A comparative study of the effect of solvents on the optical, structural and morphological properties of ZnO–GO nanocomposites synthesized by sol-gel method

Sudha Maurya*[1], Sandhya Pillai[2]

Department of Nanotechnology, Christian College of Engineering and Technology,
Bhilai, Durg, Chhattisgarh, India

*sudhamaurya1911@gmail.com

Zinc Oxide-Graphene Oxide (ZnO–GO) nanocomposites were prepared using solvents polyvinylpyrrolidone (PVP) and N-Methyl-2 Pyrrolidone (NMP) by sol-gel technique and their optical, structural and morphological properties were investigated. X-ray Diffraction (XRD) studies show the presence of planes of GO and ZnO confirming the formation of composites. The particle sizes were calculated using Scherrer's formula and were found to be in the nanometer range. Scanning Electron Microscopy (SEM) images show the formation of layered structures dispersed non-uniformly over clusters of particles. Energy Dispersive X-Ray (EDX) spectra confirm the presence of carbon, zinc and oxygen in the composites. The optical absorbance of ZnO–GO synthesized using PVP was higher than ZnO–GO with NMP with the absorption edge shifting to shorter wavelength in the presence of NMP. The band gap values were found to be in the range of 2.7–3.0 eV. The band gap of ZnO–GO synthesized using NMP was higher than ZnO–GO synthesized using PVP.

Keywords: GO, ZnO, ZnO–GO Nanocomposite, PVP, NMP.

Received: 2 November 2019

Revised: 30 November 2019

1. Introduction

Zinc Oxide (ZnO), a wide band gap II–VI semiconductor has been a subject of extensive research owing to its numerous interesting properties, making it a desirable material for application in conductive oxide [1], solar cell [2], display and sensors [3, 4], and photocatalysis [5, 6]. However, pure ZnO suffers from weak photo response [7], fast recombination of electron-hole pairs [8] and low operating speed.

GO is a layer of graphene functionalized with oxygen-containing moieties, such as hydroxyl (OH), carbonyl (C=O) and alkoxy (C–O–C) groups. It possesses unique properties that are different from graphene due to the existence of various oxygenated functional groups on the surface of GO. Graphene Oxide (GO) has attracted researchers due to its high surface area, high mobility of charge carriers and excellent stability. Hybrid of GO and ZnO (nanocomposites) can offer better prospects to enhance the photoresponsivity, stability and flexibility of ZnO for various applications [9, 10].

ZnO can be prepared by different means, of which the sol-gel is a popular method because of its low cost, reliability, reproducibility, simplicity. The choice of solvents used for reaction and capping the particles affects the shape and size of the composites [11]. Although there have been several reports on the synthesis of these composites using different solvents, a comparative study of the effect of solvents on the properties of the composites have not been presented to date. In the present work ZnO–GO nanocomposites were prepared using two polymer solvents – PVP and NMP. There are reports that a polymer matrix is useful in the formation of nanoparticles as it possesses the properties of the host polymer as well as the guest nanoparticles [12]. The polymers can also help in easier shaping and formation of the composite materials. PVP is a good surface stabilizer, growth modifier and particle disperser [13]. It also inhibits agglomeration by steric effect [14]. NMP is a 5 member ring compound containing nitrogen. It has high dissolving power and high purity. It can dissolve organic and inorganic compounds well or even better than chlorofluorocarbon (CFC) solvents. This paper presents the structural, morphological and optical characterization of ZnO–GO nanocomposites prepared using PVP and NMP as capping agents.

2. Experimental techniques

2.1. Synthesis of Zinc Oxide (ZnO)

ZnO nanoparticles were synthesized by sol gel method. The appropriate quantity of Zinc acetate was dissolved in deionized water and mixed with an equal quantity of aqueous 0.05 M NaOH solution slowly with continuous stirring at 50 °C. The reaction mixture was maintained at this temperature for 2 hours and then cooled to room temperature. The resultant precipitate was centrifuged and then washed with deionized water and dried at room temperature.

2.2. Synthesis of Graphene Oxide (GO)

Graphene oxide (GO) was synthesized using modified Hummers method from pure graphite powder [15]. First, 108 ml of sulphuric acid (H_2SO_4) and 12 ml of phosphoric acid (H_3PO_4) (volume ratio 9:1) were mixed and stirred using ultrasonic bath (53 KHz, 80 W) for several minutes. 0.9 g of graphite powder was added into the solution under stirring condition. The mixture was ultrasonicated for an hour and then kept in an ice bath keeping the temperature at approximately 5 °C. Then, 5.28 g of potassium permanganate ($KMnO_4$) was then added slowly into the solution. This mixture was stirred under ultrasonic irradiation for 6 hours until the solution became dark green and thereafter was magnetically stirred for 1 hr after removing from the icebath. To eliminate excess of $KMnO_4$, 2.7 ml of hydrogen peroxide (H_2O_2) was dropped slowly and stirred for 10 minutes. On adding hydrogen peroxide, the residual $KMnO_4$ and MnO_2 was reduced to soluble salts. The solution was cooled and 20 ml of hydrochloric acid (HCl) and 60 ml of deionized water (DIW) was added and centrifuged for 7 minutes.The suspension was filtered using high quality Whatman filter paper The residue obtained after decantation w washed with HCl and DIW for 3 times to remove the metal ions. The filtrate was again mixed with DIW several times so as to remove any other impurities and then ultrasonicated for 1 hr to obtain dispersion of GO. The washed GO solution was dried using oven at 90 °C for 24 hours to produce the GO powder.

2.3. Synthesis of ZnO–GO nanocomposites

ZnO–GO nanocomposites were synthesized with two different ratios of ZnO to GO – namely $ZnO_{0.5}$–$GO_{0.5}$ and $ZnO_{0.7}$–$GO_{0.3}$. 0.5 g graphene oxide and 0.1 g PVP/NMP was dispersed in 500 ml deionised water to form graphene oxide solution. 0.5 g ZnO nanoparticles were added into graphene oxide solution and the mixture was stirred at room temperature for 2 hrs. The resultant precipitate was filtered and thoroughly washed with deionized water to remove impurities and dried at 80 ° C for 5 hrs to obtain $ZnO_{0.5}$–$GO_{0.5}$ nanocomposites. $ZnO_{0.7}$–$GO_{0.3}$ nanocomposites were also synthesized using the above method.

FIG. 1. ZnO–GO nanocomposites

2.4. Characterization Methods

XRD studies were performed at NIT Raipur using PANalytical 3KW X'pert powder – Multifunctional X-ray diffractometer, SEM and EDX studies were also carried out at NIT Raipur using ZEISS EVO 18 Scanning Electron Microscope and INCA 250 EDS with X-MAX 20 nm detector. Optical absorbance spectral studies were done using ELICO-SL210 UV-VIS spectrophotometer.

3. Results and discussion

3.1. Absorbance spectra

Fig. 2(a) depicts the optical absorbance spectra of $ZnO_{0.5}$–$GO_{0.5}$–$PVP_{0.1}$ and $ZnO_{0.5}$–$GO_{0.5}$–$NMP_{0.1}$ while Fig. 2(b) shows the absorbance spectra of $ZnO_{0.7}$–$GO_{0.3}$–$PVP_{0.1}$ and $ZnO_{0.7}$–$GO_{0.3}$–$NMP_{0.1}$ nanocomposites. The absorption edge in these composites is around 420 nm for those prepared with PVP while in the case of composites
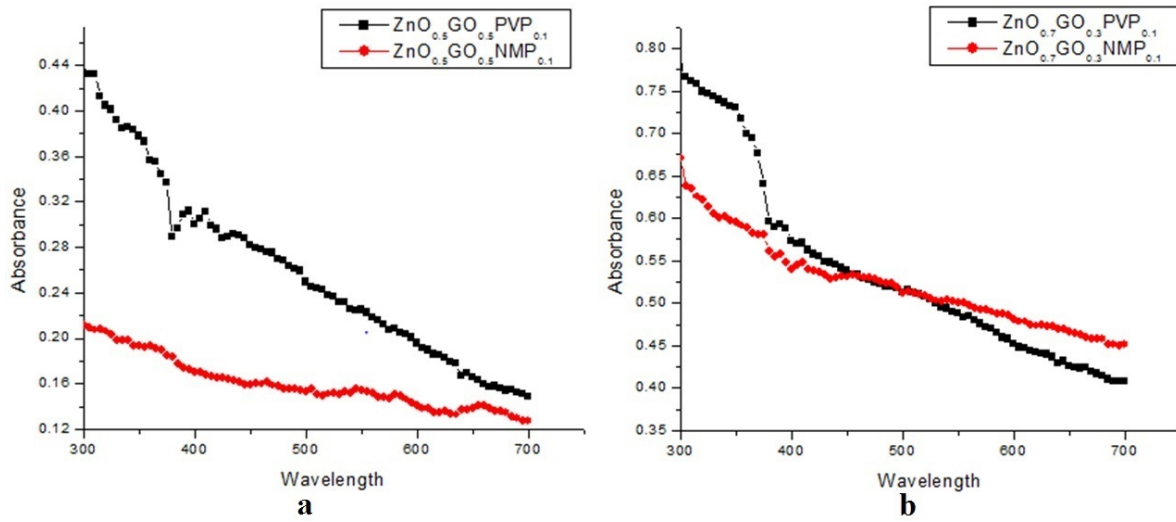
FIG. 2. (a)Absorbance spectra of $ZnO_{0.5}$–$GO_{0.5}$–$PVP_{0.1}$ and $ZnO_{0.5}$–$GO_{0.5}$–$NMP_{0.1}$ Nanocomposites; (b)Absorbance spectra of $ZnO_{0.7}$–$GO_{0.3}$–$PVP_{0.1}$ and $ZnO_{0.7}$–$GO_{0.3}$–$NMP_{0.1}$ Nanocomposites

prepared with NMP, the absorption edge shifts to shorter wavelength around 400 nm. This is in agreement with other reports on the absorption edge of GO–ZnO composites [8, 16]. Tauc's plots (plot between $(\alpha h v)^2$ vs hv where α is the absorption coefficient) were used to determine the band gap of the material from the absorbance data. Fig. 3(a) represents the Tauc's plot of $ZnO_{0.5}$–$GO_{0.5}$–$PVP_{0.1}$ and $ZnO_{0.5}$–$GO_{0.5}$–$NMP_{0.1}$ and Fig. 3(b) shows the Tauc's plot of $ZnO_{0.7}$–$GO_{0.3}$–$PVP_{0.1}$ and $ZnO_{0.7}$–$GO_{0.3}$–$NMP_{0.1}$. The corresponding values of band gap are presented in Table 1 and are found to be in the range between 2.7 and 3.0 eV. The band gap values of composites prepared with NMP are higher than those with PVP.
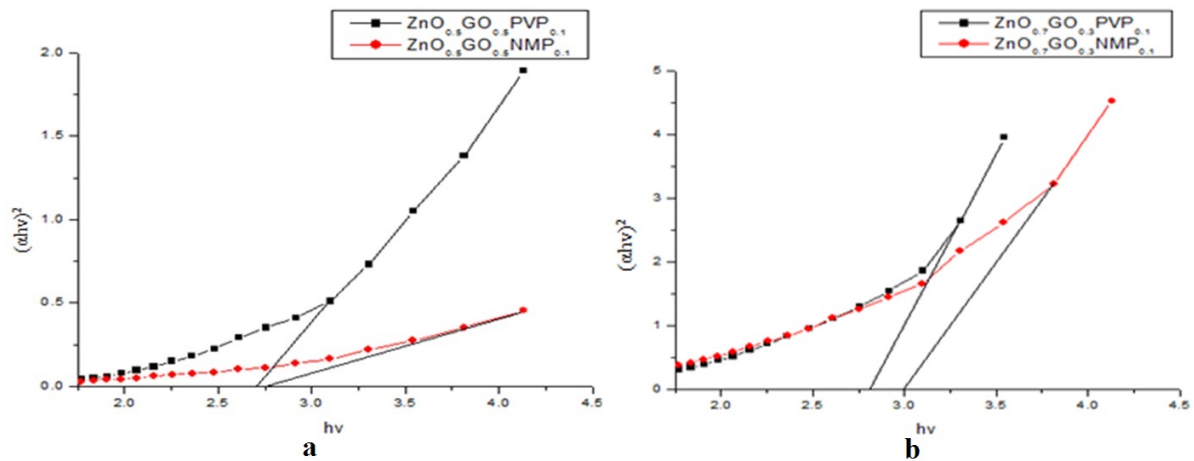

FIG. 3. (a)Tauc's plot of $ZnO_{0.5}$–$GO_{0.5}$–$PVP_{0.1}$ and $ZnO_{0.5}$–$GO_{0.5}$–$NMP_{0.1}$ Nanocomposites; (b)Tauc's plot of $ZnO_{0.7}$–$GO_{0.3}$–$PVP_{0.1}$ and $ZnO_{0.7}$–$GO_{0.3}$–$NMP_{0.1}$ Nanocomposites

3.2. XRD Studies

Figure 4(a) and 4(b) represent the X-ray diffractograms of $ZnO_{0.5}$–$GO_{0.5}$–$PVP_{0.1}$ and $ZnO_{0.5}$–$GO_{0.5}$–$NMP_{0.1}$ and the corresponding data are presented in Tables 2 and 3 respectively. The assignments of the different peaks were made by comparison with JCPDS data of GO and JCPDS data 36-1451 of ZnO and calculation of lattice constants, which showed agreement with the reported values. In both the cases, maximum intensity corresponds to the (100) plane of ZnO. The other prominent planes corresponding to ZnO are (002), (101), (102), (110), (103), (200), (004) which have been observed in both the cases. Diffraction line (002) of GO is also observed.

TABLE 1. Band Gap values of ZnO–GO Nanocomposites

S No.	Sample	Band Gap (eV)
1	$ZnO_{0.5}GO_{0.5}PVP_{0.1}$	2.7
2	$ZnO_{0.5}GO_{0.5}NMP_{0.1}$	2.75
3	$ZnO_{0.7}GO_{0.3}PVP_{0.1}$	2.8
4	$ZnO_{0.7}GO_{0.3}NMP_{0.1}$	3.0
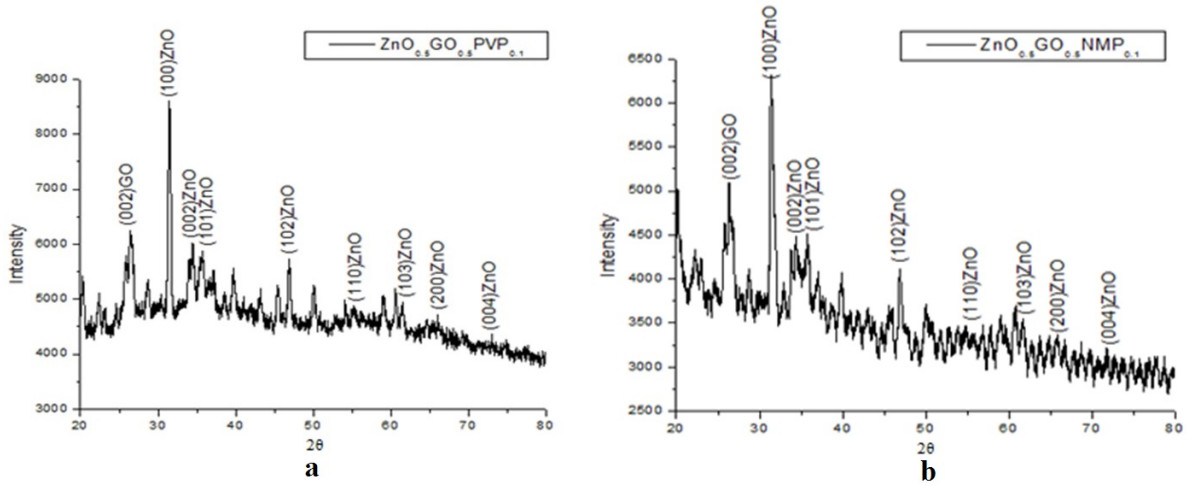
FIG. 4. (a)X-ray diffractogramof $ZnO_{0.5}$–$GO_{0.5}$–$PVP_{0.1}$ Nanocomposites; (b)X-ray diffractogram of $ZnO_{0.5}$–$GO_{0.5}$–$NMP_{0.1}$ Nanocomposites

TABLE 2. XRD data of $ZnO_{0.5}$–$GO_{0.5}$–$PV_{0.1}$ Nanocomposites

d Value(A^0)		Relative Intensity		hkl	Lattice Constant c (A^0)	
(Obs)	(Rep)	(Obs)	(Rep)		(Obs)	(Rep)
3.3714	3.3608	–	–	(002)GO	–	–
2.8392	2.8143	100	57	(100)ZnO	$a = 3.278$	$a = 3.25, c = 5.207$
2.6031	2.6033	70	44	(002)ZnO	$c = 5.206$	$a = 3.25, c = 5.207$
2.5104	2.4759	68.24	100	(101)ZnO	$a = 3.308, c = 5.206$	$a = 3.25, c = 5.207$
1.9347	1.9111	66.69	23	(102)ZnO	$a = 3.339, c = 5.206$	$a = 3.25, c = 5.207$
1.6327	1.6247	55.52	32	(110)ZnO	$a = 3.265$	$a = 3.25, c = 5.207$
1.5054	1.4771	57.58	29	(103)ZnO	$a = 3.49, c = 5.206$	$a = 3.25, c = 5.207$
1.4125	1.4072	54.78	4	(200)ZnO	$a = 3.262$	$a = 3.25, c = 5.207$
1.2941	1.3017	50.70	2	(004)ZnO	$c = 5.176$	$a = 3.25, c = 5.207$

Fig. 5(a) and 5(b) represent the X-ray diffractograms of $ZnO_{0.7}$–$GO_{0.3}$–$PVP_{0.1}$ and $ZnO_{0.7}$–$GO_{0.3}$–$NMP_{0.1}$ and the corresponding data are presented in Tables 4 and 5 respectively. The diffraction lines observed with $ZnO_{0.7}$–$GO_{0.3}$ are quite different from the lines observed in the case of $ZnO_{0.5}$–$GO_{0.5}$. The maximum intensity peak in both $ZnO_{0.7}$–$GO_{0.3}$–$PVP_{0.1}$ and $ZnO_{0.7}$–$GO_{0.3}$–$NMP_{0.1}$ composites is (002) plane of ZnO. The other planes observed are (100), (101), (102), (110) of ZnO and (002) plane of GO. The presence of diffraction lines of both GO and ZnO confirms the formation of the nanocomposites. The existence of only one GO peak may be due to the partial reduction of the GO to Graphene sheet [15].

The particle sizes were calculated using the Debye–Scherrer's formula ($D=0.94\lambda/\beta_{1/2}\cos\theta$) and the corresponding values are presented in Table 6. The average particle sizes were found to be in the nanometer range.

TABLE 3. XRD data of $ZnO_{0.5}$–$GO_{0.5}$–$NMP_{0.1}$ Nanocomposites

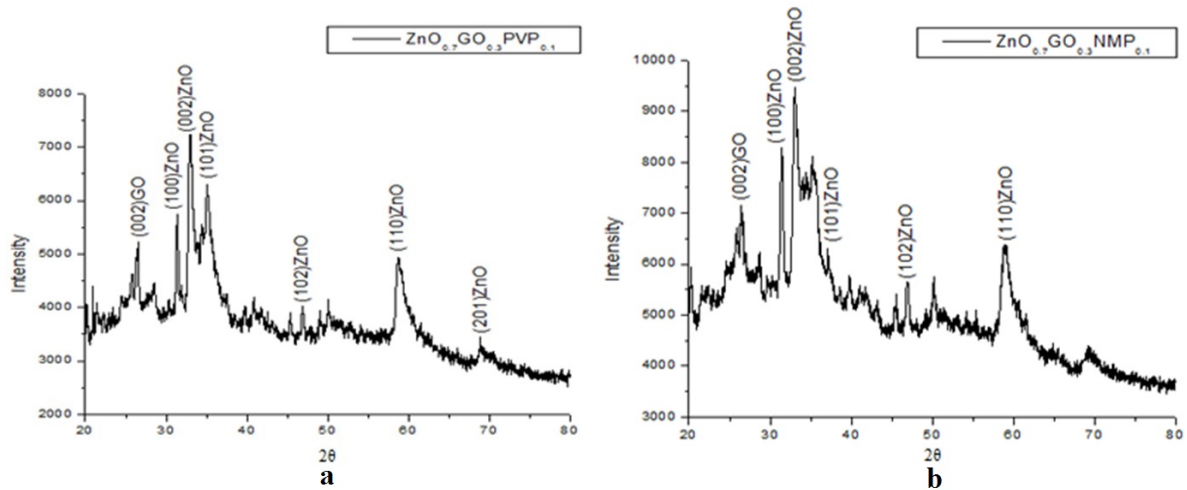| d Value(A^0)		Relative Intensity		hkl	Lattice Constant (A^0)	
(Obs)	(Rep)	(Obs)	(Rep)		(Obs)	(Rep)
3.3846	3.3608	–	–	(002)GO	–	–
2.8462	2.8143	100	57	(100)ZnO	$a = 3.286$	$a = 3.25, c = 5.207$
2.5992	2.6033	70.93	44	(002)ZnO	$c = 5.198$	$a = 3.25, c = 5.207$
2.5104	2.4759	71.29	100	(101)ZnO	$a = 3.31, c = 5.198$	$a = 3.25, c = 5.207$
1.9347	1.9111	65.01	23	(102)ZnO	$a = 3.345, c = 5.198$	$a = 3.25, c = 5.207$
1.6168	1.6247	55.03	32	(110)ZnO	$a = 3.233$	$a = 3.25, c = 5.207$
1.5008	1.4771	56.17	29	(103)ZnO	$a = 3.466, c = 5.198$	$a = 3.25, c = 5.207$
1.417	1.4072	53.35	4	(200)ZnO	$a = 3.272$	$a = 3.25, c = 5.207$
1.2986	1.3017	49.47	2	(004)ZnO	$c = 5.194$	$a = 3.25, c = 5.207$

FIG. 5. (a)X-ray diffractogram of $ZnO_{0.7}$–$GO_{0.3}$–$PVP_{0.1}$ Nanocomposites; (b)X-ray diffractogramof $ZnO_{0.7}$–$GO_{0.3}$–$NMP_{0.1}$ Nanocomposites

TABLE 4. XRD data of $ZnO_{0.7}$–$GO_{0.3}$–$PVP_{0.1}$ Nanocomposites

d Value(A^0)		Relative Intensity		hkl	Lattice Constant (A^0)	
(Obs)	(Rep)	(Obs)	(Rep)		(Obs)	(Rep)
3.3583	3.3608	–	–	(002)GO	–	–
2.8485	2.8143	79.52	57	(100)ZnO	$a = 3.289$	$a = 3.25, c = 5.207$
2.7116	2.6033	100	44	(002)ZnO	$c = 5.423$	$a = 3.25, c = 5.207$
2.554	2.4759	87.14	100	(101)ZnO	$a = 3.289, c = 5.768$	$a = 3.25, c = 5.207$
1.9347	1.9111	55.58	23	(102)ZnO	$a = 3.289, c = 5.272$	$a = 3.25, c = 5.207$
1.5724	1.6247	68.22	32	(110)ZnO	$a = 3.144$	$a = 3.25, c = 5.207$

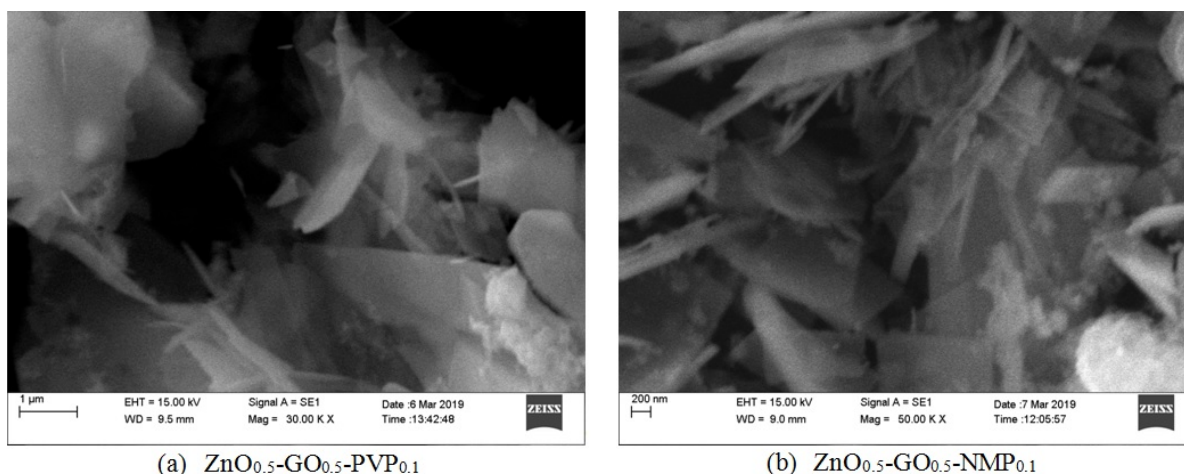TABLE 5. XRD data of $ZnO_{0.7}$–$GO_{0.3}$–$NMP_{0.1}$ Nanocomposites

d Value(A^0)		Relative Intensity		hkl	Lattice Constant (A^0)	
(Obs)	(Rep)	(Obs)	(Rep)		(Obs)	(Rep)
3.3681	3.3608	–	–	(002)GO	–	–
2.8392	2.8143	87.63	57	(100)ZnO	$a = 3.278$	$a = 3.25, c = 5.207$
2.7095	2.6033	100	44	(002)ZnO	$c = 5.419$	$a = 3.25, c = 5.207$
2.4804	2.4759	67.96	100	(101)ZnO	$a = 3.278, c = 5.099$	$a = 3.25, c = 5.207$
1.9326	1.9111	59.97	23	(102)ZnO	$a = 3.278, c = 5.276$	$a = 3.25, c = 5.207$
1.6554	1.6247	53.88	32	(110)ZnO	$a = 3.31$	$a = 3.25, c = 5.207$

TABLE 6. Particle sizes of ZnO–GO Nanocomposites

S No.	Sample	Particle size (nm)
1	$ZnO_{0.5}GO_{0.5}PVP_{0.1}$	9.55
2	$ZnO_{0.5}GO_{0.5}NMP_{0.1}$	6.48
3	$ZnO_{0.7}GO_{0.3}PVP_{0.1}$	7.6
4	$ZnO_{0.7}GO_{0.3}NMP_{0.1}$	6.55

3.3. SEM Studies

The SEM micrographs of the $ZnO_{0.5}$–$GO_{0.5}$–$PVP_{0.1}$, $ZnO_{0.5}$–$GO_{0.5}$–$NMP_{0.1}$, $ZnO_{0.7}$–$GO_{0.3}$–$PVP_{0.1}$ and $ZnO_{0.7}$–$GO_{0.3}$–$NMP_{0.1}$ at a magnification of 50KX are shown in Fig. 6(a), 6(b), 7(a) and 7(b) respectively. A layered structure consisting of a mixture of sheets and rods along with small clusters of particles distributed on the surface of GO is seen in all the cases, confirming the interaction between ZnO and GO. The distribution of sheets and rods is on the surface of GO in the case of ZnO–GO–NMP composites in comparison to ZnO–GO–PVP composites. The images suggest that the formation of sheets and rods of ZnO prevent the stacking of graphene sheets and contribute to the electron transfer between ZnO rods and GO.

(a) $ZnO_{0.5}$-$GO_{0.5}$-$PVP_{0.1}$ (b) $ZnO_{0.5}$-$GO_{0.5}$-$NMP_{0.1}$

FIG. 6. SEM image of (a) $ZnO_{0.5}$–$GO_{0.5}$–$PVP_{0.1}$ Nanocomposites and (b) $ZnO_{0.5}$–$GO_{0.5}$–$NMP_{0.1}$ Nanocomposites

3.4. EDX Studies

Figures 8(a), 8(b), 9(a) and 9(b) represent the EDX spectra of $ZnO_{0.5}$–$GO_{0.5}$–$PVP_{0.1}$, $ZnO_{0.5}$–$GO_{0.5}$–$NMP_{0.1}$, $ZnO_{0.7}$–$GO_{0.3}$–$PVP_{0.1}$ and $ZnO_{0.7}$–$GO_{0.3}$–$NMP_{0.1}$ respectively. The presence of C, Zn and O is detected in all the cases confirming the formation of the nanocomposites. In the case of the ZnO–GO composites prepared in the presence of NMP, the C content is higher in comparison to the composite prepared in the presence of PVP. PVP is a

(a) $ZnO_{0.7}$-$GO_{0.3}$-$PVP_{0.1}$ (b) $ZnO_{0.7}$-$GO_{0.3}$-$NMP_{0.1}$
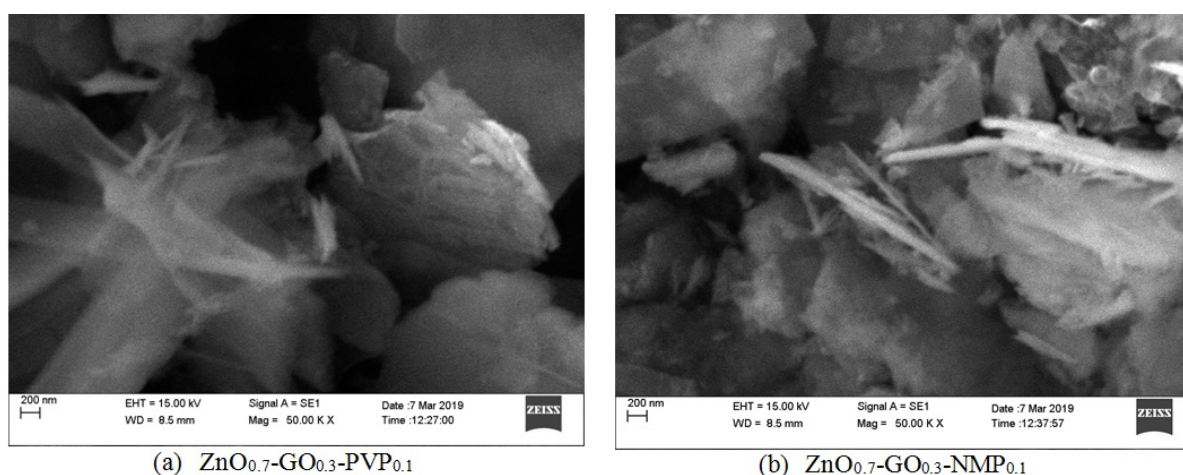
FIG. 7. SEM image of (a) $ZnO_{0.7}$–$GO_{0.3}$–$PVP_{0.1}$ Nanocomposites and (b) $ZnO_{0.7}$–$GO_{0.3}$–$NMP_{0.1}$ Nanocomposites

known surface stabilizing water soluble polymer effective in solubilization of Carbon materials [8], thereby resulting in the decreased percentage of Carbon atoms in these composites.

Element	Weight%	Atomic%
C K	11.50	19.84
O K	53.28	69.00
Zn K	35.22	11.17

a

Element	Weight%	Atomic%
C K	28.64	40.84
O K	50.07	53.59
Zn K	21.29	5.58

b
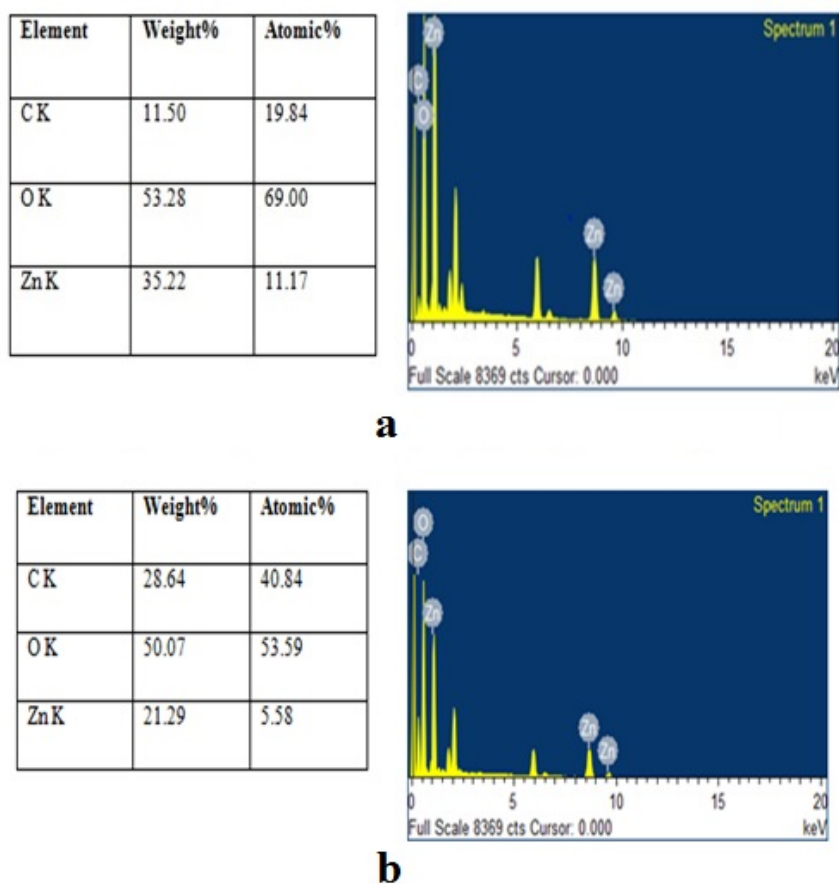
FIG. 8. EDX spectra of (a) $ZnO_{0.5}$–$GO_{0.5}$–$PVP_{0.1}$ Nanocomposites and (b) $ZnO_{0.5}$–$GO_{0.5}$–$NMP_{0.1}$ Nanocomposites

Element	Weight%	Atomic%
C K	11.06	22.11
O K	39.92	59.89
Zn K	49.02	18.00

a

Element	Weight%	Atomic%
C K	35.67	50.16
O K	41.67	43.99
Zn K	22.66	5.86

b
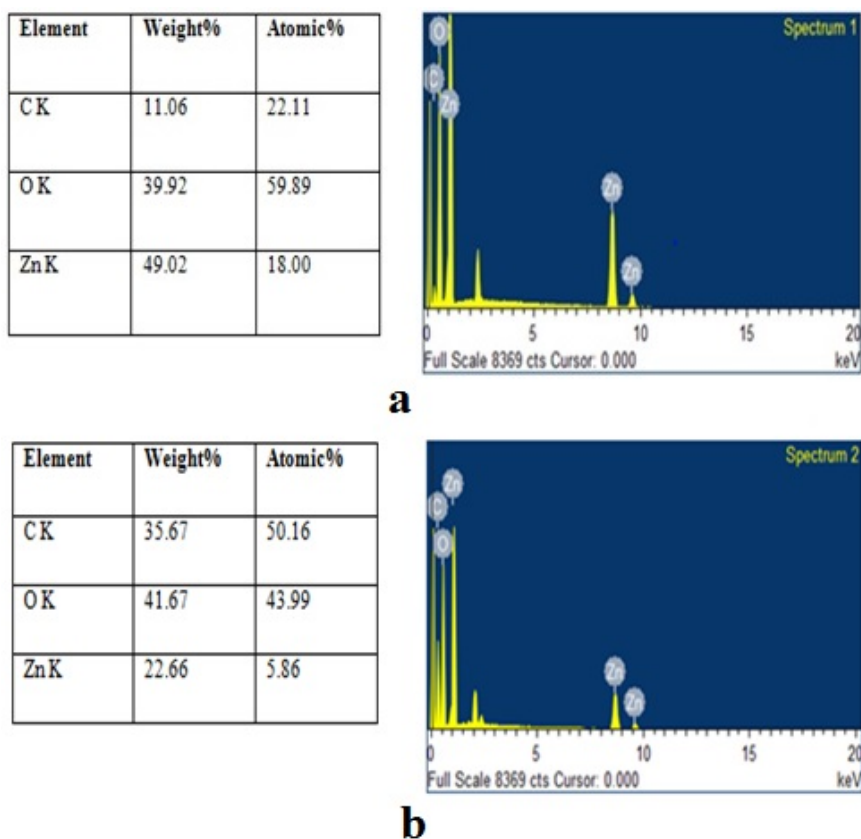
FIG. 9. EDX spectra of (a) $ZnO_{0.7}$–$GO_{0.3}$–$PVP_{0.1}$ Nanocomposites and (b) $ZnO_{0.7}$–$GO_{0.3}$–$NMP_{0.1}$ Nanocomposites

3.5. Conclusion

ZnO–GO nanocomposites were synthesized successfully using PVP and NMP as solvents by the sol-gel technique. The structural properties investigated using XRD studies showed the presence of planes of both GO and ZnO confirming the formation of composites. The particle sizes determined from XRD were found to be in nano range. A layered structure comprising of sheets and rods anda non-uniform distribution of agglomerating particles was observed from SEM micrographs. EDX spectra showed reflections of Carbon, Zinc and Oxygen in the composites. ZnO–GO synthesized using PVP showed higher absorbance in comparison toZnO–GO with NMP. A shift in absorption edge to shorter wavelength in the presence of NMP was also observed. The band gap values were found to range from 2.7–3.0 eV with the band gap of ZnO–GO with NMP showing a higher value than ZnO–GO with PVP. It is quite clear from our observations that the optical band gaps of the nanocomposites are affected by varying the solvents. However, a marked difference in the structure of the composites is not observed by the presence of different solvents.

Acknowledgment

References

[1] Muslih E.Y., Kim K.H. Preparation of Zinc Oxide (ZnO) Thin Film as Transparent Conductive Oxide (TCO) from Zinc Complex Compound on Thin Film Solar Cells: A Study of O_2 Effect on Annealing Process. *IOP Conf. Series: Materials Science and Engineering*, 2017, **214**, P. 012001.

[2] Law M., Greene L.E., Johnson J.C., Saykally R. and Yang P.D. Nanowire Dye-Sensitized Solar Cells, *Nature Materials*, 2005, **4**, P. 455.

[3] Al-Fandi M., Oweis R., Albiss B.A., AlZoubi T., M-Ali Al-Akhras, Qutaish H., Khwailah H., Al-Hattami S., Al-Shawwa E. A prototype Ultraviolet Light Sensor based on ZnO Nanoparticles/Graphene Oxide Nanocomposite Using Low Temperature Hydrothermal Method, International Conference on Advanced Materials (ICAM 2015). *IOP Publishing IOP Conf. Series: Materials Science and Engineering*, 2015, **92**. P. 012009.

[4] Wan Q., Li Q.H., Chen Y.J., Wang T.H., He X.L., Li J.P., Lin C.L. Fabrication and ethanol sensing characteristics of ZnO nanowire gas sensors. *Appl. Phys.Lett.*, 2017, **84**, P. 3654.

[5] Seyed A. Hosseini, ShabnamBabaei.Graphene Oxide/Zinc Oxide (GO/ZnO) Nanocomposite as a Superior Photocatalyst for Degradation of Methylene Blue (MB)-Process Modeling by Response Surface Methodology (RSM). *J. Braz. Chem. Soc.*, 2017, **28**(2), P. 299–307.

[6] Kant S., Kumar A. A comparative analysis of structural, optical and photocatalytic properties of ZnO and Ni doped ZnOnanospheres prepared by sol-gel method. *Adv. Mater. Lett.*, 2012, **3**, P. 350–354.

[7] Shao D., Qin L., Sawyer S. High Responsivity, Bandpass Near-UV Photodetector Fabricated From PVA-In$_2$O$_3$ Nanoparticles on a GaN Substrate. *Photonics J IEEE*, 2012, **4**(3), P. 715–720.

[8] Labhane P.K., Patle L.B., Huse V.R., Sonawane G.H., Sonawane S.H. Synthesis of reduced graphene oxide sheets decorated by zinc oxide-nanoparticles: Crystallographic, optical, morphological and photocatalytic study. *Chemical Physics Letters*, 2016, **661**, P. 13–19.

[9] Maira B. Moreno-Trejo, Yolanda Agapito-Navarro, Uriel Marquez-Lamas, Tania Lara Ceniceros, Jose Bonilla-Cruz, Margarita Sanchez-Domínguez. Preparation of Zinc Oxide Nanostructures and Hybrid Graphene/Zinc Oxide nanomaterials by a polysaccharide aqueous-based method, Third US-Mexico Meeting Advances in Polymer Science and XXVII SPM National Congress Nuevo Vallarta, December 2014 MACROMEX 2014.

[10] Dongzhi Zhang, Jingjing Liu, Bokai Xia. Layer-by-Layer Self-Assembly of Zinc Oxide/Graphene Oxide Hybrid Toward Ultrasensitive Humidity Sensing. *IEEE Electron Device Letters*, 2016, **37**(7).

[11] Phindile B. Khoza, Makwena J. Moloto, Lucky M. Sikhwivhilu.The Effect of Solvents, Acetone, Water, and Ethanol, on the Morphological and Optical Properties of ZnO Nanoparticles Prepared by Microwave. *Journal of Nanotechnology*, 2012, **2012**, Article ID 195106, 6 pages.

[12] Ibrahim Mustapha Alibe, Khamirul Amin Matori, Hj Ab Aziz Sidek, Yazid Yaakob, Umer Rashid, Ali Mustapha Alibe, Mohd Ha?z Mohd Zaid, Salisu Nasir, Maharaz Mohammed Nasir. Effects of polyvinylpyrrolidone on structural and optical properties of willemite semiconductor nanoparticles by polymer thermal treatment method. *Journal of Thermal Analysis and Calorimetry*, 2019, **136**, P. 2249–2268.

[13] Kallum M. Koczkur, Stefanos Mourdikoudis, Lakshminarayana Polavarapu, Sara E. Skrabalak. Polyvinylpyrrolidone (PVP) in nanoparticle synthesis. *Dalton transactions*, 2015, **41**.

[14] Shingo Tachikawa, Atsushi Noguchi, Takeharu Tsuge, Masahiko Hara, Osamu Odawara, Hiroyuki Wada. Optical Properties of ZnO Nanoparticles Capped with Polymers, **Materials**, 2011, **4**, P. 1132–1143.

[15] Zaaba N.I., Foo K.L., Hashim U., Tan S.J., Wei-Wen Liu, Voon C.H. Synthesis of Graphene Oxide using Modified Hummers Method: Solvent Influence. *Procedia Engineering*, 2017, **184**, P. 469–47.

[16] Gayathri S., Jayabal P., Kottaisamy M., Ramakrishnan V. Synthesis of ZnO decorated graphene nanocomposite for enhanced photocatalytic properties. *Journal of Applied Physics*, 2014, **115**, P. 173504.