Investigation on physical properties of nanosized copper oxide (CuO) doped with cobalt (Co): A material for electronic device application

Anil Maini | Mohammad Ashraf Shah

Abstract
This study has reported about the preparation and characterization of Copper oxide (CuO) nanoparticles doped with Cobalt series at low temperature by Sol-gel method. The characterization techniques like X-ray diffraction (XRD), scanning electron microscope (SEM), Raman spectroscopy, defused reflectance spectroscopy (DRS), and DC measurement have been used to confirm its phase formation, that is, monoclinic, surface porous morphology, the redshift of Raman peaks confirms optical phonon confinement, whereas increasing bandgap signifies the quantum confinement effect. The semiconducting nature of samples has been observed by two probe method. Furthermore, the study has focused in detail on the effect of cobalt doping with varying concentrations by wt % on its structural, morphological, optical, and conductivity features.

KEYWORDS
bandgap, raman and dc measurement, Sol-gel, XRD

1 | INTRODUCTION
Currently, the development of a huge number of new materials has been made possible by the nanotechnology field that deals with material size ranging from 1 to 100 nm. The metal oxide (MO) nanomaterials have received specific research attention of researchers owing to their different properties such as their catalytic, magnetic, electronic, optical, biological, and medicinal properties as compared to the bulk counterparts. Among all the transition metal oxides, CuO nanoparticles have received more attention because of their outstanding physical and chemical properties. Copper oxide is composed of two main elements copper and oxygen that belong to d and p block, respectively. Copper oxide (CuO) nanoparticles (NPs) show high catalytic activity and selectivity as compared to its bulk counterparts owing to their large surface to volume ratio. CuO nanostructures are well-known antibacterial materials and find applications in various fields such as superconductors, photocatalytic degradation, gas sensors, and biosensors. The inter-linkage between the nanoparticles and living cells depends upon the size, shape, and composition of nanostructures. The most common methods employed for the synthesis of CuO nanoparticles are sonochemical method, electrochemical method, one-step solid-state reaction method, sol-gel technique, colloidal thermal, high-temperature combustion, and so on. Among all these techniques, sol-gel is the wet chemical technique which is...
the cheapest, versatile, easy to handle, and does not need special laboratory equipments. In general, when metal oxide NPs are doped with transition metals, the particle size gets reduced and which in turn increases the rate of the catalytic reduction reaction. Besides, whenever transition metals are doped in metal oxides, the lattice defects are observed which significantly affects the charge transfer processes to ease catalytic reactions.\(^2\)

In our report, Cobalt (Co\(^{2+}\)) is taken as a dopant because the ionic radii of Cobalt (0.72 Å) are almost similar to Cu\(^{2+}\) (0.71 Å). CuO: Co NPs show high chemical reactivity to produce more active sites for reduction reactions, and it is the subject of wide-ranging research in an attempt to establish clearly defined composition/structure/properties correlations.\(^1\) Various research papers have been published so far on the effect of doping or Co doping on transition metals such as Fe, ZrO\(_2\), Fe/Co, Ni, Fe/Ni, Mn, Mn/Co, and La/Ni.\(^2\) In our study, doping of cobalt ions (Co\(^{2+}\)) in CuO NPs has been studied. Moreover, the study analyzes the structural, optical, and electrical properties of Co-doped CuO nanostructures for the purpose of electronic device applications.

2 | **EXPERIMENTAL DETAILS**

2.1 | **Materials**

Purchasing of all chemicals was done through Sigma-Aldrich suppliers and was used without further purification. Copper nitrate (Cu (NO\(_3\))\(_2\))5H\(_2\)O and citric acid (C\(_6\)H\(_8\)O\(_6\)) were of analytical reagent (AR) grade with 99.5% purity.

2.2 | **Synthesis procedure**

Initially, we prepared a gel solution made of Copper nitrate (Cu(NO\(_3\))\(_2\))5H\(_2\)O and citric acid (C\(_6\)H\(_8\)O\(_6\)) with molar ratio 1:3.6 with vigorous stirring over the magnetic stirrer. Next, the as-prepared solution was continuously stirred at a constant temperature of 700°C for half an hour. Then, the solution was further heated at a constant temperature of 1000°C until it was converted into a dry powder. Further, the sample was annealed at a temperature of 2000°C for 1 hour to reduce grain boundaries. Finally, the obtained powder was then calcined at a constant temperature of 500°C for 5 hours to remove the impurities if any. The obtained calcined powder was observed to be in a good crystalline phase of CuO. A careful analysis of the diffraction patterns shows that there is no trace of cobalt-related phase (metallic cobalt, oxides of cobalt, or any binary copper-cobalt phase) for all Co-doped CuO nanoparticles.

3 | **CHARACTERIZATION**

The synthesized black power of Co-doped CuO nanoparticles was then characterized by various techniques such as X-ray diffraction (XRD, Rigaku Smart laboratory) using CuK\(_\alpha\) radiation, scanning electron microscope (SEM, Hitachi S-3600N). Absorption spectra have been measured by UV-Vis spectrometer (Hitachi-3400). The Raman spectra of nanoparticles were collected by using Raman microscopes with a high-resolution instrument (Horiba Jobin Yvon laser Spectrometer-6400) of 785 nm laser. The current-voltage was measured by a Keithley 6517A electrometer.

4 | **RESULTS AND DISCUSSIONS**

4.1 | **Structural analysis**

X-ray diffraction (CuK\(_\alpha\), \(\lambda = 1.54056\) Å) pattern of prepared pure, as well as doped CuO NPs, has been shown in Figure 2 with a range of 20 from 20° to 80°. The characterization peaks of pure CuO NPs were observed at 20 values: 32.5°, 35.53°, 38.75°, 48.76°, 53.58°, 58.31°, 61.58°, 66.24, 68.08°, 73.07°, and 76.01° which corresponds to the peaks (1 1 0), (−1 1 1), (1 1 1), (−2 0 2), (0 2 0), (−1 1 3), (0 2 2), (220), (−321), and (203), respectively, as per JCPDS data (05-0661) and is consistent with the previous literature.\(^3\)–\(^5\) The observed peaks confirm the formation of different planes of the monoclinic phase of CuO nanoparticles. A careful analysis of the diffraction patterns shows that there is no trace of cobalt-related phase (metallic cobalt, oxides of cobalt, or any binary copper-cobalt phase) for all Co-doped CuO.
compositions. This indicates that Co ions have been successfully substituted into Cu sites without affecting the crystal structure of the parent CuO compound. This is due to the fact that ionic radius of Co$^{2+}$ (0.65 Å) is close to that of Cu$^{2+}$ (0.73 Å) and thereby Co$^{2+}$ easily occupies Cu$^{2+}$ sites within CuO crystal lattice. Figure 2 shows the X-ray diffraction pattern of pure CuO nanoparticles and cobalt doped CuO with doping concentrations (3, 6, and 9 wt %).

\[
\delta = (1/D^2)
\]

(2)

where,

- $D$ is the crystallite size.
- $\delta$ is the dislocation density.

Also, strain ($\varepsilon$) is calculated as:

\[
\varepsilon = \beta \cos \theta / 4
\]

(3)

where,

- $\beta$ is the full width at half maximum and,
- $\theta$ is the angle of Bragg diffraction.

Figure 2 also depicts that on increasing the cobalt dopant concentration (by wt %), the peak intensities get reduced. The reduction in peak intensity is because of declination of the crystallinity of CuO nanoparticles on cobalt doping by wt %. As enumerated in Table 1, the crystalline size is 33.13, 30.25, 29.05, and 27.65 at the doping concentration of 0, 3, 6, and 9 wt%, respectively, and accordingly, reduction in size was observed on account of doping. Furthermore, the broadening in peaks observed on increasing doping concentration. The broadening in peaks could be due to defects that arise because of metal ion doping. In this case, up to 9% Co doping oxygen vacancies may lead to a smaller grain size near the surface, whereas for above 10% doping, a vacancy-rich inner phase may favor the crystallite reorganization into larger grains. Also in our case, it is observed that the dislocation density and strain are increased with the decrease of grain size of CuO, this is because in nano regime surface to volume ratio increases.

4.2 | Morphological properties

The morphological analysis of the as-synthesized samples by the sol-gel method was carried out by using a scanning electron microscope (SEM) at a different scale. The prepared samples were directly transferred to the SEM chamber without disturbing the original nature. Figure 3A–D shows the highly magnified SEM images of copper oxide with cobalt doped concentration of 0, 3, 6, and 9 wt %, respectively. The systematic variation in the morphology of the CuO: Co samples with Co concentrations of 0, 3, 6, and 9 wt% is shown in Figure 3, which indicates porous and nondistinguishable boundaries in which the grain size steadily decreases with increasing Co concentration. The grains for the un-doped CuO compared with the CuO: Co samples are more packed with a wider size distribution. Thus, upon varying the percentage of cobalt within the parent CuO compound, it has been observed that the shape of grains apparently changes. Thus, it reveals that Co doping with the CuO parent material forms smaller grains (mostly <50 nm) with more homogeneous size distributions and porous surfaces.
4.3 Raman spectroscopy

The pure and Co-doped CuO NPs have further been examined by Raman spectroscopy as shown in Figure 4A and B. The pure CuO NPs as shown in Figure 4A depicted three Raman active modes at 283, 330, and 616 cm$^{-1}$ for a pure sample. The peak at 283 cm$^{-1}$ corresponds to the $A_g$ mode, and the other two peaks at 330 and 616 cm$^{-1}$ correspond to the two $B_g$ modes. Similarly, in the case of 9% Co-doped CuO NPs, three Raman active modes are observed at 273 cm$^{-1}$ corresponding to the one $A_g$ mode and 320 cm$^{-1}$ and 602 cm$^{-1}$ corresponding to two $B_g$ modes which confirms the shift in Raman peaks on doping. The doped CuO Raman spectra show the blue shift in peaks which indicates the following points:

- That particle size decreases on increasing doping concentration and
- Strain in the structure of CuO with dislocation density also increases on increasing doping concentration.

Furthermore, from Heisenberg uncertainty principle, the relationship between particle size and photon position can be expressed as follows:

$$\Delta X \times \Delta P \geq \frac{\hbar}{2}$$

where $\Delta X$ is the particle size, $\Delta P$ is the phonon momentum distribution, and $\hbar$ is the reduced Planck’s constant.

As the particle size decreases, the phonon is increasingly confined within the particle and the phonon momentum distribution increases, as a result phonon dispersion causes asymmetric broadening and may lead to a blue shift of the Raman bands which is in good agreement with the XRD analysis result that we observed above. The shifting
of \(E_{2\text{H}}\) mode toward lower wave number with increase in full width at half maximum (FWHM) and intensity upon doping is shown in Figure 4B this behavior is similar with the XRD result.

Hence, the above observation successfully verifies the XRD data shown in Table 1. Moreover, a considerable broadening in all three peaks was also observed. The decrease in peak intensity could be ascribed to the decrease of the lattice symmetry due to Co doping and to an increase in the phonon confinement with the decrease in particle sizes.\(^{37}\)

### 4.4 Optical properties

The optical nature of all Co: CuO nanoparticles was analyzed by diffused reflectance UV-Vis-NIR spectroscopy, and the obtained results are shown in Figure 5. It has been noted from Figure 5 that the reflectance % of CuO varies with the addition of Co doping by wt%. Moreover, the cutoff wavelength shows the blue shift in Co: CuO nanoparticles compared to pure CuO, which justifies that the Co doping improves the optical property of CuO nanoparticles for optoelectronic applications.\(^{38}\)

The optical energy gap (\(E_g\)) of the pure & Co: CuO NPs was calculated by applying Tauc’s plot (Kubelka-Munk theory) between \(h\nu\) vs \([F(R) h\nu]^2\) and is depicted in Figure 6(A) as calculated by Zargar et al.\(^{39}\) It is noticed that the Co (up to 9 wt %) doping increases the bandgap of the pure CuO nanoparticles (2.33eV). Upon doping, the bandgap energy gets increased due to the quantum confinement effect. This is evident from the crystallite size decrement upon Co doping compared to pure CuO and is clearly shown in Figure 6B. This is evident from the crystallite size increment upon Co doping when compared with pure CuO as seen from XRD results. The optical bandgap values are laying in the range 2.33-2.69 eV; a similar effect has already been reported by

---

**FIGURE 5**  Diffused reflectance spectra of CuO: Co samples with doping concentrations (0, 3, 6, and 9 wt %).

**FIGURE 6**  A, Tauc’s plot for energy bandgap determination of CuO: Co samples with doping concentrations (0, 3, 6, and 9 wt %). B, Display of Quantum Confinement effect with respect to particle size.

**FIGURE 7**  I-V characteristics measurement of CuO: Co samples with doping concentrations (0, 3, 6, and 9 wt %).
Chou et al. Bandgap in semiconductors changes due to various factors like crystallinity, crystallite size, doping, and ionic radii.

4.5 | DC conductivity mechanism

The electrical transport mechanism plays a vital role in a material which is to be used for device purposes. To elucidate the impact of Co-doping on electrical properties of as-prepared CuO NPs, the current vs. voltage (I-V) characteristics were measured in sandwich structure using Cu-electrodes on both sides of pellets made from synthesized Co: CuO NPs and are depicted in Figure 7, which confirms that current in CuO increases with the increase of voltage and also with Co concentration but overall identifies diode characteristics. The increase of the conduction mechanism may be because of the increase of cationic deficiencies and the existence of lower oxidation states of the dopant and is clearly shown in the next figure, that is, Figure 7.

The mean resistivity ($\rho$) and conductivity ($\sigma$) of synthesized Co: CuO were determined from $\rho = \frac{R \times A}{t}$ (here, $R$ is resistance, $A$ is area, and $t$ is thickness). Figure 8 shows the variation plot of $\ln(\rho)$ versus $1/T$ for the samples with respect to the temperature dependency of the DC conductivity, which can be obtained by using Arrhenius equation, given by

$$\rho = \rho_0 \exp\left(\frac{E_a}{kT}\right)$$ (5)

| Cobalt content (wt%) in doped CuO | Resistivity $\rho$ ($\Omega cm$) | Mobility $\mu$ ($cm^2 V^{-1} s^{-1}$) | Band gap (eV) | Activation energy (eV) |
|----------------------------------|-------------------------------|-----------------------------------|---------------|-----------------------|
| 0                                | $7.55 \times 10^2$            | 1.71                              | 2.33          | 0.39                  |
| 3                                | $4.71 \times 10^2$            | 2.23                              | 2.43          | 0.33                  |
| 6                                | $2.55 \times 10^2$            | 4.36                              | 2.53          | 0.27                  |
| 9                                | $1.073 \times 10^2$           | 6.7                               | 2.69          | 0.21                  |

Table 2: Electrical parameters are listed in the given table.

Figure 8: Arrhenius plot of CuO: Co samples with doping concentrations (0, 3, 6, and 9 wt %)

Figure 9: A, Co-relation between Particle size and activation energy versus Cobalt concentration in CuO$_{1-x}$Co$_x$ (x = 0%, 3%, 6%, and 9%) samples B, error bar of particle size with Co-doping
where \( \rho \) is the resistivity for absolute temperature \( T \), and \( K \) is the Boltzmann’s constant; \( E_g \) is the activation energy, and \( \rho_0 \) is a parameter that usually depends on the material. The activation energy helps us to find the trap levels that are situated below the conduction band.42

As shown in Figure 8, we found that activation energies and the mobility of the synthesized CuO: Co samples usually decrease upon transition metal doping, which is further correlated with the structural variation. As mentioned in the XRD section, the calculated crystallite size usually decreases as Co doping (by wt%) increases. Such an effect can influence the increasing number of dangling bonds, and as a result, there will be barrier height in the crystallite boundaries.43 Furthermore, the packed morphology with a larger grain size favors suitable mobility.44 The conduction of the prepared materials may be attributed to the native defect of oxygen vacancy states present in the CuO: Co composite materials. The electrical parameters drawn via two probe method are listed in Table 2, and Figure 9A is shown for better comparison. Both these values decrease with the rise in Cobalt concentration in the sample due to bandgap energy of Co which facilitates the charge conduction at low energy along with the error bar fitting of particle size is shown in Figure 9B. This means both direct energy bandgap and activation energy can be easily controlled simultaneously by changing Co-content with respect to the variation of particle size. Such CuO:Co materials may find plenty of application in solar energy storage devices.

5  |  CONCLUSIONS

To summarize the reported work, a simple Sol-gel method has been used for the preparation of pure and cobalt (Co) doped CuO NPs of sizes around 30 ± 10 nm samples. The reported decline in peak intensity is due to a reduction in the crystallinity of CuO nanoparticles on cobalt doping that can be attributed to the lowering of the lattice symmetry and enhancement in the phonon confinement on account of particle sizes due to Co doping. An increase in grain size and surface roughness with Co concentrations was confirmed from SEM. In Raman spectra, \( A_g \) phonon mode shows redshift that is optical phonon confinement induced by uncertainty in photon wave vectors means downshift of Raman peaks. The Co doping further results in the absorption of the peak in the visible region area and successfully enhances the ability to absorb visible light that arises on account of the d-d transition involved between closely spaced \( \text{Co}^{2+} \) and \( \text{Cu}^{2+} \) ions. The observed bandgap of pure CuO NPs and 9% Co-doped CuO NPs are 2.33 and 2.69 eV, respectively, and the reduction of the bandgap is because of particle size reduction and quantum confinement effect. The conduction in these samples is through a thermally assisted process. These properties of Co:CuO samples as prepared from the sol-gel technique confirm that the composite material is quite suitable for multifunctional device applications.

ACKNOWLEDGMENTS

We would like to thank Dr. A.H. Sofi from the Department of Physics, Central University of Kashmir for his constant support and encouragement during our laboratory work. His advice is priceless, and we acknowledge his guidance. We are also thankful to Dr. Saleem Ahmad Yatoo (SESD, Central University of Gujarat) and Mr. Arun Kumar (Research Scholar, Department of Physics, NIT Srinagar) for needful suggestions.

ORCID

Anil Maini © https://orcid.org/0000-0002-7638-1247

REFERENCES

1. Horikoshi S, Serpone N. Microwaves in Nanoparticle Synthesis: Fundamentals and Applications. Hoboken, NJ: John Wiley & Sons; 2013:1–352.
2. Usman MS, El Zowalaty ME, Shameli K, Zainuddin N, Salama M, Ibrahim NA. Synthesis, characterization, and antimicrobial properties of copper nanoparticles. Int J Nanomed. 2013;8:4467.
3. Hemalatha T, Akilandeswari S. Synthesis and characterization of hmta assisted cuo nanoparticles with its potential antibacterial application. Int J Recent Sci Res. 2015;6:7502–7.
4. Zargar RA, Hassan MM, Boora N, Ahmed I, Ahmed S, Nissa K-U, et al. A comparative study of micro- and nano-ZnO films fabricated by sol-gel syringe spray method. Int J Ceramic Eng Sci. 2020;2:169–76.
5. Devi HS, Singh TD. Synthesis of copper oxide nanoparticles by a novel method and its application in the degradation of methyl orange. Adv Electr Comput Eng. 2014;4(1):83–8.
6. Li Y, Tan B, Wu Y. Mesoporous Co3O4 nanowire arrays for lithium ion batteries with high capacity and rate capability. Nano Let. 2008;8(1):265–70.
7. Singh J, Kaur G, Rawat M. A brief review on synthesis and characterization of copper oxide nanoparticles and its applications. J Bioelectron Nanotechnol. 2016;1(1):9.
8. Guajardo-Pacheco MJ, Morales-Sánchez JE, González-Hernández J, Ruiz F. Synthesis of copper nanoparticles using soybeans as a chelant agent. Mater Lett. 2010;64(12):1361–4.
9. Rizvi SB, Ghaderi S, Keshigar M, Seifalian AM. Semiconductor quantum dots as fluorescent probes for in vitro and in vivo molecular and cellular imaging. Nano Rev. 2020;1(1):5161.
10. Martinez-Gutiérrez F, Olive PL, Banuelos A, Orrantia E, Nino N, Sanchez EM, et al. Synthesis, characterization, and evaluation of antimicrobial and cytotoxic effect of silver and titanium nanoparticles. Nanomed Nanotech Bio Medi. 2010;6(5):681–8.
11. Nam I, Kim ND, Kim GP, Park J, Yi J. Amorphous Mn Oxide-Ordered Mesoporous Carbon Hybrids as a High Performance Electrode Material for Supercapacitors. J Nanosci Nanotechnol. 2012;12(7):5704–8.
12. Sharma A, Dutta RK, Roychowdhury A, Das D, Goyal A, Kapoor A. Cobalt doped CuO nanoparticles as a highly efficient heterogeneous catalyst for reduction of 4-nitrophenol to 4-aminophenol. Applied. Catalysis A Gen. 2017;543:257–65.
13. Silambarasan M, Manikandan S, Rajan KS. Viscosity and thermal conductivity of dispersions of sub-micron TiO2 particles in water prepared by stirred bead milling and ultrasonication. Int J Heat Mass Transfer. 2012;55:7991–8002.

14. Hosseinpour M, Ahmadi Sj, Mousavand T, Outokesh M. Production of granulated-copper oxide nanoparticles for catalytic application. J Mat Res. 2010;25:2025–34.

15. Devi HS, Singh TD. Synthesis of copper oxide nanoparticles by a novel method and its application in the degradation of methyl orange. Adv Electr Eng. 2014;4:83–8.

16. Shah MA, Quarshi A. Novel surfactant-free synthesis of MgO nanoparticles. J Alloys Compd. 2009;482:548–52.

17. Kumar V, Elgamiel R, Diamant R, Gedanken Y, Norwig A. Sonochemical preparation and characterization of nanocrystalline copper oxide embedded in poly (vinylalcohol) and its effect on crystal growth of copper oxide. Langmuir. 2001;17(5):1406–10.

18. Borghain K, Singh JB, Rao MR, Shripathi T, Mahamuni S. Quantum size effects in CuO nanoparticles. Phy Rev B. 2000;61(16):11093.

19. Xu JF, Ji W, Shen ZX, Tang SH, Ye XR, Jia DZ, et al. Preparation and characterization of CuO nanoparticles. J Solid State Chem. 1999;147(2):516–9.

20. Eliseev AA, Lukashin AV, Vertegel AA, Heifts LI, Zhivor AI, Tetryakov YD. Complexes of Cu (II) with polyvinyl alcohol as precursors for the preparation of CuO/SiO2 nanocomposites. Mater Res Innov. 2000;3(5):308–12.

21. Son DI, You CH, Kim TW. Structural, optical, and electronic properties of colloidal CuO nanoparticles formed by using a colloid-thermal synthesis process. Appl Surf Sci. 2009;255(21):8794–7.

22. Chang Y, Zeng HC. Controlled synthesis and self-assembly of single-crystalline CuO nanorods and nanoribbons. Cryst Growth Des. 2004;4(2):397–402.

23. Jiang Y, Decker S, Mohs C, Klabunde KJ. Catalytic solid state reactions on the surface of nanoscale metal oxide particles. J Catal. 1998;180(1):24–35.

24. Basith NM, Vijaya JJ, Kennedy LJ, Bououdina M. Structural, morphological, optical, and magnetic properties of Ni-doped CuO nanostructures prepared by a rapid microwave combustion method. Mater Sci Semicond Process. 2014;17:110–8.

25. Zhu H, Zhao F, Pan L, Zhang Y, Fan C, Zhang Y, et al. Structural and magnetic properties of Mn-doped CuO thin films. J Appl Phys. 2007;101(9):09H111.

26. Paul JD, Venkateswaran C, Vennila SR. Critical analysis on the structural and magnetic properties of bulk and nanocrystalline CuFeO. Adv Mater Sci Eng. 2010;2010:715872.

27. Baumann TF, Worsley MA, Han TY, Satcher JH Jr. High surface area carbon aerogel monoliths with hierarchical porosity. J Non Cryst Solids. 2008;354(29):3513–5.

28. Viruthagiri G, Gopinathan E, Shanmugam N, Gobi R. Synthesis and characterization of ZrO2–CuO co-doped ceria nanoparticles via chemical precipitation method. Spectrochimica Acta Part A. 2014;131:556–63.

29. Yakout SM, El-Sayed AM. Structural, morphological and ferromagnetic properties of pure and (Mn, Co) codoped CuO nanostructures. J Supercond Nov Magn. 2016;29(11):2961–8.

30. Khmissee H, El Sayed AM, Shaban M. Structural, morphological, optical properties and wettabillity of spin-coated copper oxide: influences of film thickness, Ni, and (La, Ni) codoping. J Mater Sci. 2016;51(12):5924–38.

31. Ponnarasam V, Krishnan A. Synthesis, structural and optical properties of cobalt doped CuO nanoparticles. Int J Nanosci. 2016;16(02):1650031.

32. Anu TN, Kumar K, Sharma KK. 2020 Application of Co-doped copper oxide nanoparticles against different multidrug resistance bacteria. Inorg Nano-Met Chem. 2020;50(10):1-11.

33. Salavati-Niasari M, Davar F, Mir N. Synthesis and characterization of metallic copper nanoparticles via thermal decomposition. Polyhedron. 2008;27(17):3514–8.

34. Makinson JD, Lee JS, Magner SH, De Angelis RJ, Weins WN, Hieronymus AS. X-ray diffraction signatures of defects in nanocrystalline materials. Adv X-Ray Anal. 2000;42:407–11.

35. Zargar RA, Arora M, Hafiz AK. Investigation of physical properties of screen printed nanosizedZnO films for optoelectronic applications. Eur Phys J Appl Phys. 2015;70:10403.

36. Goldstein HF, Kim DS, Peter YY, Bourne LC, Chaminade JP, Nganga L. 1990 Apr 1 Raman study of CuO single crystals. Phys Rev B Condens Matte. 1990;41(10):7192.

37. Arora AK, Rajalakshmi M, Ravindran TR, Sivasubramanian V. Raman spectroscopy of optical phonon confinement in nanostructured materials. J Raman Spectrosc. 2007;38:604–17.

38. Toboonsung B, Singjai P. Formation of CuO nanorods and their bundles by an electrochemical dissolution and deposition process. J Alloys Compd. 2011;509(10):4132–7.

39. Zargar RA, Bhat MA, Reshi HA, Khan SD. CdZnO coated film: a material for photovoltaic applications. Results Phys. 2018;9:1673–6.

40. Chou MH, Liu SB, Huang CY, Wu SY, Cheng CL. Confocal Raman spectroscopic mapping studies on a single CuO nanowire. Appl Surf Sci. 2008;254(23):7539–43.

41. Cho S. Optical and electrical properties of CuO thin films deposited at several growth temperatures by reactive RF magnetron sputtering. Met Mater Int. 2013;19(6):1327–31.

42. Zargar RA, Arora M, Bhat RA. Study of nanosized copper-doped ZnO dulate magnetic semiconductor thick films for spintronic device applications. Appl Phys A. 2018;124(1):36–9.

43. Kajikawa Y. Effects of potential barrier height and its fluctuations at grain boundaries on thermoelectric properties of polycrystalline semiconductors. J Appl Phys. 2013;114(5):053707.

44. Lamri Zeggar M, Chabane L, Aida MS, Attaf N, Zebar N. Solution flow rate influence on properties of copper oxide thin films deposited by ultrasonic spray pyrolysis. Mater Sci Semicond Process. 2015;30:645–50.

How to cite this article: Maini A, Shah MA. Investigation on physical properties of nanosized copper oxide (CuO) doped with cobalt (Co): A material for electronic device application. Int J Ceramic Eng Sci. 2021;00:1–8. https://doi.org/10.1002/ces2.10097