International Information and Engineering Technology Association
Advancing the World of Information and Engineering

Revue des Composites et des Matériaux Avancés-Journal of Composite and Advanced Materials
Vol. 33, No. 1, February, 2023, pp. 53-57
Journal homepage: http://iieta.org/journals/rcma

Fabrication and Investigating the Structural and Dielectric Characteristics of In_2O_3-GO/PMMA-PC Nanostructures for Electronics Nanodevices

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https://doi.org/10.18280/rcma.330108

Received: 2 May 2022
Accepted: 1 February 2023

Keywords:
In_2O_3, nanocomposites, PMMA, dielectric properties, graphene oxide

ABSTRACT

In this work, nanocomposites films of (PMMA-PC/In_2O_3-GO) were prepared using casting with various concentrations of (In_2O_3&GO) nanoparticles (0, 1.4%, 2.8%, 4.2%, and 5.6%). The structural and dielectric characteristics of the nanocomposite system (PMMA-PC/In_2O_3-GO) have been explored for usage in different optoelectronic applications. As a result, the topographical morphology of (PMMA-PC/In_2O_3-GO) nanocomposite films were studied using a scanning electron microscope (SEM). SEM images show many homogeneous and coherent aggregates or chunks on the upper surface. The dielectric characteristics of nanocomposites films were studied in the frequency range (100HZ-5MHZ). The dielectric constant, dielectric loss, and A.C electrical conductivity all rise with adding of (In_2O_3-GO) NPs. The dielectric constant and dielectric loss were reduced, while electrical conductivity was raised with rise in the frequency. Finally, the (PMMA-PC/In_2O_3-GO) nanocomposites may be useful in different electronics fields.

1. INTRODUCTION

Nanomaterials are a very important issue in the expanding use of polymers and nanomaterials with different physicochemical characteristics. One of their most distinguishing characteristics is their dielectric properties, which may be greatly altered by varying the shape, size, and conductivity of the combined elements in the polymeric matrix [1, 2]. Nanocomposites have based the concept of creating and fabricating innovative materials with exceptional flexibility and well physical characteristic using nanoscale building components. This definition can encompass porous medium, colloids, gels, and copolymers in the widest concept, although it is most commonly used to refer to the solid combination of a bulk matrix and nano-dimensional phase(s) with characteristics that differ owing to differences in structure and chemistry, the nanocomposites (mechanical, electrical, thermal, optical, catalytic) characteristics, and electrochemical will be extraordinarily different from those of the component materials [3]. Because of various benefits such as low weight, easy production processes, cheap cost, high fatigue strength, and strong corrosion resistance, many applications rely on the contribution of nanomaterial in polymers [4]. Polymethylmethacrylate (PMMA) is a transparent rigid thermoplastic polymer that is extensively employed as a shatter-proof replacement for glass. Due to its various technical advantages over other transparent polymers. It is often employed, in a sheet form, as light weight or shatter-resistant alternative to glass. PMMA is frequently utilized related to its moderate physical and mechanical characteristics, easy processing, and few cost [5]. Nanocomposites with PMMA matrix doped with different materials have various applications such as electronics, optoelectronics and optics fields [6-9]. Polycarbonate (PC) as a thermoplastic polymeric matrix is considered of hardest polymers materials with the transparency highest level. Then, films of polycarbonate (PC)-based nanocomposites include not only flexibility but as well excellent tensile strength [10]. Grapheneoxide (GO) is an oxidation product of graphene, having several oxygen-containing groups, such as hydroxyl, carboxyl, epoxide, and carbonyl functional groups. The presence of these functional groups makes GO sheets strongly hydrophilic, allowing them to disperse easily into water with great stability [11]. This research aims to fabricate (PMMA-PC/In_2O_3-GO) nanocomposites and investigate the structural and dielectric characteristics to employ them in various dielectric and electronic applications.

2. MATERIALS AND METHOD

Polymethylmethacrylate (PMMA), polycarbonate (PC), indium oxide (In_2O_3NPs), and graphene oxide (GO) were employed in this study. The casting technique was used to prepare nanocomposites films (PMMA-PC/In_2O_3-GO). The films were prepared by dissolving 1g of the (PMMA-PC) blend with 80/20 percent in chloroform using a magnetic stirrer. The (In_2O_3- GO) NPs were introduced in the polymeric blend by (1.4, 2.8, 4.2 and 5.8) wt.%. The dielectric properties are determined in the frequency range 100Hz-5MHz using an LCR meter.

The dielectric constant (έ) is given by [12]:

$$έ = C_p/C_0 \quad (1)$$

C_o and C_P are vacuum and parallel capacitances. The dielectric loss (ε″) is determined by [13]:

$$\varepsilon'' = \acute{\varepsilon}\, D \quad (2)$$

D is the dispersion factor. The A.C conductivity was determined using [14]:

$$\sigma_{A.C} = w\, \varepsilon''\varepsilon_o \quad (3)$$

W is the angular frequency.

3. RESULTS AND DISCUSSION

Figure 1 shows SEM images of (PMMA-PC/In_2O_3-GO) nanocomposites with various concentrations of (In_2O_3-GO)NPs. The surface morphology of the nanocomposites (PMMA-PC/In_2O_3-GO) films can be seen in this figure. SEM image of nanocomposite film at low (In_2O_3-GO) concentration, the image reveals a lot of randomly distributed aggregates or particles on the top surface, which are attributed to the presence of 1.4% of In_2O_3-GO, which are aggregated in clusters form. The results show that when the concentration of nanoparticles rises, the number and size of white dots on the surface increase (In_2O_3-GO). This may be attributed to the formation of larger clusters, which in turn expanded to form network paths of aggregates through the PMMA/PC blend. The surface morphology of the films shows a homogeneous density of grain boundaries. The results also show that nanoparticles prefer to form well-dispersed aggregates in (PMMA-PC) blend films, which might be a symptom of a homogenous growth process. As well as, this change belongs to the strong interfacial interaction of the functional groups on the surface of nanoparticles (In_2O_3-GO) with a blend polymer that displayed an important change in the nanocomposites morphology and mechanical reaction. Figure 2 and Figure 3 indicate the variation of the dielectric constant with frequency and contents of In_2O_3 and GO NPs respectively. The dielectric constant of the (PMMA-PC) blend was increased from 1.6 to 4.3 when In_2O_3-GO nanoparticles contents reached 5.6%. At higher frequencies, directional polarization decreases, resulting in a reduction in the dielectric constant with frequency. At low frequencies, the molecule can be fully oriented, but at middle frequencies, there is limited time for orientation [15]. At high frequencies, molecular orientation is impossible [16]. The shape of the compound, especially if it comprises air gaps and agglomerates, can also have a significant impact on the dielectric constant [17]. Figure 4 indicates the effect of (In_2O_3-GO) concentrations on dielectric loss for (PMMA-PC) blend at 100Hz. The dielectric loss diminishes as the frequency rises to 100 kHz or higher until it approaches a constant value. According to Koop's theory, a polycrystalline material consists of grains and grain boundaries, with the former being more resistant than the latter, when the material is exposed to an alternating electric field charge carriers tend to concentrate at the grain boundary contacts, forming dipoles. Accumulation of charge carriers results in Maxwell Wagner interfacial polarization of space charge polarization. Due to the increasingly resistive nature of the grain boundaries, more charges are restricted in the composite film at the interfaces when the frequency is low. Figure 5 shows the value of dielectric loss increases as the concentration of additives (In_2O_3-GO) NPs increases, this is due to the rise in charge carriers generated by the addictives concentration increase [18, 19].

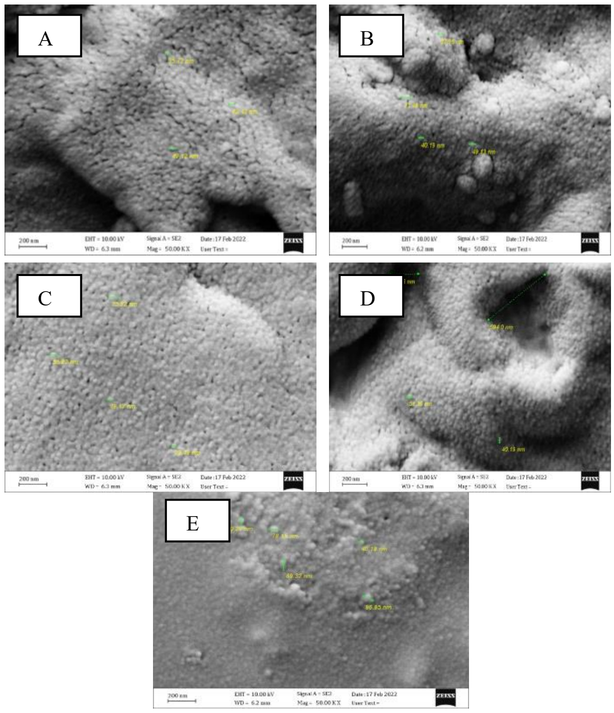

Figure 1. SEM images for (PMMA-PC/In_2O_3-GO) Nanocomposites: (A) for pure (B) for 1.4 wt.% In_2O_3-GO NPs (C) for 2.8 wt.% In_2O_3-GO NPs (D) for 4.2wt.% In_2O_3-GO NPs (E) for 5.6 wt.% In_2O_3-GO NPs

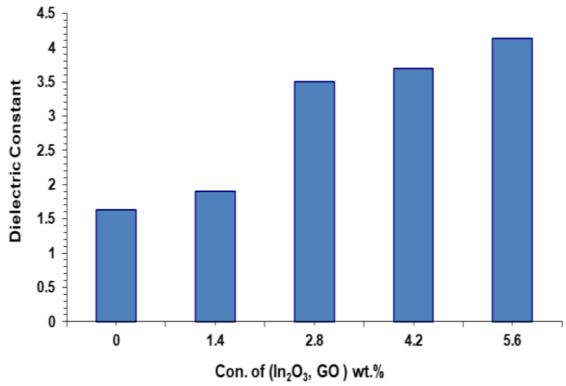

Figure 2. Effect of the content of (In_2O_3-GO) NPs on dielectric constant for (PMMA-PC) blend at 100Hz

Figure 6 shows the variation of A.C electrical conductivity for (PMMA-PC) blend with contents of In_2O_3-GO NPs. As the content of In_2O_3-nanoparticles increases, the A.C electrical conductivity of nanocomposites rises. Because the composition of dopant nanoparticles causes a rise in the number of charge carriers, the resistance of nanocomposites steadily reduces and the A.C electrical conductivity increases [20-22]. Furthermore, the nanoparticles create a route network in nanocomposites [23], particularly at nanoparticle concentrations of (4.8% and 5.6%) for (PMMA-PC/In_2O_3-GO) nanocomposites. Figure 7 shows the A.C electrical conductivity of (PMMA-PC/In_2O_3-GO) nanocomposites changes with frequency, the A.C electrical conductivity of (PMMA-PC/In_2O_3-GO) nanocomposites rises as the frequency of the electric field increases, the frequency works like a pumping force, in this case, the charge carriers are pushed between various conduction states [24]. At low frequencies, there was a decrease in the number of ionization processes for (In_2O_3-GO) NPs in the (PMMA-PC) mixture because there was a higher charge rise at the electrode-electrolyte interface. In the high-frequency region, charge carriers were more mobile, as a result, the electrical conductivity of (PMMA-PC/In_2O_3-GO) nanocomposites rises with frequency [25, 26]. The values of dielectric constant, dielectric loss, and A.C electrical conductivity for (PMMA /PC/In_2O_3/GO) nanocomposites at 100 Hz listed in Table 1.

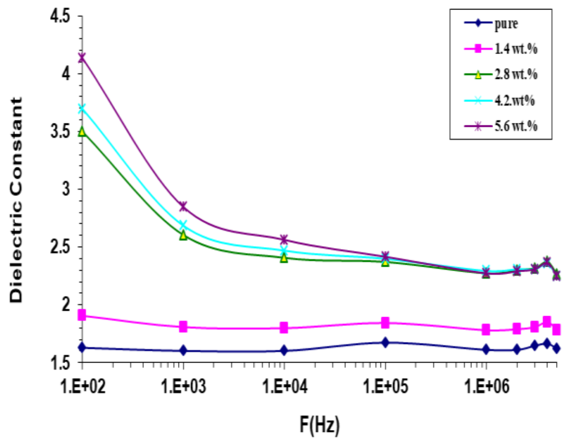

Figure 3. Variation of dielectric constant of (PMMA-PC-In_2O_3 -GO) nanocomposites with frequency

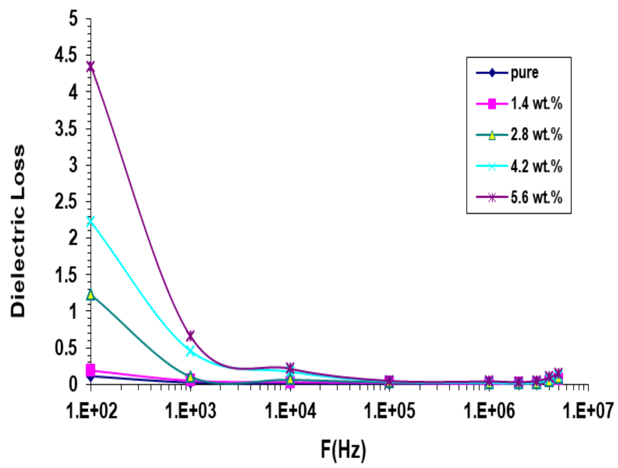

Figure 4. Dielectric loss variation with frequency for (PMMA-PC/In_2O_3-GO) nanocomposites at room temperature

Table 1. Values of dielectric constant, dielectric loss, and A.C electrical conductivity for (PMMA/PC/In_2O_3/GO) nanocomposites at 100 Hz

Wt.% NPs	ε′	ε"	$\sigma_{A.C}$ $(\Omega.cm)^{-1}$
0	1.63	0.111	6.33×10^{-12}
1.4	1.9	0.191	1.06×10^{-11}
2.8	3.49	1.22	6.81×10^{-11}
4.2	3.69	2.22	1.23×10^{-10}
5.6	4.13	4.34	2.41×10^{-10}

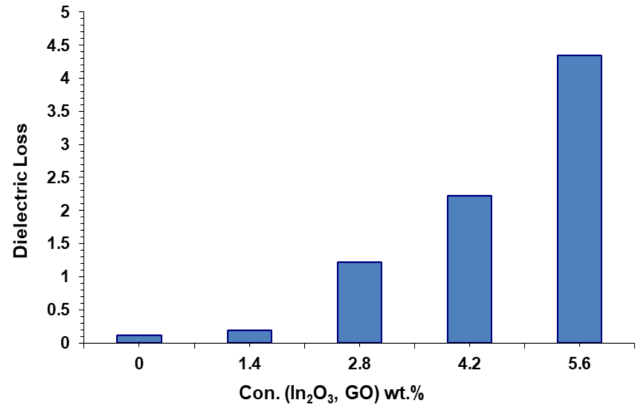

Figure 5. Dielectric loss for (PMMA-PC) blend at 100Hz as a function of (In_2O_3 - GO) NPs content

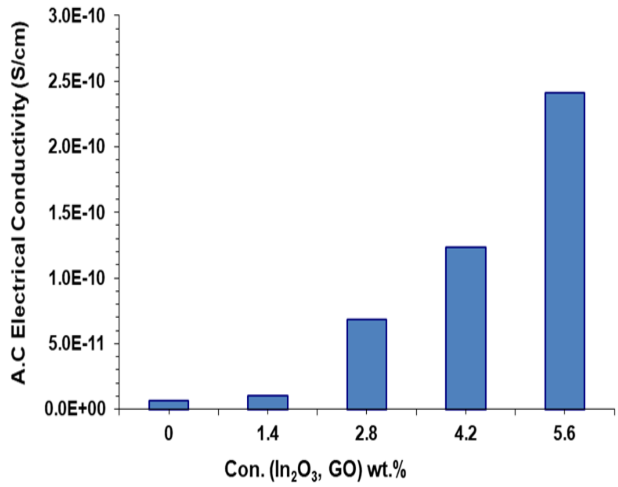

Figure 6. Variation of A.C electrical conductivity for (PMMA-PC) blend with contents of In_2O_3-GO NPs

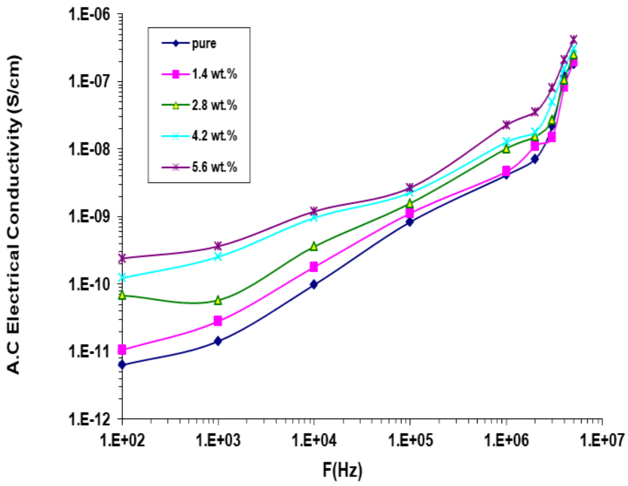

Figure 7. The change of A.C electrical conductivity for (PMMA-PC/In_2O_3-GO) nanocomposites with frequency

4. CONCLUSIONS

This work includes the synthesis of (PMMA -PC/In_2O_3- GO) nanocomposite and studying the structure, and dielectrical properties to use in different electrical applications. SEM shows that aggregates or chunks on the surface that are homogenous and coherent were studied using a scanning electron microscope SEM. The dielectric constant, dielectric loss and A.C electrical conductivity rise as the content of (In_2O_3-GO) increases. The dielectric constant and dielectric loss reduce as frequency rises, although the A.C electrical conductivity increases. When (In_2O_3-GO) NPs concentrations reached 5.6 percent, the dielectric constant of the (PMMA-PC) blend increased by a ratio of 60.61%, also the dielectric loss and A.C electrical conductivity increased by a ratio of 97.37%. The results indicate that the (PMMA-PC/In_2O_3-GO) nanocomposites could be used in a variety of optoelectronics applications.

REFERENCES

[1] Hashim, A., Habeeb, M.A., Hadi, A., Jebur, Q.M., Hadi, W. (2017). Fabrication of novel (PVA-PEG-CMC-Fe_3O_4) magnetic nanocomposites for piezoelectric applications. Sensor Letters, 15(12): 998-1002. https://doi.org/10.1166/sl.2017.3935

[2] Obaid, H.N., Habeeb, M.A., Rashid, F.L., Hashim, A. (2013). Thermal energy storage by nanofluids. Journal of Engineering and Applied Sciences, 8(5): 143-145.

[3] Yang, J., Yan, X., Wu, M., Chen, F., Fei, Z., Zhong, M. (2012). Self-assembly between graphene sheets and cationic poly (methyl methacrylate) (PMMA) particles: Preparation and characterization of PMMA/graphene composites. Journal of Nanoparticle Research, 14: 1-9. https://doi.org/10.1007/s11051-011-0717-0

[4] Firdaus, R.M., Rosli, N.I.M., Ghanbaja, J., Vigolo, B., Mohamed, A.R. (2019). Enhanced adsorption of methylene blue on chemically modified graphene nanoplatelets thanks to favorable interactions. Journal of Nanoparticle Research, 21: 1-18. https://doi.org/10.1007/s11051-019-4701-4

[5] Alhusaiki-Alghamdi, H.M. (2021). The spectroscopic and physical properties of PMMA/PCL blend incorporated with graphene oxide. Results in Physics, 24: 104125. https://doi.org/10.1016/j.rinp.2021.104125

[6] Hazim, A., Abduljalil, H.M., Hashim, A. (2021). First principles calculations of electronic, structural and optical properties of (PMMA–ZrO_2–Au) and (PMMA–Al_2O_3–Au) nanocomposites for optoelectronics applications. Transactions on Electrical and Electronic Materials, 22: 185-203. https://doi.org/10.1007/s42341-020-00224-w

[7] Hazim, A., Abduljalil, H.M., Hashim, A. (2020). Analysis of structural and electronic properties of novel (PMMA/Al_2O_3, PMMA/Al_2O_3-Ag, PMMA/ZrO_2, PMMA/ZrO_2-Ag, PMMA-Ag) nanocomposites for low cost electronics and optics applications. Transactions on Electrical and Electronic Materials, 21: 48-67. https://doi.org/10.1007/s42341-019-00148-0

[8] Hazim, A., Abduljalil, H.M., Hashim, A. (2021). Design of PMMA doped with inorganic materials as promising structures for optoelectronics applications. Transactions on Electrical and Electronic Materials, 22: 851-868. https://doi.org/10.1007/s42341-021-00308-1

[9] Hazim, A., Abduljalil, H.M., Hashim, A. (2020). Structural, spectroscopic, electronic and optical properties of novel platinum doped (PMMA/ZrO_2) and (PMMA/Al_2O_3) nanocomposites for electronics devices. Transactions on Electrical and Electronic Materials, 21: 550-563. https://doi.org/10.1007/s42341-020-00210-2

[10] Eskandari, M., Najafi Liavali, M., Malekfar, R., Taboada, P. (2020). Investigation of optical properties of polycarbonate/TiO_2/ZnO nanocomposite: Experimental and DFT calculations. Journal of Inorganic and Organometallic Polymers and Materials, 30: 5283-5292. https://doi.org/10.1007/s10904-020-01644-0

[11] Kachere, A.R., Kakade, P.M., Kanwade, A.R., Dani, P., Rondiya, S.R., Dzade, N.Y., Bhosale, S.V. (2021). Zinc oxide/graphene oxide nanocomposites: Synthesis, characterization and their optical properties. ES Materials & Manufacturing, 16: 19-29. http://dx.doi.org/10.30919/esmm5f516

[12] Shivashankar, H., Mathias, K.A., Sondar, P.R., Shrishail, M.H., Kulkarni, S.M. (2021). Study on low-frequency dielectric behavior of the carbon black/polymer nanocomposite. Journal of Materials Science: Materials in Electronics, 32: 28674-28686. https://doi.org/10.1007/s10854-021-07242-1

[13] El-Wahab, A., Aly, L., El-Hag Ali, A. (2017). Dielectric properties, impedance analysis, and electrical conductivity of Ag doped radiation grafted polypropylene. Egyptian Journal of Radiation Sciences and Applications, 30(1): 95-107. https://doi.org/10.21608/ejrsa.2017.1260

[14] Prabha, K., Jayanna, H.S. (2015). Study the frequency dependence of dielectric properties of gamma irradiated $PVA_{(1-x)}PS_x$polymer blends. Open Journal of Polymer Chemistry, 5(4): 47. http://dx.doi.org/10.4236/ojpchem.2015.54006

[15] Ahmed, H., Hashim, A. (2020). Fabrication of PVA/NiO/SiC nanocomposites and studying their dielectric properties for antibacterial applications. Egyptian Journal of Chemistry, 63(3): 805-811. https://dx.doi.org/10.21608/ejchem.2019.11109.1712

[16] Jebur, Q., Hashim, A., Habeeb, M. (2020). Fabrication, structural and optical properties for (polyvinyl alcohol–polyethylene oxide–iron oxide) Nanocomposites. Egyptian Journal of Chemistry, 63(2): 611-623. https://dx.doi.org/10.21608/ejchem.2019.10197.1669

[17] Chand, N., Jain, D. (2005). Effect of sisal fibre orientation on electrical properties of sisal fibrereinforced epoxy composites. Composites Part A: Applied Science and Manufacturing, 36(5): 594-602. https://doi.org/10.1016/j.compositesa.2004.08.002

[18] Ferrari, A.C. (2007). Raman spectroscopy of graphene and graphite: Disorder, electron–phonon coupling, doping and nonadiabatic effects. Solid State Communications, 143(1-2): 47-57. https://doi.org/10.1016/j.ssc.2007.03.052

[19] Stoyanov, H., Mc Carthy, D., Kollosche, M., Kofod, G. (2009). Dielectric properties and electric breakdown strength of a subpercolative composite of carbon black in thermoplastic copolymer. Applied Physics Letters, 94(23): 232905. https://doi.org/10.1063/1.3154553

[20] Habeeb, M., Hamza, R.S.A. (2018). Synthesis of (Polymer blend-MgO) nanocomposites and studying electrical properties for piezoelectric application.

Indonesian Journal of Electrical Engineering and Informatics (IJEEI), 6(4): 428-435. http://dx.doi.org/10.52549/ijeei.v6i4.511
[21] Hashim, A. (2021). Fabrication and characteristics of flexible, lightweight, and low-cost pressure sensors based on PVA/SiO_2/SiC nanostructures. Journal of Materials Science: Materials in Electronics, 32(3): 2796-2804. https://doi.org/10.1007/s10854-020-05032-9
[22] Al-Ramadhan, Z., Algidsawi, A.J.K., Hashim, A. (2011). The DC electrical properties of (PVC-Al2O3) composites. In AIP Conference Proceedings, 1400(1): 180-185. https://doi.org/10.1063/1.3663109
[23] Tietze, M. L., Benduhn, J., Pahner, P., Nell, B., Schwarze, M., Kleemann, H., Krammer, M., Zojer, K., Vandewal, K., Leo, K. (2018). Elementary steps in electrical doping of organic semiconductors. Nature Communications, 9(1): 1182. https://doi.org/10.1038/s41467-018-03302-z
[24] Abbas, N.K., Habeeb, M.A., Algidsawi, A.J.K. (2015). Preparation of Chloro Penta Amine Cobalt (III) chloride and study of its influence on the structural and some optical properties of polyvinyl acetate. International Journal of Polymer Science, 2015: 926789. https://doi.org/10.1155/2015/926789
[25] Zuo, G., Abdalla, H., Kemerink, M. (2016). Impact of doping on the density of states and the mobility in organic semiconductors. Physical Review B, 93(23): 235203. https://doi.org/10.1103/PhysRevB.93.235203
[26] Kadhim, K.J., Agool, I.R., Hashim, A. (2017). Effect of zirconium oxide nanoparticles on dielectric properties of (PVA-PEG-PVP) blend for medical application. Journal of Advanced Physics, 6(2): 187-190. https://doi.org/10.1166/jap.2017.1313