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# Green synthesis of CuO nanoflakes from copper pincer complex for effective *N*-arylation of benzimidazole

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#### ABSTRACT

Nanostructured CuO is synthesized in water using copper pincer complex as precursor without any stabilizing agent and characterized by X-ray diffraction (XRD), field emission scanning electron microscopy (FESEM), transmission electron microscopy (TEM), X-ray photoelectron spectroscopy (XPS) and energy dispersive X-ray analysis (EDAX). The selected area electron diffraction (SAED) and magnetization measurements indicate lattice fringes spacing of 0.25 nm for (111) plane and ferromagnetic nature of the CuO nanoflakes, respectively. Benzimidazole undergoes *N*-arylation reaction with aryl halides in the presence of CuO nanoflakes and  $K_2CO_3$  in *N*,*N*-dimethylacetamide (DMAc) at 120 °C. The reusability of the CuO nanoflakes is also tested and the results are found to be good.

Keywords: Copper pincer complex; CuO nanoflakes; Catalytic studies; N-arylation

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#### **1. Introduction**

Metal oxide nanomaterials have attracted great interest because of many unique properties linked to the nanometer size of the particles [1-3]. The oxides of transition metal elements are an imperative class of semiconductors, which have applications in solar energy transformation, magnetic storage media, electronics, catalysis, etc [4-6]. Among the metal oxides, CuO nanomaterials are of special interest because of their versatility in catalysis [7-9].

N-arylation of heterocycles is an important reaction in organic synthesis due to the application of N-arylated products in various fields such as pharmaceuticals, natural products synthesis, materials chemistry, etc [10-15]. To be specific, N-arylated benzimidazoles such as MRL-1237 and Telmisartan have been used as drug molecules, and 2,2',2"-(1,3,5-benzinetriyl)tris(1-phenyl-1-H-benzimidazole) was found to be an useful OLED material [16]. Many homogenous Cu catalysts have been reported for N-arylation of heterocycles [17]. Even though the homogeneous systems are active, they could not be commercialized due to the difficulty in the separation of catalyst and reusability. Hence may researchers have focused on the development of heterogeneous catalysts for the N-arylation reaction [7]. Among the various heterogeneous catalysts, nano CuO was found to be efficient and highly reusable [18]. CuO nanostructured materials have been prepared from various sources like CuCl<sub>2</sub>·5H<sub>2</sub>O, CuI, Cu(NO<sub>3</sub>)<sub>2</sub>, etc. [19-22]. To the best of our knowledge, no one has utilized Cu pincer complex as precursor for producing CuO nanomaterials. Cu pincer complexes have found importance mainly in homogeneous catalysis [23-24]. We have used Cu pincer complexes as a precursor for the preparation of nano CuO and studied its catalytic application towards N-arylation of benzimidazole under heterogeneous conditions. Nano CuO prepared from Cu pincer complex was found to possess a flake structure and exhibited very good catalytic efficiency and reusability in aforesaid reaction. CuO with different morphologies have been used as catalysts in various organic transformations but the use of nanoflake CuO in catalysis is rare [25].

#### 2. Experimental

#### 2.1. Synthesis of CuO

Cu pincer complex (50 mg) was synthesized by following a literature procedure [26-27] and then it was dissolved in 20 mL of distilled water under reflux condition. To the above solution  $K_2CO_3$  (40 mg) was added and the resulting mixture (pH = 6-7) was refluxed for 45 min. Then, the solution was cooled to room temperature and the solid product was separated by centrifugation, washed with distilled water and dried in hot air oven at 110 °C.

#### 2.2. Procedure for N-arylation of benzimidazole

CuO (15 mg, 5 mol %) was added to a mixture of aryl halide (1 mmole), benzimidazole (142 mg, 1.2 mmole) and  $K_2CO_3$  (276 mg, 2 mmole) in *N*,*N*-dimethyl acetamide (DMAc) (3 mL) and stirred at 120 °C. After the required time, the reaction mixture was cooled to room temperature and the catalyst was separated by centrifugation. The product was extracted with ethyl acetate, dried over anhydrous sodium sulphate and analyzed by GC. The recovered catalyst was washed thoroughly with water, ethanol and toluene, and dried under vacuum before reuse.

#### 3. Results and discussion

#### 3.1. Catalyst characterization

The X-ray diffraction pattern of the prepared material (Fig. 1) is in good agreement with that of reported CuO [16], which confirms the formation of CuO. The sharp and intense peaks indicated that the CuO is pure, crystalline and well arranged in specific orientation. The XRD reflections for CuO are observed at 20 value of  $32.17^{\circ}$ ,  $35.37^{\circ}$ ,  $38.80^{\circ}$ ,  $48.87^{\circ}$ ,  $58.36^{\circ}$ ,  $61.57^{\circ}$  and  $66.04^{\circ}$  representing (110), ( $\bar{1}11$ ), (111), ( $\bar{2}02$ ), (202), ( $\bar{1}13$ ) and ( $\bar{3}11$ ) planes of pure monoclinic structure (JCPDS No. 89-5895). The ( $\bar{1}11$ ) peak is more intense than (111) peak, which confirmed that the growth is more favorable in the ( $\bar{1}11$ ) direction than (111) direction.

To ensure the morphological difference of newly prepared CuO in comparison with existing reports, the FESEM and TEM images were recorded for the CuO (Fig. 2 & 3). The FESEM images portrayed flake morphology of the CuO (Fig. 2a & 2b). The TEM images further confirmed the flake morphology for the CuO with average size of 300-400 nm (Fig. 3a & 3b). The CuO flakes were analyzed by Selected Area Electron Diffraction (SAED) and HRTEM (inset of Fig. 3a) methods. The appearance of stretched out diffraction spots in the SAED pattern

of the CuO indicated the single crystalline nature which can be indexed to the phase pure monoclinic structure. The lattice analyses of HRTEM image confirmed the single crystalline nature and nano dimension of the CuO flakes with a lattice fringes spacing of 0.25 nm for ( $\overline{1}11$ ) plane (inset of Fig. 3b). The SAED pattern spots the diffraction points to obtain *hkl* planes. The single crystalline nature was confirmed by ( $\overline{1}11$ ), (110), ( $\overline{3}11$ ) and ( $\overline{2}02$ ) planes and the d spacing. The Cu and oxygen elements were observed in the EDAX spectrum of the CuO nanoflakes (Fig. S1). There is no evidence for the presence of impurities.

The XPS spectrum of the CuO shows peaks for Cu2p, Cu3p, C1s, O1s and the Auger lines (LMM) (Fig. S2c). High resolution spectrum of Cu2p shows four peaks at *ca*. 940, 949, 960 and 968 eV. The doublets at 940 and 960 eV are assigned to binding energy of Cu2p<sub>3/2</sub> and Cu2p<sub>1/2</sub>, respectively, with spin-orbit splitting of 8.8 eV (Fig. S2a & S2b). The other two shoulder peaks (satellite peaks) identified at 949 and 968 eV are possibly due to unstoichiometric cupric oxide (Cu<sub>1- $\delta$ </sub>O). The satellite peaks were ~9 eV above the main Cu2p peaks and the main Cu2p peaks indicate the formation of CuO [28].

The magnetization property as a function of magnetic field for the CuO nanoflakes was calculated using a VSM at 25 °C (Fig. S3). The M-H loop analysis indicated less coercivity (16.35 Oe), magnetic saturation (3.96 emu/g) and remanence (0.426 emu/g) values which confirmed the ferromagnetic nature of the CuO nanoflakes.

During DSC analysis, the CuO nanoflakes (7.9 mg) were heated under open atmosphere at 10 °C/min rate up to 200 °C. The result revealed the endothermic decomposition nature of the CuO nanoflakes, which includes the thermal decomposition of water molecules present on the surface of the material without any phase transition (Fig. S4a). In TGA analysis, the CuO nanoflakes were first held at 100 °C for 30 minutes to remove excess moisture and then the temperature was increased from 100 to 800 °C with a heating rate of 10 °C/min. The weight percentage *versus* temperature graph is provided in Fig. S4b. There are two weight losses in the temperature ranges 175-225 and 500-600 °C. The total weight loss is only about ~2% and the final remained weight is almost constant at even above 800 °C, which indicated the stability of the CuO nanoflakes (Fig. S4b).

#### 3.2. Catalysis

In order to obtain persuasive results, the reaction variables such as solvent, base, amount of substrates and catalyst quantity were optimized. For this purpose, 4-bromotoluene and benzimidazole were chosen as model substrates. Among the four different solvents tested, DMAc was found to be a better one (Table 1, entries 1-3 and 4). Similarly  $K_2CO_3$  (2 mmole) was identified as efficient base (Table 1, entries 2, 5-9 and 10). 5 mol % of CuO was sufficient for the effective *N*-arylation of benzimidazole (Table 1, entries 2, 12 and 13). Less than 5 mol% of CuO decreased the yield of the product. In the absence of the catalyst no reaction took place (Table 1, entry 11). The optimum temperature was 120 °C (Table 1, entries 2, 14-15 and 16). The conversion of benzimidazole during its *N*-arylation reaction with 4-bromotoluene was 98% at 120 °C in DMAc after 18 h (Table 1, entry 2). Extension of reaction time did not yield any fruitful results (Table 1, entries 18 and 19).

The scope of the present catalytic system was extended by the reaction of benzimidazole with various aryl halides (Table 2). The conversion is reasonably high (43 - 98 %) and comparable with already reported catalytic systems for *N*-arylation of benzimidazole [16, 29]. Aryl iodides gave good conversions compared to bromides and chlorides due to their better leaving ability (Table 2, entries 2, 4-5, 8 and 12). As the electron withdrawing effect of the substituent at the phenyl ring increases, the reactivity towards *N*-arylation also increases (Table 2, entries 7, 11 and 12). Presence of more electron releasing groups at the phenyl ring hindered the reaction rate (Table 2, entries 1 and 3) as well as the conversion (Table 2, entries 3 and 9). Interestingly, hetero aryl halides enhance the rate of the reaction (Table 2, entries 6 and 10). Selective coupling of aryl halide with the secondary amine restricted the formation of self-coupled product (Table 2, entry 9). We could reuse CuO nanoflakes for at least four times for *N*-arylation of benzimidazole with 4-bromotoluene and results are shown in Fig. S5.

#### Conclusions

The CuO nanoflakes was successfully synthesized using pincer copper complex in water medium. This CuO nanoflakes was found to be a promising catalyst for the *N*-arylation of benzimidazoles. This report opens a new avenue for utilizing pincer complexes as precursors for the preparation of catalytically active nanomaterials.

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#### Appendix A. Supplementary data

Supplementary data to this article can be found online

### Table 1

Optimization of reaction conditions for the CuO nanoparticles-catalyzed N-arylation of benzimidazole with 4-bromotoluene<sup>*a*</sup>



	Amount of Amount of						CC
Entry	Solvent <sup>b</sup>	Base	hase	Allount of	Temperature	Time	Conversion
Liiu y	Solvent	Dase	(mmole)	(mol %) (°C)	(h)	(%)	
1	DMF	K <sub>2</sub> CO <sub>3</sub>	2	5	120	18	83
2	DMAc	K <sub>2</sub> CO <sub>3</sub>	2	5	120	18	98
3	THF	$K_2CO_3$	2	5	120	18	15
4	DMSO	$K_2CO_3$	2	5	120	18	83
5	DMAc	КОН	2	5	120	18	31
6	DMAc	K <sub>3</sub> PO <sub>4</sub>	2	5	120	18	6
7	DMAc	(CH <sub>3</sub> ) <sub>3</sub> COK	2	5	120	18	19
8	DMAc	K <sub>2</sub> CO <sub>3</sub>	1	5	120	18	69
9	DMAc	K <sub>2</sub> CO <sub>3</sub>	3	5	120	18	92
10	DMAc	K <sub>2</sub> CO <sub>3</sub>	4	5	120	18	55
11	DMAc	$K_2CO_3$	2	0	120	18	No reaction
12	DMAc	K <sub>2</sub> CO <sub>3</sub>	2	2.5	120	18	31
13	DMAc	$K_2CO_3$	2	10	120	18	97
14	DMAc	$K_2CO_3$	2	5	80	18	Trace
15	DMAc	$K_2CO_3$	2	5	100	18	12
16	DMAc	$K_2CO_3$	2	5	140	18	23
17	DMAc	$K_2CO_3$	2	5	120	8	43
18	DMAc	$K_2CO_3$	2	5	120	24	97
19	DMAc	$K_2CO_3$	2	5	120	48	96

<sup>*a*</sup> All the reactions were performed with 1.2 mmole (142 mg) of benzimidazole and 1 mmole (171 mg) of 4-bromotoluene. <sup>*b*</sup> 3 mL of solvent was used in all the reactions. Bold letters indicate optimized condition (entry 2)

### Table 2

CuO nanoflakes-catalyzed N-arylation of benzimidazole with various aryl halides<sup>a</sup>

	$\begin{array}{ c c }\hline H \\ N \\ N \\ \hline N \\ 1a \\ 1b \\ \end{array} + Ar-X$	CuO nanoflakes K <sub>2</sub> CO <sub>3</sub> , DMAc 120 °C	A N N Ic	J <b>r</b> >
Entry	Ar-X (1b)	Product (1c)	Time (h)	$\begin{array}{c} \text{GC} \\ \text{Conversion} \\ (\%)^b \end{array}$
1	Br		18	98
2			18	94
3	Br		24	80
4	Br		24	55
5	Br		24	43



<sup>*a*</sup> All the reactions were performed with 1 mmole of ArX, 1.2 mmole (142 mg) of benzimidazole, 2 mmole (276 mg) of  $K_2CO_3$  in 3 mL of DMAc at 120 °C. <sup>*b*</sup> GC Conversion.

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Fig. 1. XRD pattern of CuO at 25 °C.

(a)

(b)



Fig. 2. FESEM images of CuO.

(a)





**Fig. 3.** TEM images of CuO nanoflakes. (inset, a) SAED pattern of CuO, (inset, b) parallel fringes with spacing.

### **Graphical abstract**





### Highlights

- CuO nanoflakes were prepared from Cu pincer complex in water medium
- CuO nanoflakes catalyze N-arylation of benzimidazole
- > Catalyst is efficient and reusable

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