.56–1.6 (1 H, m).

Table 1. Formation of 2-phenyl-1,3-dithiolane under various conditions[a]

Entry	Catalyst	Solvent[b]	Time (min)	Yield (%)[Ref]
1	28% $BF_3.SiO_2$/ 0.3 g	-	2.5	72
2	33% $BF_3.SiO_2$/ 0.3 g	-	2.5	86
3	37% $BF_3.SiO_2$/ 0.3 g	-	2.5	92
4	45% $BF_3.SiO_2$/ 0.3 g	-	2.5	93
5	37% $BF_3.SiO_2$/ 0.2 g	-	2.5	62
6	37% $BF_3.SiO_2$/ 0.5 g	-	2.5	93
7	37% Nano-$BF_3.SiO_2$/ 0.07 g	-	2.5	95
8	$BF_3.OEt_2$/0.3 ml	-	10	85
9	37% $BF_3.SiO_2$/ 0.3 g	EtOH	30	37
10	37% $BF_3.SiO_2$/ 0.3 g	$CHCl_3$	120	72
11	37% $BF_3.SiO_2$/ 0.3 g, 2nd run	-	2.5	90
12	37% $BF_3.SiO_2$/ 0.3 g, 3rd run	-	2.5	88
13	37% Nano-$BF_3.SiO_2$/ 0.07 g, 2rd run	-	2.5	89
14	NBS / 15 mol%	CH_2Cl_2	40	80[6]
15	$NiCl_2$ / 10 mol%	CH_2Cl_2	45	89[8]
16	$In(OTf)_3$ / 5 mol%	CH_2Cl_2	8	89[5]
17	$CoCl_2$ / 5 mol%	CH_3CN	150	89[9]
18	$LiClO_4$ /5 equiv.	Et_2O	120	72[21]
19	P_2O_5/Al_2O_3 /15 mol%	-	1	92[22]

[a]Benzaldehyde (1 mmol) and 1,2-ethandithiol (1.2 mmol) were applied.
[b]The reactions have been carried out at room temperature (entries 1-18) or under microwave irradiation (entry 19).

Table 2. Thioacetalization of aldehydes and ketones in the presence of 37% nano-$BF_3.SiO_2$ or 37% $BF_3.SiO_2$ at room temperature under grinding and solvent-free conditions.[a]

Entry	R^1	R^2	n	Time (min)	Yield[a] [Yield][b]	Ref.
1	Ph	H	2	2.5	92[93]	22
2	4-NO_2-C_6H_4	H	2	2.5	92[94]	22
3	4-Cl-C_6H_4	H	2	2.5	90[92]	22
4	3-Br-C_6H_4	H	2	2.5	89[90]	16
5	4-Br-C_6H_4	H	2	2.5	92[92]	10
6	2,6-di-Cl-C_6H_3	H	2	2.5	91[93]	16
7	4-OH-C_6H_4	H	2	2.5	87[86]	6
8	4-isopro-C_6H_4	H	2	2.5	89[90]	16
9	4-Me-C_6H_4	H	2	2.5	89[90]	10
10	3,4-di-OH-C_6H_3	H	2	2.5	86[85]	-
11	4-MeO-C_6H_4	CH_3	2	2.5	87[88]	22
12	4-NO_2-C_6H_4	CH_3	2	2.5	86[88]	22
13	-$(CH_2)_5$-		2	2.5	81[83]	6
14	Ph	H	3	1.5	93[92]	10
15	4-NO_2-C_6H_4	H	3	1.5	94[95]	10
16	2-NO_2-C_6H_4	H	3	1.5	90[92]	10
17	4-Cl-C_6H_4	H	3	1.5	92[95]	10
18	4-OH-C_6H_4	H	3	1.5	88[88]	9
19	4-Me-C_6H_4	H	3	1.5	89[91]	10
20	3,4-di-OH-C_6H_3	H	3	1.5	86[88]	-
21	2,3-di-OH-C_6H_3	H	3	1.5	92[94]	-
22	4-MeO-C_6H_4	CH_3	3	1.5	92[91]	11
23	4-Cl-C_6H_4	CH_3	3	1.5	93[92]	11
24	4-NO_2-C_6H_4	CH_3	3	1.5	92[94]	11
25	-$(CH_2)_5$-		3	1.5	80[82]	11
26	C_6H_4-C=C-	H	3	1.5	85[84]	9

[a] The ratio of substrate (mmol) : dithiol (mmol) : 37% $BF_3.SiO_2$ (g) is 1 : 1.2: 0.3.

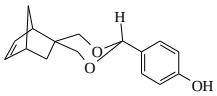
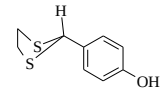
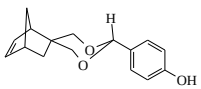
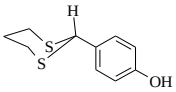
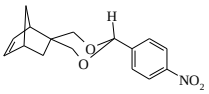
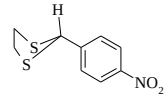
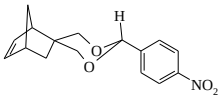
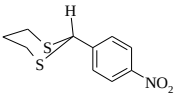
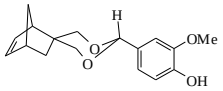
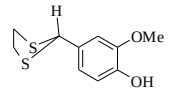
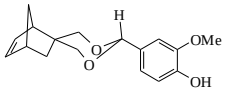
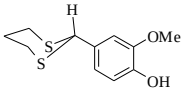
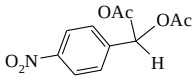
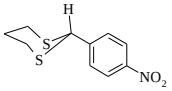
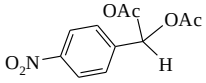
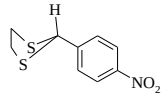
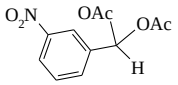
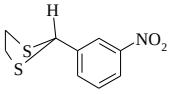
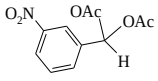
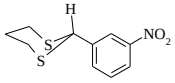
[b]The ratio of substrate (mmol) : dithiol (mmol) : 37% nano-$BF_3.SiO_2$ (g) is 1 : 1.2: 0.07.

^{13}C NMR (125 MHz, $CDCl_3$, ppm) δ: 25.52, 32.38, 44.43, 115.51, 119.73, 119.99, 126.10, 141.95, 144.86.

3. Results and Discussion

Recently, the use of solid supported catalysts has received considerable importance in organic synthesis because of their ease of handling, enhanced reaction rates, high selectivity, simple work-up, and recoverability. $BF_3.SiO_2$ [16-18] and nano-$BF_3.SiO_2$ [19-20] are bench-top catalysts which are reusable, readily available, eco-friendly, versatile and efficient for promotion of many acid catalyzed organic transformations. These catalysts do not need special precautions for handling or storage, and they can be stored at an ambient temperature for months without losing their catalytic activity. In this study, we investigated the application of $BF_3.SiO_2$ and nano-$BF_3.SiO_2$ for thioacetalization of aldehydes and ketones or transthioacetalization of acetals and acylals. We have found that nano-$BF_3.SiO_2$ and $BF_3.SiO_2$ are efficient,

Table 3. Transthioacetalization in the presence of 37% nano- $BF_3.SiO_2$ or 37% $BF_3.SiO_2$ at room temperature under solvent free and grinding conditions.

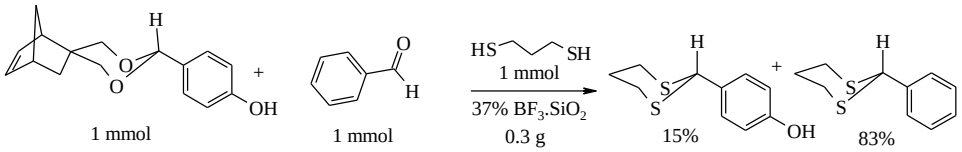
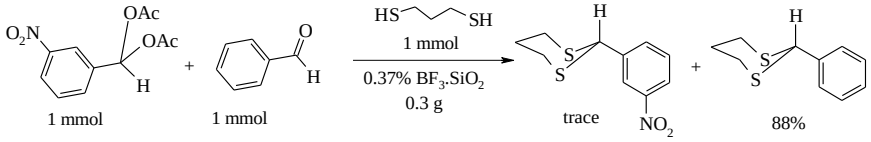
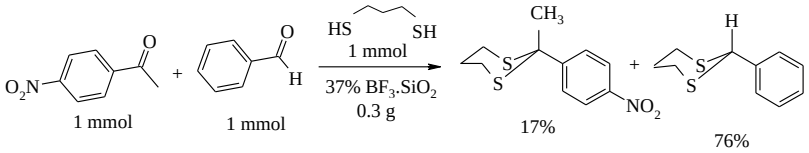
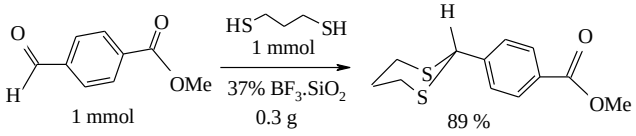
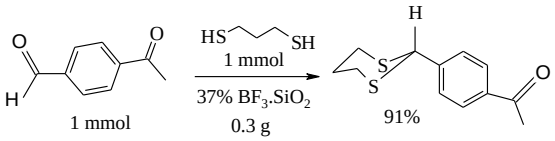
Entry	Substrates	Products	Time(min)	Yield[a] [Yield][b] (%)
1			3	78[80]
2			1.5	80[82]
3			3	85[86]
4			1.5	89[92]
5			3	84[85]
6			1.5	88[88]
7			1.5	83[84]
8			3	81[80]
9			3	79[81]
10			1.5	84[85]

[a]The ratio of substrate (mmol) : dithiol (mmol) : 37% $BF_3.SiO_2$ (g) is 1: 1.2: 0.3

[b]The ratio of substrate (mmol) : dithiol (mmol) : 37% nano-$BF_3.SiO_2$ (g) is 1 : 1.2: 0.07

reusable and eco-friendly catalysts for chemoselective thioacetalization of aldehydes and ketones. So, we applied these catalysts for transthioacetalization of acetals and acylals into their corresponding 1,3-dithiolanes or 1,3-dithianes in good to excellent yields. The reactions were carried out at room temperature under solvent-free and grinding conditions in 1.5-2.5 minutes (Scheme 1). To optimize the reaction conditions, we initially tried to convert benzaldehyde to 2-phenyl-1,3-dithiolane using $BF_3.SiO_2$ and 1,2-ethanedithiol in different conditions. Then we have compared it with other applied catalysts (Table 1). We demonstrated that the best case is to use 37% $BF_3.SiO_2$ (0.3 g) or 37% nano-$BF_3.SiO_2$ (0.07 g) under grinding and solvent-free conditions at room temperature (Table 1, entries 3 and 7). Therefore, we employed the above mentioned conditions for the conversion of various aldehydes and ketones to their corresponding 1,3-dithiolanes or 1,3-dithianes. The rings of 1, 3-dithianes were formed faster than 1, 3-dithiolanes with higher yields (scheme 1, table 2). Also, using this procedure, acetals and acylals were converted to their corresponding thioacetals in good yields (Table 3). The chemoselectivity studies have shown that $BF_3.SiO_2$, converts the aldehyde group to thioacetal in the presence of ketone, ester, acetal or acylal (table 4). Short reaction time, high yield, simplicity of operation, reusability, chemoselectivity and easy work-up are some advantages of this method.

Table 4. Chemoselectivity of thioacetalization in the presence of $BF_3.SiO_2$

Entry	Schemes
1	
2	
3	
4	
5	

Most of the products are known and were characterized by comparison of physical properties, the FT-IR and ^1H NMR data with those reported in the literature. The structure of new products was elucidated by spectroscopic data. To study the reusability of $BF_3.SiO_2$, after each run, the product was dissolved to $CHCl_3$ and filtered. The catalyst residue was washed with acetone and reused. Treatment with acetone removes the tar from the catalyst surface more efficiently (Table 1, entries 11 and 12). The catalyst was reusable although a gradual decline was observed in its activity. The applicability of the present method to a large scale process was examined with 20 mmol of benzaldehyde and 24 mmol of 1, 2-ethanedithiol which gave 2-phenyl -1,3-dithiolane in 85% yield.

4. Conclusion

In conclusion, nano-$BF_3.SiO_2$ and $BF_3.SiO_2$ were applied for the preparation of 1,3-dithiolanes or dithianes from aldehydes and ketones, acetals and acylals in a simple and straightforward protocol. Short reaction time, high yields, simplicity of operation, reusability, chemoselectivity and easy work-up are some advantages of this method. The type of reaction and especially reaction conditions fall into the click chemistry category.

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References

[1] E. J. Corey, D. Seebach, J. Org. Chem. 31 (1966) 4097-4099.
[2] B.T. Groebel, D. Seebach, Synthesis (1977) 357-402.
[3] J.S. Yadav, B.V.S. Reddy, S.K. Pandey, Synlett (2001) 238-239.
[4] M. Zahouily, A. Mezdar, J. Rakik, A. Elmakssoudi, A. Rayadh, S. Sebti, J. Mol. Catal. A: Chem. 233 (2005) 43-47.
[5] S. Muthusamy, S.A. Babu, C. Gunanathan, Tetrahedron 58 (2002) 7897-7901.
[6] A. Kamal, G. Chouhan, Synlett (2002) 474-476.
[7] A. Kamal, G. Chouhan, Tetrahedron Lett. 43 (2002) 1347-1350.
[8] A.T. Khan, E. Mondal, P.R. Sahu, S. Islam, Tetrahedron Lett. 44 (2003) 919-922.

[9] S.K. De, Tetrahedron Lett. 45 (2004) 1035-1036.
[10] S.K. De, Tetrahedron Lett. 45 (2004) 2339-3241.
[11] S.K. De, J. Mol. Catal. A: Chem. 226 (2005) 77-79.
[12] E. J. Lenardao, E. L. Borges, S. R. Mendes, G. Perin, R.G. Jacob, Tetrahedron Lett. 49 (2008) 1919-1921.
[13] H. Flink, T. Putkonen, A. Sipos, R. Jokela, Tetrahedron 66 (2010) 887-890.
[14] C. C. Schneider, F. Manarin, R. B. Panatieri, O. S. R. Barros, G. Zeni J. Braz. Chem. Soc., 21 (2010) 2088-2092.
[15] B. Karimi, M. Khalkhali, J. Mol. Catal. A: Chem. 271 (2007) 75-79.
[16] B. Sadeghi, B. F. Mirjalili, M. M. Hashememi, Tetrahedron Lett. 49 (2008) 2575-2577.
[17] B. F. Mirjalili, A. Bamoniri, A. Akbari, Tetrahedron Lett. 49 (2008) 6454-6456.
[18] B. Sadegi, B. F. Mirjalili, M. M. Hashemi, J. Iran. Chem. Soc. 5 (2008) 694-698.
[19] B. F. Mirjalili, A. Bamoniri, A. Akbari, J. Iran. Chem. Soc. 8 (2011) 135-140.
[20] B. B. F. Mirjalili, A. Bamoniri, A. Akbari, Chem. Heterocycl. Compd., 47(2011) 487-491.
[21] A.T. Khan, T. Parvin, L. H. Choudhury, Synthesis, (2006) 2497-2502.
[22] A. Zarei, A. R. Hajipour, L. Khazdooz, B. F. Mirjalili, S. Zahmatkesh, J. Mol. Catal. A: Chem. 301 (2009) 39-46.