Наносистеми, наноматеріали, нанотехнології
Nanosistemi, Nanomateriali, Nanotehnologii
2026, т. 24, № 1, сс. 267–280
https://doi.org/10.15407/nnn.24.01.0267

PACS numbers: 68.55.J-, 72.80.Tm, 77.22.Gm, 78.20.Ci, 78.66.Sq, 78.67.Bf, 78.67.Sc

Fabrication and Exploring the Morphological, Optical, and Dielectric Properties of PVA/MgO/Fe_2O_3 Nanocomposites for Nanoelectronics Applications

Ahmed Hashim[1], Aseel Hadi[2], and M. H. Abbas[1]

[1]*College of Education for Pure Sciences,*
Department of Physics,
University of Babylon,
Hillah, Iraq
[2]*College of Materials Engineering,*
Department of Ceramic and Building Materials,
University of Babylon,
Hillah, Iraq

The PVA/MgO/Fe_2O_3 nanocomposites' films are fabricated in the present work to utilize in different nanoelectronics applications. The morphological, optical, and dielectric properties of PVA/MgO/Fe_2O_3 nanocomposites are studied. The results show that the MgO/Fe_2O_3 nanoparticles (NPs) have good distribution inside the polymer matrix. The absorbance of PVA is increased, while the transmittance and energy gap are decreased with rising in the MgO/Fe_2O_3-NPs' content. The dielectric properties (dielectric constant, dielectric loss, and electrical conductivity) are enhanced with increasing MgO/Fe_2O_3-NPs' content. The final results confirm that the PVA/MgO/Fe_2O_3 nanocomposites can be useful for different nanoelectronics applications.

У цій роботі було виготовлено плівки нанокомпозитів полівініловий спирт (ПВС)/MgO/Fe_2O_3 для використання у різних наноелектронних застосуваннях. Були досліджені морфологічні, оптичні та діелектричні властивості нанокомпозитів ПВС/MgO/Fe_2O_3. Результати показали, що наночастинки MgO/Fe_2O_3 мають хороший розподіл всередині полімерної матриці. Вбирання ПВС збільшувалося, тоді як пропускання та ширина забороненої зони зменшувалися зі збільшенням вмісту наночастинок MgO/Fe_2O_3. Діелектричні властивості (діелектрична проникність, діелектричні втрати й електропровідність) поліпшувалися зі збільшенням вмісту наночастинок MgO/Fe_2O_3. Остаточні результати підтвердили, що нанокомпозити ПВС/MgO/Fe_2O_3 можуть бути корисними для різних застосувань наноелектроніки.

Key words: PVA, MgO/Fe_2O_3, nanocomposites, optical properties, dielectric constant,

Ключові слова: полівініловий спирт, MgO/Fe_2O_3, нанокомпозити, оптичні властивості, діелектрична проникність.

(Received 10 March, 2024)

1. INTRODUCTION

Organic–inorganic hybrid optical materials are extremely valuable from a technological perspective. Hybrid compositions with remarkable properties may emerge once the relationships between the properties of inorganic elements and polymer matrices are clarified. Polymeric nanocomposites, because of their interesting properties, are also a significant class in the field of applied materials science technology. Polymer composites display a variety of fascinating optical features, including a high/low refractive index, tailored absorption/emission spectra, and strong optical nonlinearities. Hybrids are eligible for potential optoelectronic applications because they possess such rare properties [1–4].

Polymer nanocomposites are one of the most important materials in the academic and industrial areas, and are produced by dispersing nanofillers with one or more dimensions at nanoscale into the polymeric matrix. Recently, researchers have been attracted to polymer nanocomposites over conventional microcomposites due to their wide applications in electromechanical systems and their large interfacial area per unit volume of the dispersion medium [5].

Polyvinyl alcohol (PVA) anions are suitable bridging ligands for constructing network coordination polymers. PVA is a semi-crystalline polymer and its crystalline index depends on the synthetic process and physical ageing. It has gained increasing attention in the biomedical field due to bioinertness [6]. Metal-oxide nanoparticles (NPs) production has received a lot of interest over the last two decades. Plethoras of ways have also been developed to prepare nanoparticles. Magnesium oxide (MgO) was chosen for this study because of its several features, including high purity, non-toxicity, and odorlessness. They also have a high hardness and a high melting point [7].

Fe_2O_3 NPs have special properties like good electron mobility, magnetic ability, and a 2.2 eV optical energy-band gap, which are useful for optoelectronic applications. Fe_2O_3 NPs have potential applications in the fields of medicine, life sciences and computer technology like magnetic resonance imaging (MRI), drug carriers in delivery, gene carriers in gene therapy, nanofertilizers, nonfungicides, nanopesticides, nanofood, food packing, nanocoating, nanosensors, nanoscale memory, nanowires, spintronics, *etc*. They can be used as filters in sunscreens, biosensors [8]. The nanocomposites were investigated to employ in various fields included sensors [9–15], optical fields [16–25], antibacterial [26–34], energy storage [35–43], radiation shielding and bioenvironmental [44–48], electronics and optoelectronics [49–63]. This paper aims to prepare of PVA/MgO/Fe_2O_3 nanocomposites to employ in various photonics and optics applications.

2. MATERIALS AND METHODS

Films of PVA/MgO/Fe_2O_3 nanocomposites were fabricated using casting process with different contents of MgO/Fe_2O_3 NPs are 2.5% and 5% with concentration 50% MgO: 50% Fe_2O_3.

The optical properties of PVA/MgO/Fe_2O_3 nanocomposites were tested using the double beam spectrophotometer (Shimadzu, UV-1800Å) at wavelength from 340 nm to 740 nm.

The dielectric properties of PVA/MgO/Fe_2O_3 nanocomposites were examined at frequency range (100 Hz–$2\cdot10^6$ Hz) by LCR meter (HIOKI 3532-50 LCR HI TESTER). The absorption coefficient α is given [64] by

$$\alpha = 2.303A/t, \tag{1}$$

where A is the absorbance and t is the film thickness.

The energy gap is calculated [65] by

$$\alpha h\nu = C\left(h\nu - E_g\right)^r, \tag{2}$$

where C is the constant; $h\nu$ is the energy of photon; E_g is the energy gap, and $r = 2$ and 3 for allowed and forbidden indirect transitions, respectively.

The dielectric constant ε' is defined [66] by

$$\varepsilon' = C_p/C_0, \tag{3}$$

wherever C_p is the matter capacitance and C_0 is the vacuum capacitance.

Dielectric loss ε'' is determined [67] by

$$\varepsilon'' = \varepsilon' D, \tag{4}$$

where D is the dispersion factor. The A.C. electrical conductivity is given [68] by

$$\sigma_{\text{A.C.}} = 2\pi f \varepsilon' D \varepsilon_0, \tag{5}$$

3. RESULTS AND DISCUSSION

The performances of absorbance and transmittance for PVA/MgO/Fe_2O_3 nanocomposites with wavelength are demonstrated in Figs. 1, 2, respectively. As represented in these figures, the PVA/MgO/Fe_2O_3 nanocomposites have high absorbance with low transmittance at UV region because the high photons energies at these spectra. The absorbance decreases and transmittance increases with increasing wavelength. Also, the absorbance of PVA raises,

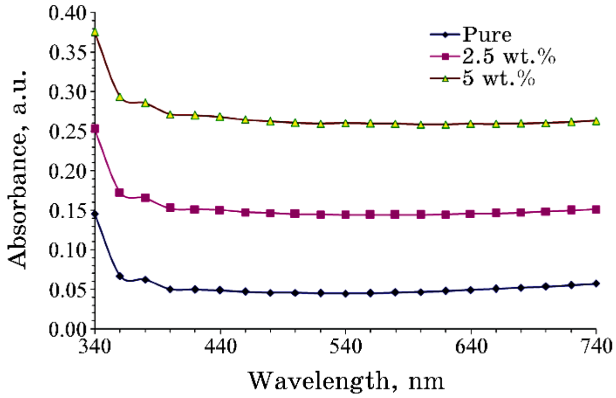


Fig. 1. Performance of absorbance for the PVA/MgO/Fe_2O_3 nanocomposites with wavelength.

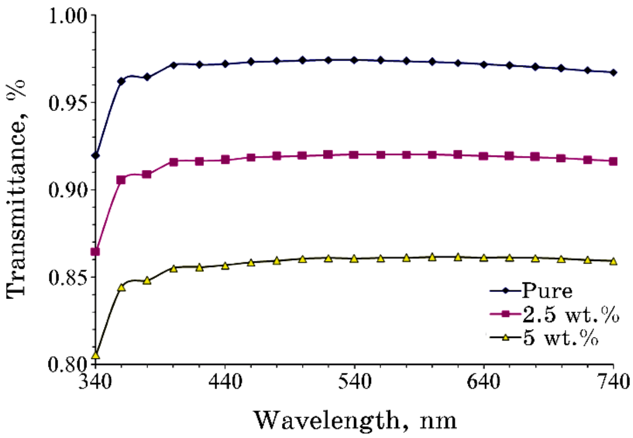
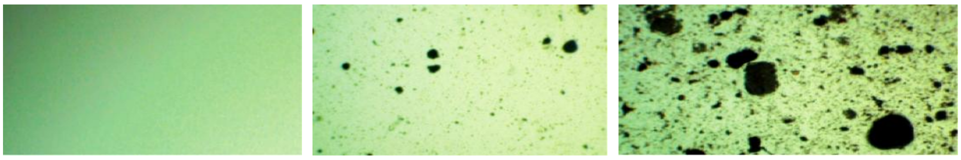


Fig. 2. Variation of transmittance for the PVA/MgO/Fe_2O_3 nanocomposites with wavelength.

while the transmittance reduces with increasing MgO/Fe_2O_3-NPs' content, which is related to increase of charge carriers density, as shown in Fig. 3, which are absorb or scat the photons [69–83].

The energy gaps for $PVA/MgO/Fe_2O_3$ nanocomposites of allowed and forbidden indirect transitions are shown in Figs. 4 and 5, respectively. The energy gaps of PVA are reduced with rising MgO/Fe_2O_3-NPs' content; this is related to the creation of complexes of charge transfer in the polymer matrix. These charges transfer complexes rise the electric conduction by generating extra charges, this effect in a decrease of the energy gap. With increasing MgO/Fe_2O_3 content, the dopant molecules begin bridging the gap separating the two localized levels and reduce the potential barrier between them, thereby create easily the charge carrier transfer between localized levels [84–97].

The variations of dielectric constant and dielectric loss for $PVA/MgO/Fe_2O_3$ nanocomposites with frequency are confirmed in Figs. 6, 7, respectively. As shown in these figures, the dielectric constant and dielectric loss are decreased with increasing frequency.



a *b* *c*

Fig. 3. Optical microscopic images for the $PVA/MgO/Fe_2O_3$ nanocomposites (×10): *a*—pure; *b*—2.5 wt.% MgO/Fe_2O_3 NPs, *c*—5 wt.% MgO/Fe_2O_3 NPs.

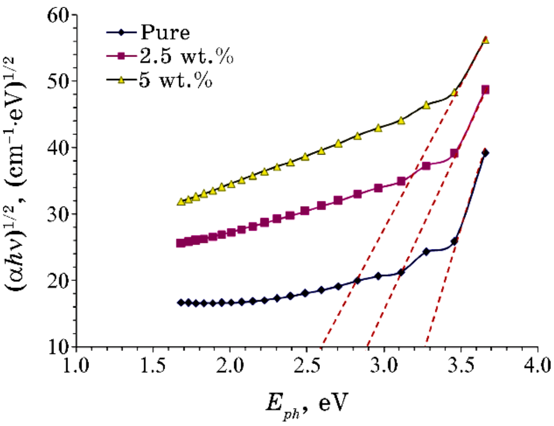


Fig. 4. Energy gap for the $PVA/MgO/Fe_2O_3$ eV nanocomposites of allowed indirect transition.

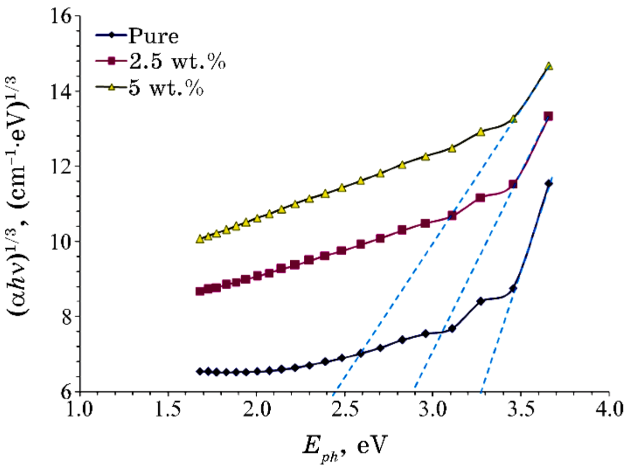


Fig. 5. Energy gap for the PVA/MgO/Fe_2O_3 nanocomposites of forbidden indirect transition.

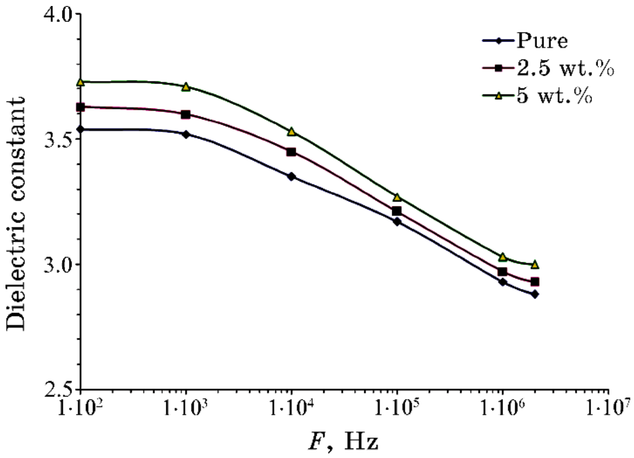


Fig. 6. Variation of dielectric constant for the PVA/MgO/Fe_2O_3 nanocomposites with frequency.

For low frequency, the polymer molecules obtain enough time to orient themselves according to the applied field. With rising frequency, the molecules are not getting sufficient time to orient themselves according to the direction of the electrical field. Therefore, the overall polarization effect decreases and, consequently, the value of dielectric constant decreases too as it is directly proportional to the amount of polarization. At elevated frequencies as the polarization decreases the dielectric loss and dissipation factor, also decreased, as sufficient time is not provided to the polymer chain to

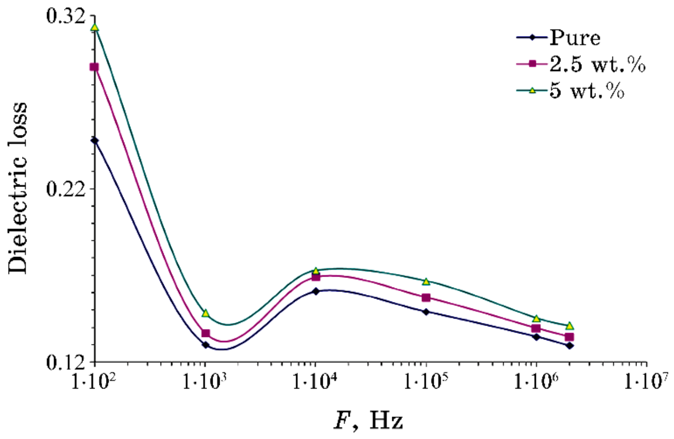


Fig. 7. Variation of dielectric loss for the PVA/MgO/Fe_2O_3 nanocomposites with frequency.

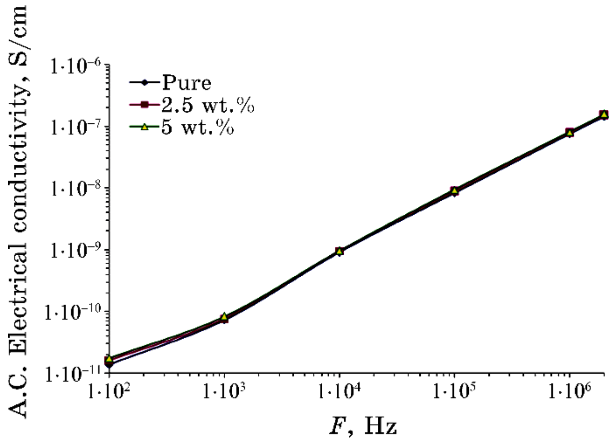


Fig. 8. Variation of electrical conductivity for the PVA/MgO/Fe_2O_3 nanocomposites with frequency.

generate phase angle. Thus, at high frequencies the contribution of orientational or dipole polarization vanishes and the effect is only for electronic polarization, which is instantaneous. The dielectric constant and dielectric loss are increased with increasing contents of nanoparticles, which is due to increase in charge-carriers' numbers [98–116].

The variation of electrical conductivity for PVA/MgO/Fe_2O_3 nanocomposites with frequency is represented in Fig. 8. The electrical conductivity rises with increasing nanoparticles contents and frequency. The increase of electrical conductivity with increasing nanoparticles contents related to raise in the charges carriers numbers. The frequency-dependent conductivity is caused by the hopping of electrons in the localized states near the Fermi level and also attributed to the charge-carriers' excitation to the levels in the conduction band [117–127].

4. CONCLUSIONS

The current work included fabrication of PVA/MgO/Fe_2O_3-nanocomposites' films to exploit in various nanoelectronics fields. The morphological, optical, and dielectric properties of PVA/MgO/Fe_2O_3 nanocomposites were studied. The results showed that the absorbance of PVA was increased while the transmittance and energy gap were decreased with rising in the MgO/Fe_2O_3-NPs' content. The dielectric properties were enhanced with increasing MgO/Fe_2O_3-NPs' content. The final results confirmed that the PVA/MgO/Fe_2O_3 nanocomposites can be useful for various nanoelectronics applications.

REFERENCES

1. A.M. El-Naggar, Z. K. Heiba, A. M. Kamal, O. H. Abd-Elkader, and M. B. Mohamed, *Polymers*, 15: 1(2023); https://doi.org/10.3390/polym15092091
2. A. G. Hadi, Z. Al-Ramadhan, and A. Hashim, *Nanosistemi, Nanomateriali, Nanotehnologii*, **20**, Iss. 2: 535 (2022); https://doi.org/10.15407/nnn.20.02.535
3. O. B. Fadil and A. Hashim, *Nanosistemi, Nanomateriali, Nanotehnologii*, **21**, Iss. 1: 153 (2023); https://doi.org/10.15407/nnn.21.01.153
4. W. O. Obaid and A. Hashim, *Nanosistemi, Nanomateriali, Nanotehnologii*, **21**, Iss. 1: 163 (2023); https://doi.org/10.15407/nnn.21.01.163
5. D. A. Nasrallah and M. A. Ibrahim, *Journal of Polymer Research*, **29**: 1 (2022); https://doi.org/10.1007/s10965-022-02943-5
6. T. A. Hanafy, *Journal of Applied Physics*, **112**: 1 (2012).
7. B. Bharati, B. T. Vijaykumar, N. Ramabai, and S. Basavaraj, *Materials Today: Proceedings*, **92**: 1640 (2023); https://doi.org/10.1016/j.matpr.2023.06.116
8. J. S. Goud and N. Narsimlu, *Indian Journal of Chemical Technology*, **29**: 737 (2022); doi:10.56042/ijct.v29i6
9. H. Ahmed and A. Hashim, *International Journal of Scientific & Technology Research*, **8**, Iss. 11: 1014 (2019).
10. B. Mohammed, H. Ahmed, and A. Hashim, *Nanosistemi, Nanomateriali, Nanotehnologii*, **20**, Iss. 1: 187 (2022); https://doi.org/10.15407/nnn.20.01.187
11. Huda Abdul Jalil Hussien, Raheem G. Kadhim, and Ahmed Hashim, *J. of Physics: Conf. Series*, **1818**: 012119 (2021); doi:10.1088/1742-

6596/1818/1/012119
12. Huda Abdul Jalil Hussien, Raheem G. Kadhim, and Ahmed Hashim, *J. of Physics: Conf. Series*, **1818**: 012186 (2021); doi:10.1088/1742-6596/1818/1/012186
13. Huda Abdul Jalil Hussien, Raheem G. Kadhim, and Ahmed Hashim, *J. of Physics: Conf. Series*, **1818**: 012187 (2021); doi:10.1088/1742-6596/1818/1/012187
14. A. G. Hadi, Z. Al-Ramadhan, and A. Hashim, *Nanosistemi, Nanomateriali, Nanotehnologii*, **19**, Iss. 4: 865 (2021); https://doi.org/10.15407/nnn.19.04.865
15. A. Hashim and Z. S. Hamad, *Nanosistemi, Nanomateriali, Nanotehnologii*, **19**, Iss. 4: 893 (2021); https://doi.org/10.15407/nnn.19.04.893
16. H. Ahmed and A. Hashim, *Silicon*, **14**: 6637 (2022); https://doi.org/10.1007/s12633-021-01449-x
17. H. Ahmed and A. Hashim, *Silicon*, **13**: 4331(2021); https://doi.org/10.1007/s12633-020-00723-8
18. H. Ahmed and A. Hashim, *Transactions on Electrical and Electronic Materials*, **22**: 335 (2021); https://doi.org/10.1007/s42341-020-00244-6
19. N. AH. Al-Aaraji, A. Hashim, A. Hadi, and H. M. Abduljalil, *Silicon*, **14**: 10037 (2022); https://doi.org/10.1007/s12633-022-01730-7
20. H. Ahmed and A. Hashim, *Opt. Quant. Electron.*, **55**: 1 (2023); https://doi.org/10.1007/s11082-022-04273-8
21. W. O. Obaid and A. Hashim, *Silicon*, **14**: 11199 (2022); https://doi.org/10.1007/s12633-022-01854-w
22. O. B. Fadil and A. Hashim, *Silicon*, **14**: 9845 (2022); https://doi.org/10.1007/s12633-022-01728-1
23. H. Ahmed and A. Hashim, *Silicon*, **15**: 2339 (2023); https://doi.org/10.1007/s12633-022-02173-w
24. H. B. Hassan, H. M. Abduljalil, and A. Hashim, *Nanosistemi, Nanomateriali, Nanotehnologii*, **20**, Iss. 4: 941 (2022); https://doi.org/10.15407/nnn.20.04.941
25. H. A. Jawad and A. Hashim, *Nanosistemi, Nanomateriali, Nanotehnologii*, **20**, Iss. 4: 963 (2022); https://doi.org/10.15407/nnn.20.04.963
26. A. Hashim, I. R. Agool, and K. J. Kadhim, *Journal of Bionanoscience*, **12**, No. 5: 608 (2018); doi:10.1166/jbns.2018.1580
27. A. Hazim, A. Hashim, and H. M. Abduljalil, *International Journal of Emerging Trends in Engineering Research*, **7**, No. 8: 68 (2019); https://doi.org/10.30534/ijeter/2019/01782019
28. A. Hazim, H. M. Abduljalil, and A. Hashim, *International Journal of Emerging Trends in Engineering Research*, **7**, No. 8: 104 (2019); https://doi.org/10.30534/ijeter/2019/04782019
29. O. B. Fadil and A. Hashim, *Nanosistemi, Nanomateriali, Nanotehnologii*, **20**, Iss. 4: 1029 (2022); https://doi.org/10.15407/nnn.20.04.1029
30. W. O. Obaid and A. Hashim, *Nanosistemi, Nanomateriali, Nanotehnologii*, **20**, Iss. 4: 1009 (2022); https://doi.org/10.15407/nnn.20.04.1009
31. M. H. Meteab, A. Hashim, and B. H. Rabee, *Nanosistemi, Nanomateriali, Nanotehnologii*, **21**, Iss. 1: 199 (2023); https://doi.org/10.15407/nnn.21.01.199
32. M. H. Meteab, A. Hashim, and B. H. Rabee, *Nanosistemi, Nanomateriali,*

Nanotehnologii, **21**, Iss. 2: 451 (2023);
https://doi.org/10.15407/nnn.21.02.451
33. H. B. Hassan, A. Hashim, and H. M. Abduljalil, *Nanosistemi, Nanomateriali, Nanotehnologii*, **20**, Iss. 3: 815 (2022); https://doi.org/10.15407/nnn.20.03.815
34. H. B. Hassan, A. Hashim, and H. M. Abduljalil, *Nanosistemi, Nanomateriali, Nanotehnologii*, **20**, Iss. 3: 821 (2022); https://doi.org/10.15407/nnn.20.03.821
35. A. S. Shareef, F. Lafta R., A. Hadi, and A. Hashim, *International Journal of Scientific & Technology Research*, **8**, Iss. 11: 1041 (2019).
36. A. Hadi, A. Hashim, and D. Hassan, *Bulletin of Electrical Engineering and Informatics*, **9**, No. 1: 83 (2020); doi:10.11591/eei.v9i1.1323
37. H. Ahmed and A. Hashim, *Nanosistemi, Nanomateriali, Nanotehnologii*, **20**, Iss. 4: 951 (2022); https://doi.org/10.15407/nnn.20.04.951
38. F. L. Rashid, A. Hadi, A. A. Abid, and A. Hashim, *International Journal of Advances in Applied Sciences*, **8**, No. 2: 154 (2019) doi:10.11591/ijaas.v8i2.pp154-156
39. M. H. Rasheed, A. Hashim, and F. L. Rashid, *Nanosistemi, Nanomateriali, Nanotehnologii*, **19**, Iss. 2: 374 (2021); https://doi.org/10.15407/nnn.19.02.347
40. A. Hashim, F. L. Rashid, N. AH. Al-Aaraji, and B. H. Rabee, *East European Journal of Physics*, **1**: 173 (2023); doi:10.26565/2312-4334-2023-1-21
41. F. L. Rashid, A. Hashim, N. AH. Al-Aaraji, and A. Hadi, *East European Journal of Physics*, **1**: 177 (2023); doi:10.26565/2312-4334-2023-1-22
42. F. L. Rashid, A. Hashim, M. H. Abbas, and A. Hadi, *East European Journal of Physics*, **1**: 181 (2023); doi:10.26565/2312-4334-2023-1-23
43. A. Hashim, F. L. Rashid, M. H. Abbas, and B. H. Rabee, *East European journal of physics*, **1**: 185 (2023); doi:10.26565/2312-4334-2023-1-24
44. A. Hashim and N. Hamid, *Journal of Bionanoscien*ce, **12**, No. 6: 788 (2018); doi:10.1166/jbns.2018.1591
45. A. Hashim and Z. S. Hamad, *Journal of Bionanoscience*, **12**, No. 4: 504 (2018); doi:10.1166/jbns.2018.1561
46. B. Abbas and A. Hashim, *International Journal of Emerging Trends in Engineering Research*, **7**, No. 8: 131 (2019); https://doi.org/10.30534/ijeter/2019/06782019
47. K. H. H. Al-Attiyah, A. Hashim, and S. F. Obaid, *Journal of Bionanoscience*, **12**: 200 (2018); doi:10.1166/jbns.2018.1526
48. H. A. J. Hussien, A. Hadi, and A. Hashim, *Nanosistemi, Nanomateriali, Nanotehnologii*, **20**, Iss. 4: 1001 (2022); https://doi.org/10.15407/nnn.20.04.1001
49. H. Ahmed and A. Hashim, *Silicon*, **14**: 4907 (2022); https://doi.org/10.1007/s12633-021-01258-2
50. H. Ahmed and A. Hashim, *Trans. Electr. Electron. Mater.*, **23**: 237 (2022); https://doi.org/10.1007/s42341-021-00340-1
51. H. Ahmed and A. Hashim, *Silicon*, **14**: 7025 (2021); https://doi.org/10.1007/s12633-021-01465-x
52. H. Ahmed and A. Hashim, *Opt. Quant. Electron.*, **55**: 280 (2023); https://doi.org/10.1007/s11082-022-04528-4
53. B. Mohammed, H. Ahmed, and A. Hashim, *Nanosistemi, Nanomateriali,*

Nanotehnologii, **21**, Iss. 1: 113 (2023);
https://doi.org/10.15407/nnn.21.01.113
54. H. Ahmed and A. Hashim, *Physics and Chemistry of Solid State*, **23**, No. 1: 67 (2022); doi:10.15330/pcss.23.1.67-71
55. H. B. Hassan, H. M. Abduljalil, and A. Hashim, *Physics and Chemistry of Solid State*, **23**, No. 3: 454 (2022); doi:10.15330/pcss.23.3.454-460
56. H. Ahmed and A. Hashim, *Nanosistemi, Nanomateriali, Nanotehnologii*, **19**, Iss. 4: 841 (2021); https://doi.org/10.15407/nnn.19.04.841
57. Huda Bukheet Hassan, Hayder M. Abduljalil, and Ahmed Hashim, *AIP Conference Proceedings* , **2591**: 040008 (2023); https://doi.org/10.1063/5.0119838
58. N. AH. Al-Aaraji, A. Hashim, H. M. Abduljalil, and A. Hadi, *Optical and Quantum Electronics*, **55**: 743 (2023); https://doi.org/10.1007/s11082-023-05048-5
59. H. B. Hassan, H. M. Abduljalil, and A. Hashim, *Nanosistemi, Nanomateriali, Nanotehnologii*, **21**, Iss. 2: 289 (2023); https://doi.org/10.15407/nnn.21.02.289
60. H. Ahmed and A. Hashim, *Silicon*, **15**: 83 (2023); https://doi.org/10.1007/s12633-022-01978-z
61. F. S. Jaber, A. Hashim, and H. M. Abduljalil, *Silicon*, **15**: 71 (2023); https://doi.org/10.1007/s12633-022-02000-2
62. H. Ahmed and A. Hashim, *Optical and Quantum Electronics*, **54**: 403 (2022); https://doi.org/10.1007/s11082-022-03784-8
63. H. Ahmed and A. Hashim, *Silicon*, **14**: 4079 (2022); https://doi.org/10.1007/s12633-021-01186-1
64. A. A. A. Ahmed, A. M. Al-Hussam, A. M. Abdulwahab, and A. N. A. A. Ahmed, *AIMS Mater. Sci.*, **5**, Iss. 3: 1 (2018); doi:10.3934/matersci.2018.3.533
65. T. A.-Baset, M. Elzayat, and S. Mahrous, *Int. J. of Polym. Sci.*, **2016**: Article ID 1707018 (2016); http://dx.doi.org/10.1155/2016/1707018
66. Sarir Uddin, Naheed Akhtar, Sumbal Bibi, Abid Zaman, Asad Ali Khaled Althubeiti, Hussein Alrobei, and Muhammad Mushtaq, *Materials*, **14**: 5430 (2021); https://doi.org/10.3390/ma14185430
67. T. A. Abdel-Baset and A. Hassen, *Physica B*, **499**: 24 (2016); http://dx.doi.org/10.1016/j.physb.2016.07.002
68. H. M. Alhusaiki-Alghamdi, *Results in Physics*, **24**: 104125 (2021); https://doi.org/10.1016/j.rinp.2021.104125
69. A. Hashim, E. H. Abdullah, F. L. Rashid, and A. Hadi, *Nanosistemi, Nanomateriali, Nanotehnologii*, **19**, Iss. 3: 697 (2021); https://doi.org/10.15407/nnn.19.03.697
70. M. Sajjad and A. Hashim, *Nanosistemi, Nanomateriali, Nanotehnologii*, **19**, Iss. 4: 831 (2021); https://doi.org/10.15407/nnn.19.04.831
71. A. Hashim, *Nanosistemi, Nanomateriali, Nanotehnologii*, **19**, Iss. 3: 647 (2021); https://doi.org/10.15407/nnn.19.03.647
72. M. K. Mohammed, E. H. Abdullah, D. Hassan, and A. Hashim, *Revue des Composites et des Matériaux Avancés–Journal of Composite and Advanced Materials*, **32**, No. 6: 305 (2022); https://doi.org/10.18280/rcma.320606
73. Y. Y. Mijbil and A. Hashim, *Nanosistemi, Nanomateriali, Nanotehnologii*, **20**, Iss. 2: 497 (2022); https://doi.org/10.15407/nnn.20.02.497

74. M. H. Rasheed, A. K. Abbas, F. Rashid, and A. Hashim, *Nanosistemi, Nanomateriali, Nanotehnologii*, **20**, Iss. 3: 761 (2022); https://doi.org/10.15407/nnn.20.03.761
75. Ahmed Hashim, Aseel Hadi, and M. H. Abbas, *Silicon*, **15**: 6431 (2023); https://doi.org/10.1007/s12633-023-02529-w
76. A. Hashim, A. Hadi, and N. A. H. Al-Aaraji, *Optical and Quantum Electronics*, **55**: 716 (2023); https://doi.org/10.1007/s11082-023-04994-4
77. A. Hashim, B. Mohammed, A. Hadi, and H. Ibrahim, *Journal of Inorganic and Organometallic Polymers and Materials*, **34**: 611 (2024); https://doi.org/10.1007/s10904-023-02846-y
78. H. B. Hassan, A. Hashim, and H. M. Abduljalil, *Optical and Quantum Electronics*, **55**: 556 (2023); https://doi.org/10.1007/s11082-023-04830-9
79. H. K. Jaafar, A. Hashim, and B. H. Rabee, *Optical and Quantum Electronics*, **55**: 989 (2023); https://doi.org/10.1007/s11082-023-05208-7
80. Ahmed Hashim, Saif M. Alshrefi, Hussein H. Abed, and Aseel Hadi, *Journal of Inorganic and Organometallic Polymers and Materials*, **34**: 703 (2024); https://doi.org/10.1007/s10904-023-02866-8
81. Hiba Kamil Jaafar, Ahmed Hashim and Bahaa H. Rabee, *Silicon*, **16**: 603 (2024); https://doi.org/10.1007/s12633-023-02706-x
82. H. A. J. Hussien, R. G. Kadhim, and A. Hashim, *Optical and Quantum Electronics,* **54**: 704 (2022); https://doi.org/10.1007/s11082-022-04094-9
83. Z. K. Heiba, M. B. Mohamed, and S. I. Ahmed, *Alexandria Engineering Journal*, **61**, Iss. 5: 3375 (2022); https://doi.org/10.1016/j.aej.2021.08.051
84. H. B. Hassan, A. Hashim, and H. M. Abduljalil, *Polymer Bulletin*, **80**: 9059 (2023); https://doi.org/10.1007/s00289-022-04502-w
85. H. A. J. Hussien, R. G. Kadhim, and A. Hashim, *Optical and Quantum Electronics*, **53**: 501 (2021); https://doi.org/10.1007/s11082-021-03157-7
86. H. A. J. Hussien, R. G. Kadhim, and A. Hashim, *Polymer Bulletin*, **79**: 5219 (2022); https://doi.org/10.1007/s00289-021-03778-8
87. Ahmed Hashim, *Opt. Quant. Electron.*, **53**: Article No. 478 (2021); https://doi.org/10.1007/s11082-021-03100-w
88. Ghaith Ahmed and Ahmed Hashim, *Silicon*, **15**: 7085 (2023); https://doi.org/10.1007/s12633-023-02572-7
89. A. Hazim, A. Hashim, and H. M. Abduljalil, *Egypt. J. Chem.*, **64**, No. 1: 359 (2021); doi:10.21608/EJCHEM.2019.18513.2144
90. A.F. Kadhim and A. Hashim, *Opt. Quant. Electron.*, **55**: 432 (2023); https://doi.org/10.1007/s11082-023-04699-8
91. L. H. Gaabour, *Optics and Photonics Journal*, **10**: 197 (2020); doi:10.4236/opj.2020.108021
92. M. H. Meteab, A. Hashim, and B. H. Rabee, *Opt. Quant. Electron.*, **55**: 187 (2023); https://doi.org/10.1007/s11082-022-04447-4
93. A. Hazim, A. Hashim, and H. M. Abduljalil, *Nanosistemi, Nanomateriali, Nanotehnologii*, **18**, Iss. 4: 983 (2020); https://doi.org/10.15407/nnn.18.04.983
94. A. Hashim and Z. S. Hamad, *Nanosistemi, Nanomateriali, Nanotehnologii*, **18**, Iss. 4: 969 (2020); https://doi.org/10.15407/nnn.18.04.969
95. Ahmed Hashim, Aseel Hadi, Hamed Ibrahim, and Farhan Lafta Rashid, *Journal of Inorganic and Organometallic Polymers and Materials*, **34**: 1678 (2024); https://doi.org/10.1007/s10904-023-02908-1

96. Ahmed Kareem, Ahmed Hashim, and Huda Bukheet Hassan, *Silicon*, **16**: 2827 (2024); https://doi.org/10.1007/s12633-024-02891-3
97. Huda Abdul Jalil Hussien and Ahmed Hashim, *J. Inorg. Organomet. Polym.*, **34**: 2716 (2024); https://doi.org/10.1007/s10904-024-03007-5
98. M. Singhi and M. Fahim, *International Journal of Scientific Research*, **3**, Iss. 11: 45 (2014).
99. Z. S. Hamad and A. Hashim, *Nanosistemi, Nanomateriali, Nanotehnologii*, **20**, Iss. 1: 159 (2022); https://doi.org/10.15407/nnn.20.01.159
100. A. Hashim and Z. S. Hamad, *Nanosistemi, Nanomateriali, Nanotehnologii*, **20**, Iss. 1: 165 (2022); https://doi.org/10.15407/nnn.20.01.165
101. A. Hashim and A. Jassim, *Nanosistemi, Nanomateriali, Nanotehnologii*, **20**, Iss. 1: 177 (2022); https://doi.org/10.15407/nnn.20.01.177
102. A. Hashim and Z. S. Hamad, *Nanosistemi, Nanomateriali, Nanotehnologii*, **20**, Iss. 2: 507 (2022); https://doi.org/10.15407/nnn.20.02.507
103. Batool Mohammed, Hind Ahmed, and Ahmed Hashim, *Journal of Physics: Conference Series*, **1879**: 032110 (2021); doi:10.1088/1742-6596/1879/3/032110
104. D. Hassan and A. H. Ah-Yasari, *Bulletin of Electrical Engineering and Informatics*, **8**, Iss. 1: 52 (2019); doi:10.11591/eei.v8i1.1019
105. D. Hassan and A. Hashim, *Bulletin of Electrical Engineering and Informatics*, **7**, Iss. 4: 547 (2018); doi:10.11591/eei.v7i4.969
106. Ahmed Hashim, M. H. Abbas, Noor Al-Huda Al-Aaraji, and Aseel Hadi, *J. Inorg. Organomet. Polym.*, **33**: 1 (2023); https://doi.org/10.1007/s10904-022-02485-9
107. A. Hashim, M. H. Abbas, N. AH. Al-Aaraji, and A. Hadi, *Silicon*, **15**: 1283 (2023); https://doi.org/10.1007/s12633-022-02104-9
108. M. H. Meteab, A. Hashim, and B. H. Rabee, *Silicon*, **15**: 1609 (2023); https://doi.org/10.1007/s12633-022-02114-7
109. N. Al-Huda Al-Aaraji, A. Hashim, A. Hadi, and H. M. Abduljalil, *Silicon*, **14**: 4699 (2022); https://doi.org/10.1007/s12633-021-01265-3
110. M. H. Meteab, A. Hashim, and B. H. Rabee, *Silicon*, **15**: 251 (2023); https://doi.org/10.1007/s12633-022-02020-y
111. A. Hashim, A. Hadi, and M. H. Abbas, *Opt. Quant. Electron.*, **55**: 642 (2023); https://doi.org/10.1007/s11082-023-04929-z
112. Huda Abdul Jalil Hussien and Ahmed Hashim, *J. Inorg. Organomet. Polym.*, **33**: 2331 (2023); https://doi.org/10.1007/s10904-023-02688-8
113. Ahmed Hashim, Aseel Hadi, Noor Al-Huda Al-Aaraji, and Farhan Lafta Rashid, *Silicon*, **15**: 5725 (2023); https://doi.org/10.1007/s12633-023-02471-x
114. Arshad Fadhil Kadhim and Ahmed Hashim, *Silicon*, **15**: 4613 (2023); https://doi.org/10.1007/s12633-023-02381-y
115. H. A. Jawad and A. Hashim, *Nanosistemi, Nanomateriali, Nanotehnologii*, **21**, Iss. 1: 133 (2023); https://doi.org/10.15407/nnn.21.01.133
116. B. Hussien, A. K. Algidsawi, and A. Hashim, *Australian Journal of Basic and Applied Sciences*, **5**, No. 7: 933 (2011).
117. A. G. Hadi, Z. Al-Ramadhan, and A. Hashim, *J. of Physics: Conf. Series*, **1879**: 032109 (2021); doi:10.1088/1742-6596/1879/3/032109
118. A. Hashim and Q. Hadi, *Nanosistemi, Nanomateriali, Nanotehnologii*, **19**, Iss. 4: 873 (2021); https://doi.org/10.15407/nnn.19.04.873

119. A. Hashim and A. Jassim, *Nanosistemi, Nanomateriali, Nanotehnologii*, **19**, Iss. 4: 883 (2021); https://doi.org/10.15407/nnn.19.04.883
120. W. O. Obaid and A. Hashim, *AIP Conference Proceedings*, **2591**: 040039 (2023); https://doi.org/10.1063/5.0120116
121. O. B. Fadil and A. Hashim, *AIP Conference Proceedings*, **2591**: 040031 (2023); https://doi.org/10.1063/5.0120171
122. A. Hashim, A. Hadi, and N. A. H. Al-Aaraji, *Nanosistemi, Nanomateriali, Nanotehnologii*, **21**, Iss. 3: 553 (2023); https://doi.org/10.15407/nnn.21.03.553
123. A. Hashim, A. Hadi, and N. A. H. Al-Aaraji, *Nanosistemi, Nanomateriali, Nanotehnologii*, **21**, Iss. 3: 545 (2023); https://doi.org/10.15407/nnn.21.03.545
124. A. Hashim, A. Hadi, M. H. Abbas, *Nanosistemi, Nanomateriali, Nanotehnologii*, **21**, Iss. 3: 505 (2023); https://doi.org/10.15407/nnn.21.03.505
125. A. Hashim, A. Hadi, and N. A. H. Al-Aaraji, *Nanosistemi, Nanomateriali, Nanotehnologii*, **21**, No. 3: 527 (2023); https://doi.org/10.15407/nnn.21.03.527
126. Ghaith Ahmed and Ahmed Hashim, *Silicon*, **15**: 3977 (2023); https://doi.org/10.1007/s12633-023-02322-9
127. Ann Mary K. Aippunny, Sajna M. Shamsudeen, Prakashan Valparambil, Siby Mathew, and Unnikrishnan N. Vishwambharan, *J. Appl. Polym. Sci.*, **133**, Iss. 25: 43568 (2016); doi:10.1002/APP.43568