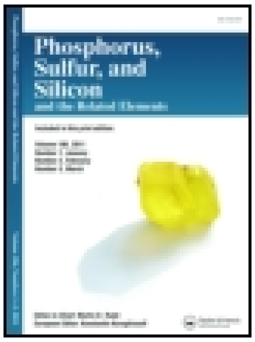

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Barium Aluminate nano-powders efficient catalyst for the synthesis of novel benzo[b]thiophene, thieno[2,3-c]thiopyran and thieno[2,3-c]pyridine derivatives

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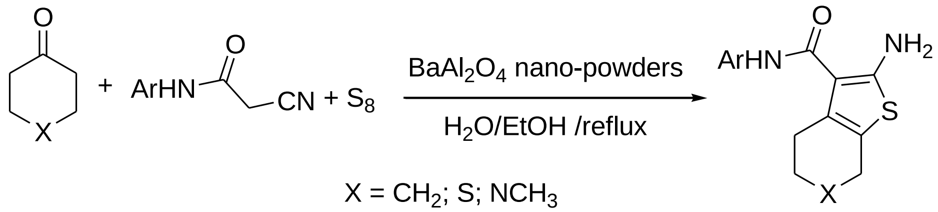
Abstract:

Uniform nanopowders of barium aluminate ($BaAl_2O_4$) can be synthesized by a facile solution reaction at room temperature using barium and aluminum salts and 2-aminoethanol as a precipitating agent. The as-prepared sample showed a good reactivity in the synthesis of benzo[b]thiophene, thieno[2,3-c]thiopyran and thieno[2,3-c]pyridine derivatives. Comparatively the method is efficient and eco-friendly, and finally, a range of compounds with variable functionalities in excellent yield can be achieved.



Keywords:

$BaAl_2O_4$; benzo[b]thiophene; thieno[2,3-c]thiopyran; thieno[2,3-c]pyridine; Gewald reaction

Introduction

In synthetic organic chemistry, multicomponent reactions (MCRs) have gained considerable popularity in recent years due to their flexible, convergent, and atom-efficient nature. MCRs are the basic reaction for the preparation of different heterocyclic compounds which are among of the most interesting compounds in medicinal chemistry. In this context, the development of multicomponent reactions is of prime importance, especially in the field of organic synthesis and medicinal chemistry [1-12].

Substituted 2-aminothiophenes are important intermediates in organic synthesis, which have been employed as building blocks to synthesize natural products, dyes, agrochemicals, and conductivity-based sensors. Therefore, the synthesis of 2-aminothiophenes has recently attracted considerable attention. Among all the reported methods, the Gewald reaction has gained significant attention [13-17]. Many organic bases, such as morpholine and pyridine, were proved to be viable catalysts for this reaction [18-25]. Highly reactive homogeneous bases catalysts are efficient for this process, but they suffer from serious contamination and corrosion problems that make essential the implementation of good separation and purification steps [23]. Recently, a green approach to Gewald reaction has stimulated the application of sustainable solid base catalysts as replacements for such liquid base catalysts so that the use of harmful substances and generation of toxic wastes are avoided [18-25].

$BaAl_2O_4$ is a significant commercial inorganic chemical owing to its applicable versatility. Barium aluminate has seldom been applied as an efficient catalyst for organic reactions [26-27]. Because of its mild basicity, eco-friendly, low cost and availability; more applied examples of

$BaAl_2O_4$ as a base catalyst are expected in the future [26-29]. The use of unconventional green solvents in organic reactions has improved not only the aspect of the reactions from the viewpoint of green and sustainable properties, but also the synthetic efficiency by stabilizing the catalyst, changing the reaction selectivity or facilitating product isolation [28]. In continuation of our research to explore eco-efficient transformations under environmentally benign conditions such as the use of a green solvent and driven by the unique properties of $BaAl_2O_4$ nanoparticles and the interest in the preparation and use of solid catalysts, herein, in this study, we investigated, for the first time, $BaAl_2O_4$ nanoparticles as an efficient and green catalyst to produce the title thiophene derivatives through the Gewald reaction in a multicomponent condensation between a ketone, elemental sulfur and cyano acetamide derivatives in ethanol as a green solvent under mild conditions (Scheme 1).

Results and discussion

$BaAl_2O_4$ nanopowder was prepared by a co-precipitation method using $Al(NO_3)_3$ and $BaCl_2$ precursors with ethanolamine as a precipitant in an aqueous solution at room temperature followed by calcination at 700°C.

The crystalline phase of $BaAl_2O_4$ sample was characterized using powder X-ray diffraction (XRD) analysis (Figure 1). The XRD pattern showed that the sample possesses a hexagonal structure characteristic for $BaAl_2O_4$ phase (space group P6322, Reference code: 00-017-0306). The peaks characteristic of hexagonal phase of $BaAl_2O_4$ are revealed at 19.6, 22.1, 28.3, 34.3, 39.8, 40.1, 45.0, and 57.8 [2θ°]. The average particle size of $BaAl_2O_4$ nanopowder was calculated suing the values of full width at half maximum (FWHM) of the most intensive XRD diffraction peaks. The crystallite size obtained from Debye–Scherrer equation was 59 nm.

Figure 2 shows FE-SEM image of $BaAl_2O_4$ nanopowder. The surface of the sample is relatively homogeneous with fine particles that are agglomerated together. The surface of nanopowder has some fine pores which are attributed to a lot of gasses released during the combustion process. The $BaAl_2O_4$ nanopowder is further characterized with energy dispersive X-ray spectroscopy (EDS). The sample consists of Ba, O and Al elements as shown in Figure 3.

TEM image corroborates that there is a few aggregation of $BaAl_2O_4$ nanopowder and shows a variable size of about 40--70 nm size with a non-uniformed distribution (Figure 4).

The particle size distribution of $BaAl_2O_4$ nanopowder is shown in Figure 5. The particle size distribution ranging from 35-90 nm. The mean diameter of nanopowder about 58 nm.

Catalytic activity

The catalytic activity of $BaAl_2O_4$ nanopowder was examined on the synthesis of benzo[b]thiophene, thieno[2,3-c]thiopyran and thieno[2,3-c]pyridine derivatives through Gewald reaction.

As a preliminary test, we investigated the conversion of a mixture of cyclohexanone (1.0 mmol), 2-cyano-*N*-phenylacetamide (1.0 mmol), and elemental sulfur (1.0 mmol) in various solvents (5 mL) under reflux condition in the presence of $BaAl_2O_4$ (0.05 g) for 10-20 h (Table 1). As shown in Table 1, the formation of 2-amino-*N*-phenyl-4,5,6,7-tetrahydrobenzo[b]thiophene-3-carboxamide as a targeted product was did not occur in non-polar solvents, in the absence of any catalyst as well as at room temperature. While polar solvents showed good yields, protic solvents such as ethanol and methanol were found to be the most efficient media for this transformation, giving the highest yield of product. Also, the yield increased from 70% to 90% when the time of the reaction was extended to 15h. Next, the effect of the different amount of the catalyst from 0.025 to 0.25 g on the productivity of the reaction was investigated. While the higher quantities of the catalyst did not effectively improve the yield, optimization finally arrived at 0.025 g (89% yield) when only a small variation in the yield was observed after increasing the amount of catalyst.

With the optimized conditions in hand, we investigated reactions with different ketones and 2-cyano-*N*-arylacetamide. In general, the desired products were obtained in high yields (Scheme 1, Table 2). The results showed that ketone play a major role on the reaction rates. 1-methylpiperidin-4-one reacted faster than cyclohexanone, while tetrahydrothiopyran-4-one yielded the product over longer reaction times. The reaction with different 2-cyano-*N*-arylacetamides leads to the formation of related products in high yield.

Experimental

All reagents were purchased from Merck and Aldrich and used without further purification. Field Emission Scanning Electron Microscope (FE-SEM) images were obtained on HITACHI S-4160. Dynamic light scattering (DLS) measurement was done using a Malvern Zetasizer Nano ZS (ZEN 3600) instrument. The Transmission Electron Microscopy (TEM) of the sample was performed on Philips EM208 transmission electron microscope with an accelerating voltage of 200 kV. The NMR spectra were recorded on a Bruker Avance DPX 400 MHz instrument. The spectra were measured in DMSO-d_6 relative to TMS (0.00 ppm). Melting points were determined in open capillaries with a BUCHI 510 melting point apparatus. TLC was performed on silica gel Polygram SIL G/UV 254 plates. The Supplemental Materials contains sample ^{1}H and ^{13}C NMR spectra of the products 1-12 (Figures S 1 -- S 24)

Preparation of Barium Aluminate nanopowder

$BaCl_2$ (20 mmol) and $Al(NO_3)_3$ (20 mmol) were dissolved in water (200 mL) (solution A). Then 2-aminoethanol (120 mmol) was dissolved in water (100 mL) (solution B). Solution (B) was added dropwise to the solution (A) under vigorous magnetic stirring. The mixture was continuously stirred for 60 min. The resulting precipitate was filtered and washed with water (500 mL) and dried at 100°C for 5 h and finally calcined at 700°C for 2h.

Typical procedure:

A mixture of tetrahydrothiopyran-4-one (1 mmol), 2-cyano-*N*-phenylacetamide (1 mmol), sulfur powder (1.5 mmol) and barium aluminate nanopowder (0.025 g) in EtOH (90% v/v) was refluxed (80°C) for the appropriate time. The progress of the reaction was monitored by TLC (Table 1). After completion of the reaction, the reaction mixture was dissolved in hot ethanol. Simple filtration removed the catalyst. The solvent was concentrated, and recrystallization purified the crude products from EtOH.

The characterization data of all compounds (Table 2, entries 1-12) are available in the Supplemental Materials.

Conclusion

In summary, a general $BaAl_2O_4$ nanopowder catalyzed Gewald reaction was developed. The products were achieved in high yields. The established system is not only efficient for the synthesis of target compounds but also endowed with many salient features of nano-particle Barium aluminate, such as cost-effective, high recyclable, reusable catalyst, environmental benign solvent system and easy isolation of the product.

Acknowledgments

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References

[1] (a) Cioc, R.C.; Ruijter, E.; Orru, R.V.A. *Green Chem*., **2014**, 16, 2958-2975; (b) Shaterian, H.R.; Yarahmadi, H.; Ghashang, M. *Tetrahedron*, **2008**, 64, 1263-1269.

[2] Shafiee, M.M.R.; Ghashang, M.; Fazlinia, A. *Curr. Nanosci*. **2013**, 9, 197-201.

[3] (a) Ghashang, M. *Curr. Org. Synth*. **2012**, 9, 727-732; (b) Liu, C.; Zhou, L.; Jiang, D.; Gu, Y. *Asian. J. Org. Chem*. **2016**, 5, 367-372.

[4] Taghrir, H.; Ghashang, M.; Biregan, M.N. *Chin. Chem. Lett*. **2016**, 27, 119-126.

[5] Ghashang, M.; Kargar, M.; Shafiee, M.R.M.; Mansoor, S.S.; Fazlinia, A.; Esfandiari, H. *Recent Pat. Nanotech*. **2016**, 9, 204-211.

[6] Shaterian, H.R.; Yarahmadi, H. *Tetrahedron Lett*. **2008**, 49, 1297-1300.

[7] Ghashang, M.; Mansoor, S.S.; Aswin, K. *Chin. J. Catal*. **2014**, 35, 127-133.

[8] Baziar, A.; Ghashang, M. *React. Kinet. Mechan. Catal*. **2016**, 118, 463-479.

[9] Yarahmadi, H.; Shaterian, H.R. *J. Chem. Res*. **2012**, 36, 52-55.

[10] Dehbashi, M.; Aliahmad, M.; Shafiee, M.M.R.; Ghashang, M. *Nano-Metal Chem*. **2013**, 43, 1301-1306.

[11] Ghashang, M. *Lett. Org. Chem*. **2012**, 9, 497-502.

[12] Shafiee, M.R.M.; Mansoor, S.S.; Ghashang, M.; Fazlinia, A. *C. R. Chim*. **2014**, 17, 131-134.

[13] Puterová, Z.; Krutošíková, A.; Végh. D.D. *Arkivoc*, **2010**, 1, 209-246.

[14] Gewald, K.; Schinke, E.; Bottcher, H. *Chem. Ber*. **1966**, 99, 94-100.

[15] Mayer, R.; Gewald, K. *Angew. Chem., Int. Ed. Engl*. **1967**, 6, 294-306.

[16] (a) Barnes, D.M.; Haight, A.R.; Hameury, T.; McLaughlin, M.A.; Mei, J.; Tedrow, J.S.; Dalla, R.T. *Tetrahedron*, **2006**, 62, 11311-11319; (b) Bai, R.; Liu, P.; Yang, J.; Liu, Ch.; Gu, Y. *ACS Sustainable Chem. Eng.* **2015**, *3*, 1292-1297.

[17] Wang, K.; Kim, D.; Domling, A. *J. Comb. Chem*. **2010**, 12, 111-118.

[18] Abaee, M.S.; Cheraghi, S. *J. Sulfur Chem*. **2014,** 35, 261-269.

[19] Liang, C.; Lei, D.; Wang, X.; Zhang, Q.; Yao, Q. *J. Sulfur Chem*. **2013**, 34, 458-463.

[20] Javadi, F.; Tayebee, R. *Micropor. Mesopor. Mat*. **2016,** 231, 100-109.

[21] Zhao, D.D.; Li, L.; Xu, F.; Wu, Q.; Lin, X.F.; *J. Mole. Catal. B: Enzym*. **2013,** 95, 29-35.

[22] Tayebee, R.; Javadi, F.; Argi, G. *J. Mole. Catal. A: Chem*. **2013,** 368, 16-23.

[23] Gouda, M.A.; Berghot, M.A.; Abd El-Ghani, G.E.; Elattar, K.M.; Khalil, A.E.M. *Turk. J. Chem.* **2011,** 35, 815-837.

[24] Huang, W.; Li, J.; Tang, J.; Liu, H.; Shen, J.; Jiang, H. *Synth. Commun.* **2005**, 35, 1351-1357.

[25] Nikolakopoulos, G.; Figler, H.; Linden, J.; Scammells, P.J. Bioorg. Med. Chem. 2006, 14, 2358-2365.

[26] Momayezan, M.; Ghashang, M.; Hassanzadeh-Tabrizi, S.A. *Bulg. Chem. Commun*., **2015,** 47, 809-815.

[27] Kazemi, N.; Ghashang, M.; Hassanzadeh-Tabrizi, S.A. *Nanosci. Nanotechnol. Asia* **2014,** 4, 88-93.

[28] Casapu, M.; Grunwaldt, J.D.; Maciejewski, M.; Wittrock, M.; Göbel, U.; Baiker, A. *Appl. Catal. B: Environment*., **2006,** 63, 232-242.

[29] Hodjati, S.; Bernhardt, P.; Petit, C.; Pitchon, V. *Appl. Catal. B: Environment*., **1998,** 19, 209-219.

[30] Gu, Y. *Green Chem*., **2012**, 14, 2091-2128.

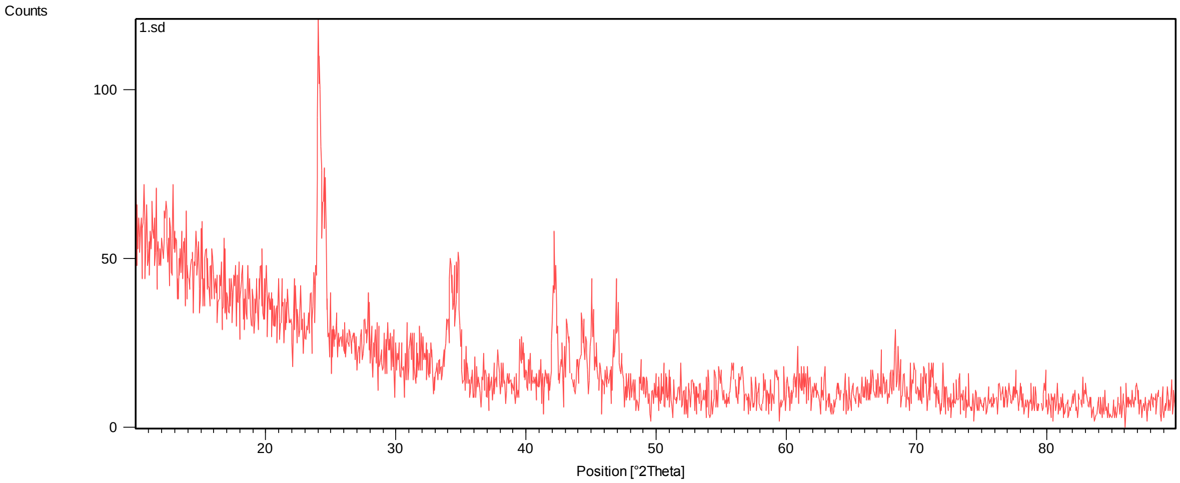


Figure 1: XRD pattern of *nano*-$BaAl_2O_4$ calcined at 700°C.

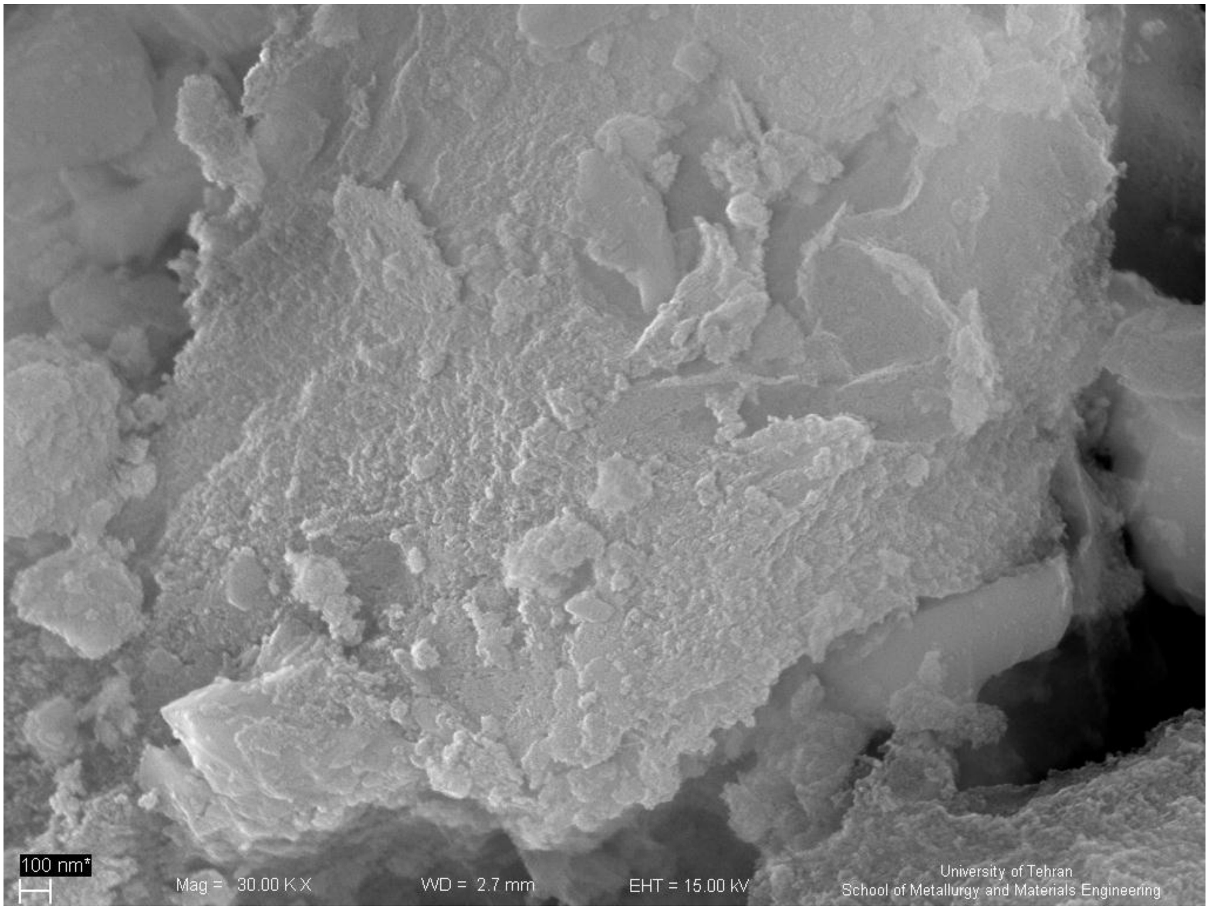


Figure 2: FE-SEM photograph of $BaAl_2O_4$ nanopowder calcined at 700°C.

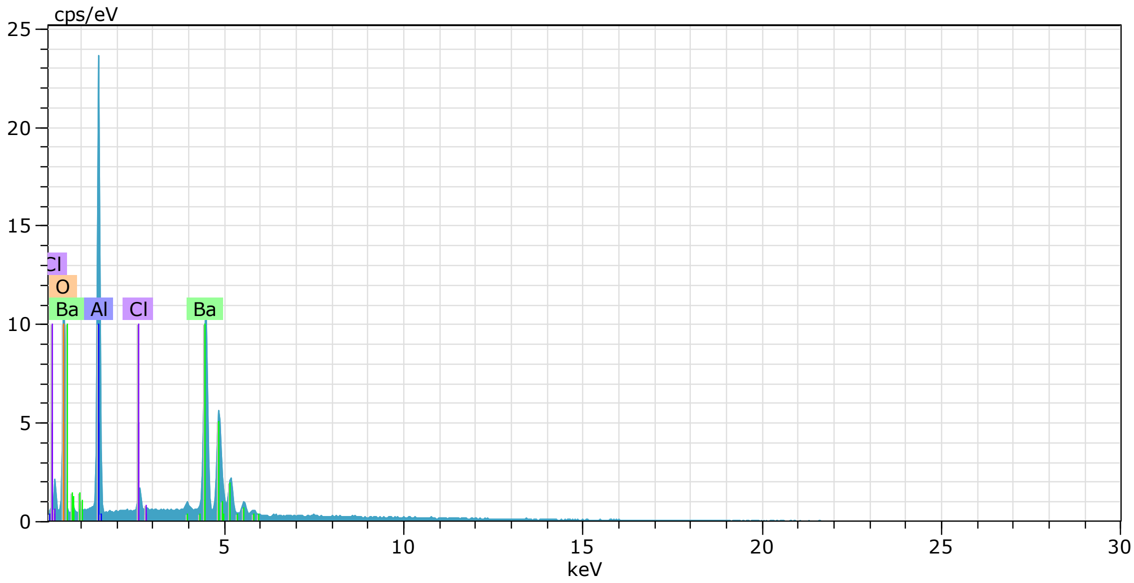


Figure 3: EDS analysis of $BaAl_2O_4$ nanopowder

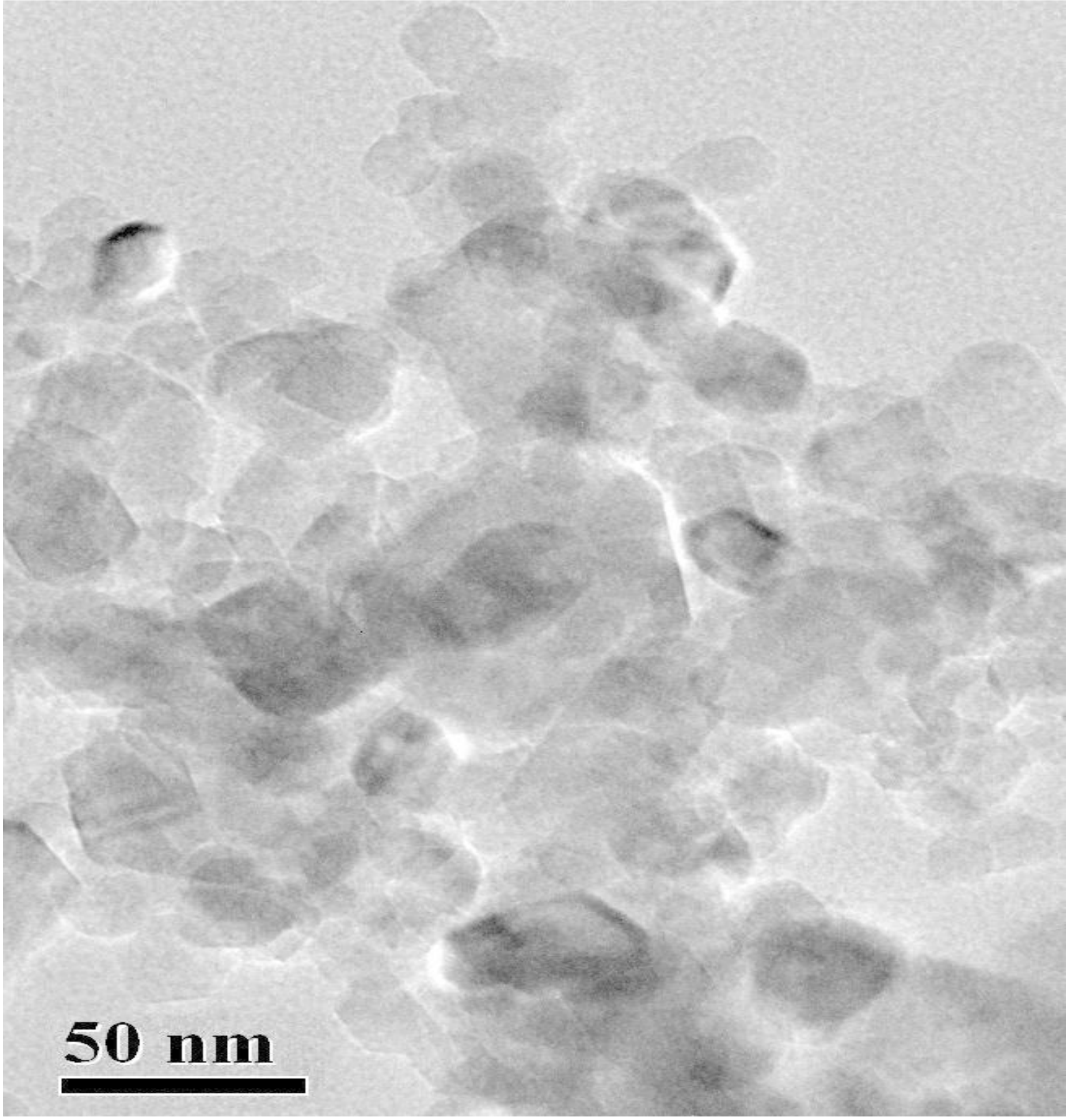


Figure 4: TEM image of $BaAl_2O_4$ nanopowder

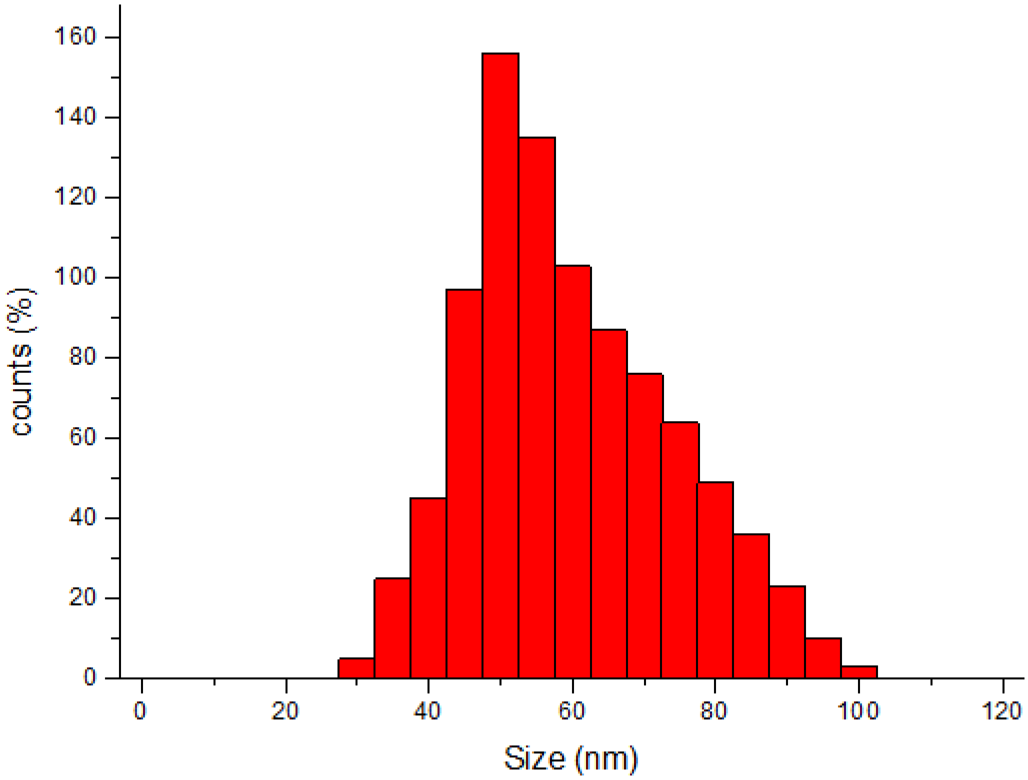
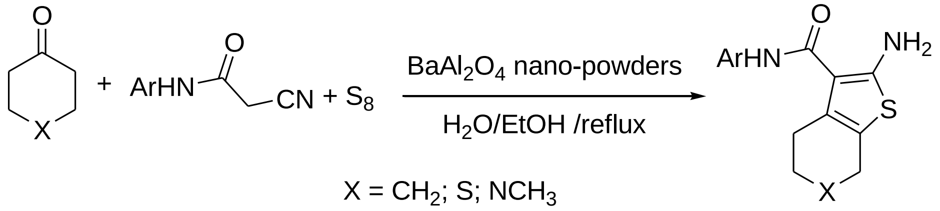


Figure 5: Particle size distribution of $BaAl_2O_4$ nanopowder determined by DLS analysis



Scheme 1: Preparation of benzo[b]thiophene, thieno[2,3-c]thiopyran and thieno[2,3-c]pyridine derivatives using $BaAl_2O_4$ nanopowders

Table 1: optimization of the reaction condition in the synthesis of 2-amino-4,5,6,7-tetrahydro-*N*-phenylbenzo[b]thiophene-3-carboxamide

Entry	Catalyst (g)	T (°C)	Solvent (5 mL)	Time (h)	Yield (%)[a]
1	0.05	Reflux	*n*-Hexane	10	-
2	0.05	Reflux	CH_2Cl_2	10	-
3	0.05	Reflux	Et_2O	10	-
4	0.05	Reflux	EtOAc	10	20
5	0.05	Reflux	EtOH	10	70
6	0.05	Reflux	MeOH	10	70
7	0.05	Reflux	EtOH	15	90
8	0.05	Reflux	EtOH	20	89
9	0.05	r.t.	-	10	-
10	-	r.t.	EtOH	10	-
11	0.025	Reflux	EtOH	15	89
12	0.075	Reflux	EtOH	5	85
13	0.1	Reflux	EtOH	5	74
14	0.25	Reflux	EtOH	10	71

[a] Isolated Yields;

Table 2. Synthesis of benzo[b]thiophene, thieno[2,3-c]thiopyran and thieno[2,3-c]pyridine derivatives

Entry	X	Ar-	Time (h)	Yield (%)	M.p. [Lit. M.p.]$^{Ref.}$ (°C)
1	-CH_2	****	15	89	142-144 [138-140]^{24}
2	-S-	****	18	94	132-134
3	-N-CH_3	****	14	85	143-145
4	-CH_2	****	15	93	137-139 [131-134]^{34}
5	-S-	****	19	87	140-142
6	-N-CH_3	****	15	86	154-156
7	-CH_2	****	14	79	153-155[-]^{25}
8	-S-	****	16	89	162-164
9	-N-CH_3	****	14	84	154-156
10	-CH_2	****	17	83	161-163[-]^{25}
11	-S-	****	20	80	165-167
12	-N-CH_3	****	16	79	178-180

[a] All of the reactions were conducted in the presence of nano-$BaAl_2O_4$ at reflux under optimized conditions