Наносистеми, наноматеріали, нанотехнології
Nanosistemi, Nanomateriali, Nanotehnologii
2025, т. 23, № 3, сс. 823–830
https://doi.org/10.15407/nnn.23.03.0823

PACS numbers: 72.80.Tm, 77.22.Ch, 77.22.Gm, 78.20.Ci, 81.07.Pr, 81.40.Tv, 82.35.Np

Fabrication and Enhanced Dielectric Properties of PVA/NiO/Ti Nanostructures for Nanoelectronic Fields

Ahmed Hashim[1], Hamed Ibrahim[2], Batool Mohammed[1],
Eman Hammod Abdullah[1], and Aseel Hadi[3]

[1]*College of Education for Pure Sciences, Department of Physics,*
University of Babylon,
Hillah, Iraq
[2]*Al-Zahraa University for Women,*
Baghdad Road (opposite pole 70),
Kerbala, Iraq
[3]*College of Materials Engineering, Department of Ceramic and Building Materials,*
University of Babylon,
Hillah, Iraq

This work aims to investigate the synthesis of PVA–NiO–Ti nanostructures and exploring their dielectric properties to use in various nanoelectronics applications. The dielectric properties of PVA–NiO–Ti nanostructures are examined in the range of frequency between 100 Hz and 2 MHz. The experimental results demonstrate that the dielectric constant, dielectric loss, and electrical conductivity of PVA are improved with increasing NiO–Ti-nanoparticles' ratio. The dielectric constant and dielectric loss of PVA–NiO–Ti nanostructures are reducing, while the electrical conductivity is rising with increasing frequency. The attained results of dielectric properties for PVA–NiO–Ti nanostructures indicate that these nanocomposites are useful for various nanoelectronics applications.

Метою цієї роботи є дослідження синтези наноструктур ПВС–NiO–Ti та вивчення їхніх діелектричних властивостей для використання в різних застосуваннях наноелектроніки. Діелектричні властивості наноструктур ПВС–NiO–Ti досліджувалися в діяпазоні частот від 100 Гц до 2 МГц. Експериментальні результати показали, що діелектрична проникність, діелектричні втрати й електропровідність ПВС поліпшувалися зі збільшенням співвідношення наночастинок NiO–Ti. Діелектрична проникність і діелектричні втрати наноструктур ПВС–NiO–Ti зменшувалися, тоді як електропровідність зростала зі збільшенням частоти. Одержані результати дослідження діелектричних властивостей наноструктур ПВС–NiO–Ti вказують на те, що ці нанокомпозити корисні для різних застосувань у наноелектроніці.

Key words: nanocomposites, PVA–NiO–Ti, dielectric properties, conductivity.

Ключові слова: нанокомпозити, ПВС–NiO–Ti, діелектричні властивості, провідність.

(Received 28 November, 2023)

1. INTRODUCTION

Hybrid (organic–inorganic) nanocomposites have recently attracted more attention for their outstanding physical and chemical properties. Hybrid nanocomposite films are used in various technological and industrial fields, including supercapacitors, optical lenses, light-emitting diodes (LED), photodetectors, solar cells, multisensors, and UV shielding [1–4]. Polymer-matrix nanocomposites, which exhibit distinct physicochemical characteristics by incorporating inorganic fillers into polymer networks, have received much attention due to their various industrial applications in drug delivery, water treatment, food industry, aeronautical and aerospace structures [5]. Metal nanoparticles (NPs) combined with polymers are greatly attractive because of the various applications offered by these materials. More development of the nanocomposites properties can be enhanced by loading nanofiller materials with aspect ratio [6]. Polyvinyl alcohol (PVA) has significant potential for groundbreaking innovations. It is a non-toxic, water-soluble, and biocompatible synthetic polymer and is mostly utilized in the pharmaceutical, packaging, and biomedical industries with various purposes. The chemical structure of PVA is simple and consists of the main structure of carbons with hydroxyl groups. Because of intra- and intermolecular hydrogen interactions, PVA samples dissolve at high temperatures (of about 80°C) and require constant stirring. Additionally, it has great film-forming properties, high chemical resistance, and a PVA surface layer that prevents nanocomposites from clumping together, which causes them to become stable and monodispersed [7]. The nanocomposites of inorganic-doped polymers or inorganic–inorganic included numerous applications in various fields involved thermal energy storage [8–16], antibacterial [17–25], optical fields [26–35], *etc.*

The present study investigates the fabrication of PVA–NiO–Ti nanostructures to utilize in various nanoelectronics applications.

2. MATERIALS AND METHODS

The samples of pure PVA and PVA–NiO–Ti nanostructures were synthesized with various contents of PVA and NiO–Ti NPs *via* casting method. The PVA of 1 gm was dissolved in 30 ml of distilled water to produce of PVA film. The NiO–Ti NPs were added to the PVA solution by contents of 1, 2 and 3 wt.% with concentration 50% NiO:50% Ti. The dielectric properties of PVA–NiO–Ti nanostructures were investigated at the frequency from 100 Hz to 2 MHz using LCR meter type (HIOKI 3532-50 LCR HI TESTER). The dielectric constant, ε', is defined by Ref. [36] as follows:

$$\varepsilon' = C_p/C_0\,, \tag{1}$$

where C_p is the matter capacitance and C_0 is the vacuum capacitor.

The dielectric loss, ε'', is determined be Ref. [37] as

$$\varepsilon'' = \varepsilon' D, \tag{2}$$

where D is represented dispersion factor.

The A.C. conductivity is given by Ref. [38] as

$$\sigma_{\text{A.C.}} = \omega\varepsilon''\varepsilon_0, \tag{3}$$

where ω is the angular frequency.

3. RESULTS AND DISCUSSION

Figures 1 and 2 confirm the variations of ε' and ε'' for PVA–NiO–Ti nanostructures with frequency, respectively. From these figures, the ε' includes elevated values at low frequency. The ε' value of dielectric constant at low frequency might be related to the electrode effect and interfacial effect of the film. The elevated value of ε'' for PVA–NiO–Ti nanostructures at low frequency is due to the charges' mobility. The ε' and ε'' are rising with increasing NiO–Ti-nanoparticles' content; this result can be related to the rise in conductivity because of the rising density of charge carriers in polymer medium [39–55].

Figure 3 illustrates the A.C. electrical conductivity behaviour with frequency for PVA–NiO–Ti nanostructures. With decreasing frequency, the more charge is accumulated at the electrode and electrode interface that leads to reducing in the number of mobile ions and, eventually, to a drop in the conductivity at low frequencies. At high frequency, the conductivity increases with the frequency as related to the mobility of charge carriers and the hopping of ions from the infinite cluster. As a result, the ion exchange process occurs effectively in the high-frequency region. The A.C. electrical conductivity of PVA is increasing with an increase in the NiO–Ti-NPs' content; this performance is due to the improvement

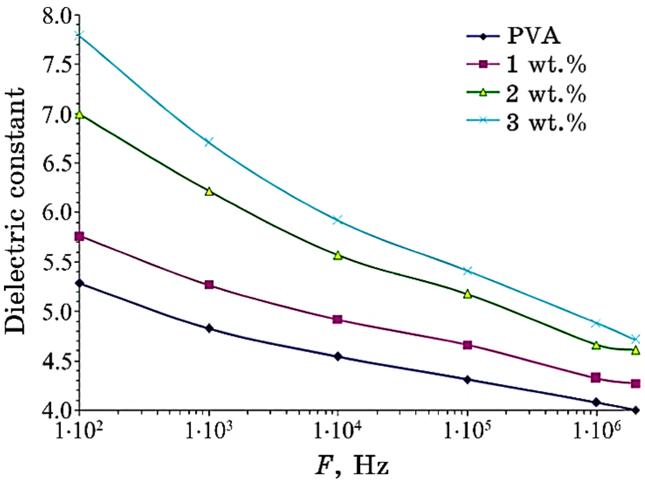

Fig. 1. Variation of ε′ for PVA–NiO–Ti nanostructures with frequency *F*.

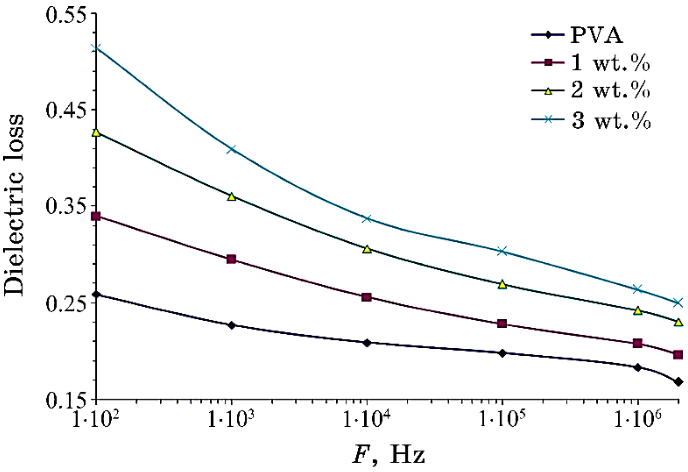

Fig. 2. Behaviour of ε″ for PVA–NiO–Ti nanostructures with frequency *F*.

of the mobility of charge ions and the larger number of charge carriers in polymer medium [56–67].

4. CONCLUSIONS

Fabrication of PVA and PVA NiO–Ti-doped nanostructures' films are investigated in this work. The dielectric properties of PVA–NiO–Ti nanostructures were studied to utilize in various nanoelectronics fields. The results demonstrate that the dielectric constant,

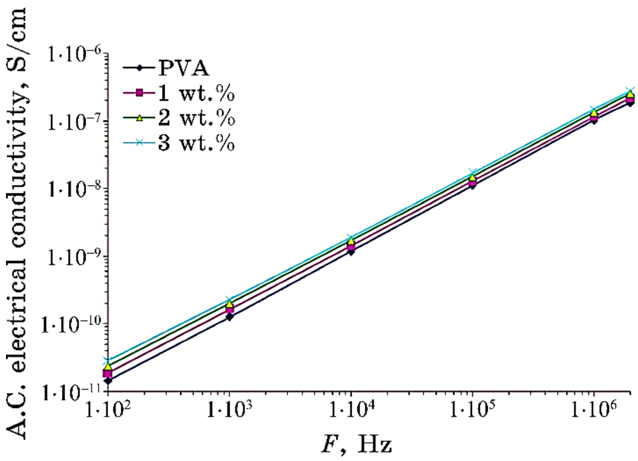

Fig. 3. Performance of A.C. electrical conductivity with frequency F for PVA–NiO–Ti nanostructures.

dielectric loss, and electrical conductivity of PVA are increased with increasing NiO–Ti-NPs' content. The dielectric constant is enhanced by 32.1% at 100 Hz, when the NiO–Ti-NPs' content of 3% is reached. The dielectric constant and dielectric loss of PVA–NiO–Ti nanostructures are decreased, while the electrical conductivity is rising with increasing frequency. The obtained results for dielectric properties of PVA–NiO–Ti nanostructures show that these nanocomposites are functional materials for deferent nanoelectronics fields.

REFERENCES

1. Ihsan A. Aljarrah, Areen A. Bani-Salameh, Ahmad A. Ahmad, Qais M. Al-Bataineh, Ahmad M. Alsaad, M.-Ali H. Al-Akhras, and Ahmad Telfah, *Polymer Bulletin*, **80**: 7533 (2022); https://doi.org/10.1007/s00289-022-04409-6
2. Ola Basim Fadil and Ahmed Hashim, *Nanosistemi, Nanomateriali, Nanotehnologii*, **21**, Iss. 1: 153 (2023); https://doi.org/10.15407/nnn.21.01.153
3. Abeer Ghalib Hadi, Zainab Al-Ramadhan, and Ahmed Hashim, *Nanosistemi, Nanomateriali, Nanotehnologii*, **20**, Iss. 2: 535 (2022); https://doi.org/10.15407/nnn.20.02.535
4. Wissam Obeis Obaid and Ahmed Hashim, *Nanosistemi, Nanomateriali, Nanotehnologii*, **21**, Iss. 1: 163 (2023); https://doi.org/10.15407/nnn.21.01.163
5. Meng Du, Xing-Zhong Cao, Rui Xia, Zhong-Po Zhou, Shuo-Xue Jin, and Bao-Yi Wang, *Chin. Phys. B*, **27**, No. 2: 027805 (2018); doi:10.1088/1674-1056/27/2/027805
6. F. H. Abd El-kader, N. A. Hakeem, R. S. Hafez, and A. M. Ismail, *Journal of Inorganic and Organometallic Polymers and Materials*, **28**: 1037 (2018); https://doi.org/10.1007/s10904-017-0763-x

7. Muhammad Saad, Hajira Tahir, Seher Mustafa, Osama A. Attala, Waleed A. El-Saoud, Kamal A. Attia, Wessam M. Filfilan, and Jahan Zeb, *Nanomaterials*, **13**, Iss. 11: 1747 (2023); https://doi.org/10.3390/nano13111747
8. A. S. Shareef, F. Lafta Rashid, A. Hadi, and A. Hashim, *International Journal of Scientific & Technology Research*, **8**, Iss. 11: 1041 (2019).
9. Aseel Hadi, Ahmed Hashim Ah-yasari, and Dalal Hassan, *Bulletin of Electrical Engineering and Informatics*, **9**, No. 1: 83 (2020); https://doi.org/10.11591/eei.v9i1.1323
10. Hind Ahmed and Ahmed Hashim, *Nanosistemi, Nanomateriali, Nanotehnologii*, **20**, Iss. 4: 951 (2022); https://doi.org/10.15407/nnn.20.04.951
11. Farhan Lafta Rashid, Aseel Hadi, Ammar Ali Abd, and Ahmed Hashim, *International Journal of Advances in Applied Sciences*, **8**, No. 2: 154 (2019); doi:10.11591/ijaas.v8i2.pp154-156
12. Maithem Hussein Rasheed, Ahmed Hashim, and Farhan Lafta Rashid, *Nanosistemi, Nanomateriali, Nanotehnologii*, **19**, Iss. 2: 347 (2021); https://doi.org/10.15407/nnn.19.02.347
13. Ahmed Hashim, Farhan Lafta Rashid, Noor Al-Huda Al-Aaraji, and Bahaa H. Rabee, *East European Journal of Physics*, **1**: 173 (2023); https://doi.org/10.26565/2312-4334-2023-1-21
14. Farhan Lafta Rashid, Ahmed Hashim, Noor Al-Huda Al-Aaraji, and Aseel Hadi, *East European Journal of Physics*, **1**: 177 (2023); doi:10.26565/2312-4334-2023-1-22
15. Farhan Lafta Rashid, Ahmed Hashim, M. H. Abbas, and Aseel Hadi, *East European Journal of Physics*, **1**: 181 (2023); doi:10.26565/2312-4334-2023-1-23
16. Ahmed Hashim, Farhan Lafta Rashid, M. H. Abbas, and Bahaa H. Rabee, *East European Journal of Physics*, **1**: 185 (2023); doi:10.26565/2312-4334-2023-1-24
17. Ahmed Hashim, Ibrahim R. Agool, and Kadhim J. Kadhim, *Journal of Bionanoscience*, **12**, No. 5: 608 (2018); doi:10.1166/jbns.2018.1580
18. Angham Hazim, Ahmed Hashim, and Hayder M. Abduljalil, *International Journal of Emerging Trends in Engineering Research*, **7**, No. 8: 68 (2019); https://doi.org/10.30534/ijeter/2019/01782019
19. Angham Hazim, Hayder M. Abduljalil, and Ahmed Hashim, *International Journal of Emerging Trends in Engineering Research*, **7**, No. 8: 104 (2019); https://doi.org/10.30534/ijeter/2019/04782019
20. Ola Basim Fadil and Ahmed Hashim, *Nanosistemi, Nanomateriali, Nanotehnologii*, **20**, Iss. 4: 1029 (2022); https://doi.org/10.15407/nnn.20.04.1029
21. W. O. Obaid and A. Hashim, *Nanosistemi, Nanomateriali, Nanotehnologii*, **20**, Iss. 4: 1009 (2022); https://doi.org/10.15407/nnn.20.04.1009
22. Mohanad H. Meteab, Ahmed Hashim, and Bahaa H. Rabee, *Nanosistemi, Nanomateriali, Nanotehnologii*, **21**, Iss. 1: 199 (2023); https://doi.org/10.15407/nnn.21.01.199
23. Mohanad H. Meteab, Ahmed Hashim, and Bahaa H. Rabee, *Nanosistemi, Nanomateriali, Nanotehnologii*, **21**, Iss. 2: 451 (2023); https://doi.org/10.15407/nnn.21.02.451
24. Huda Bukheet Hassan, Ahmed Hashim, and Hayder M. Abduljalil, *Nanosistemi, Nanomateriali, Nanotehnologii*, **20**, Iss. 3: 815 (2022); https://doi.org/10.15407/nnn.20.03.815
25. Huda Bukheet Hassan, Ahmed Hashim, and Hayder M. Abduljalil, *Nanosistemi, Nanomateriali, Nanotehnologii*, **20**, Iss. 3: 821 (2022);

https://doi.org/10.15407/nnn.20.03.821
26. Hind Ahmed and Ahmed Hashim, *Silicon*, **14**: 6637 (2022); https://doi.org/10.1007/s12633-021-01449-x
27. Hind Ahmed and Ahmed Hashim, *Silicon*, **13**: 4331 (2021); https://doi.org/10.1007/s12633-020-00723-8
28. Hind Ahmed and Ahmed Hashim, *Transactions on Electrical and Electronic Materials*, **22**: 335 (2021); https://doi.org/10.1007/s42341-020-00244-6
29. Noor Al-Huda Al-Aaraji, Ahmed Hashim, Aseel Hadi, and Hayder M. Abduljalil, *Silicon*, **14**: 10037 (2022); https://doi.org/10.1007/s12633-022-01730-7
30. Hind Ahmed and Ahmed Hashim, *Opt. Quant. Electron.*, **55**: Article No. 9 (2023); https://doi.org/10.1007/s11082-022-04273-8
31. Wissam Obeis Obaid and Ahmed Hashim, *Silicon*, **14**: 11199 (2022); https://doi.org/10.1007/s12633-022-01854-w
32. Ola Basim Fadil and Ahmed Hashim, *Silicon*, **14**: 9845 (2022); https://doi.org/10.1007/s12633-022-01728-1
33. Hind Ahmed and Ahmed Hashim, *Silicon*, **15**: 2339 (2023); https://doi.org/10.1007/s12633-022-02173-w
34. Huda Bukheet Hassan, Hayder M. Abduljalil, and Ahmed Hashim, *Nanosistemi, Nanomateriali, Nanotehnologii*, **20**, Iss. 4: 941 (2022); https://doi.org/10.15407/nnn.20.04.941
35. Haitham Ahmed Jawad and Ahmed Hashim, *Nanosistemi, Nanomateriali, Nanotehnologii*, **20**, Iss. 4: 963 (2022); https://doi.org/10.15407/nnn.20.04.963
36. Abdelghaffar Amoka Abdelmalik, Abdulrahman Sadiq, and Umar Sadiq, *Jornal of Physical Science*, **31**, No. 1: 1 (2020); https://doi.org/10.21315/jps2020.31.1.1
37. R. Divya, M. Meena, C. K. Mahadevan, and C. M. Padma, *Journal of Engineering Research and Applications*, **4**, Iss. 5: 01 (2014); https://www.researchgate.net/publication/262483892_Investigation_on_CuO_Dispersed_PVA_Polymer_Films_M_Meena
38. A. Y. Yassin, A. Raouf Mohamed, A. M. Abdelghany, and E. M. Abdelrazek, *Journal of Materials Science: Materials in Electronics*, **29**: 15931 (2018); https://doi.org/10.1007/s10854-018-9679-7
39. Mahalesh Devendrappa, Sharanabasamma M. Ambalagi, Sannakki Nagaraja, and Basavaraja Sannakki, *AIP Conference Proceedings*, **1989**: 020010 (2018); https://doi.org/10.1063/1.5047686
40. Ahmed Hashim, Aseel Hadi, and M. H. Abbas, *Opt. Quant. Electron.*, **55**: 642 (2023); https://doi.org/10.1007/s11082-023-04929-z
41. Wissam Obeis Obaid and Ahmed Hashim, *AIP Conference Proceedings*, **2591**: 040039 (2023); https://doi.org/10.1063/5.0120116
42. Ola Basim Fadil and Ahmed Hashim, *AIP Conference Proceedings*, **2591**: 040031 (2023); https://doi.org/10.1063/5.0120171
43. Ahmed Hashim, Aseel Hadi, and Noor Al-Huda Al-Aaraji, *Nanosistemi, Nanomateriali, Nanotehnologii*, **21**, Iss. 3: 553 (2023); https://doi.org/10.15407/nnn.21.03.553
44. Ahmed Hashim, Aseel Hadi, and Noor Al-Huda Al-Aaraji, *Nanosistemi, Nanomateriali, Nanotehnologii*, **21**, Iss. 3: 545 (2023); https://doi.org/10.15407/nnn.21.03.545
45. Huda Abdul Jalil Hussien and Ahmed Hashim, *J. Inorg. Organomet. Polym.*, **33**: 2331 (2023); https://doi.org/10.1007/s10904-023-02688-8

46. 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
47. Arshad Fadhil Kadhim and Ahmed Hashim, *Silicon*, **15**: 4613 (2023); https://doi.org/10.1007/s12633-023-02381-y
48. Haitham Ahmed Jawad and Ahmed Hashim, *Nanosistemi, Nanomateriali, Nanotehnologii*, **21**, Iss. 1: 133 (2023); https://doi.org/10.15407/nnn.21.01.133
49. Bahaa Hussien, Alaa J. Kadham Algidsawi, and Ahmed Hashim, *Australian Journal of Basic and Applied Sciences*, **5**, No. 7: 933 (2011); https://www.ajbasweb.com/old/ajbas/2011/July-2011/933-936.pdf
50. Abeer Ghalib Hadi, Zainab Al-Ramadhan, and Ahmed Hashim, *J. of Physics: Conf. Series*, **1879**: 032109 (2021); doi:10.1088/1742-6596/1879/3/032109
51. Ahmed Hashim and Qassim Hadi, *Nanosistemi, Nanomateriali, Nanotehnologii*, **19**, Iss. 4: 873 (2021); https://doi.org/10.15407/nnn.19.04.873
52. Ahmed Hashim and Ali Jassim, *Nanosistemi, Nanomateriali, Nanotehnologii*, **19**, Iss. 4: 883 (2021); https://doi.org/10.15407/nnn.19.04.883
53. Ahmed Hashim, Aseel Hadi, and M. H. Abbas, *Nanosistemi, Nanomateriali, Nanotehnologii*, **21**, Iss. 3: 505 (2023); https://doi.org/10.15407/nnn.21.03.505
54. Ahmed Hashim, Aseel Hadi, and Noor Al-Huda Al-Aaraji, *Nanosistemi, Nanomateriali, Nanotehnologii*, **21**, Iss. 3: 527 (2023); https://doi.org/10.15407/nnn.21.03.527
55. Ghaith Ahmed and Ahmed Hashim, *Silicon*, **15**: 3977 (2023); https://doi.org/10.1007/s12633-023-02322-9
56. Zinah Sattar Hamad and Ahmed Hashim, *Nanosistemi, Nanomateriali, Nanotehnologii*, **20**, Iss. 1: 159 (2022); https://doi.org/10.15407/nnn.20.01.159
57. Ahmed Hashim, M. H. Abbas, Noor Al-Huda Al-Aaraji, and Aseel Hadi, *Silicon*, **15**: 1283 (2023); https://doi.org/10.1007/s12633-022-02104-9
58. Mohanad H. Meteab, Ahmed Hashim, and Bahaa H. Rabee, *Silicon*, **15**: 1609 (2023); https://doi.org/10.1007/s12633-022-02114-7
59. Noor Al-Huda Al-Aaraji, Ahmed Hashim, Aseel Hadi, and Hayder M. Abduljalil, *Silicon*, **14**: 4699 (2022); https://doi.org/10.1007/s12633-021-01265-3
60. Mohanad H. Meteab, Ahmed Hashim, and Bahaa H. Rabee, *Silicon*, **15**: 251 (2023); https://doi.org/10.1007/s12633-022-02020-y
61. Ahmed Hashim and Zinah Sattar Hamad, *Nanosistemi, Nanomateriali, Nanotehnologii*, **20**, Iss. 1: 165 (2022); https://doi.org/10.15407/nnn.20.01.165
62. Ahmed Hashim and Ali Jassim, *Nanosistemi, Nanomateriali, Nanotehnologii*, **20**, Iss. 1: 177 (2022); https://doi.org/10.15407/nnn.20.01.177
63. Ahmed Hashim and Zinah Sattar Hamad, *Nanosistemi, Nanomateriali, Nanotehnologii*, **20**, Iss. 2: 507 (2022); https://doi.org/10.15407/nnn.20.02.507
64. Batool Mohammed, Hind Ahmed, and Ahmed Hashim, *Journal of Physics: Conference Series*, **1879**: 032110 (2021); doi:10.1088/1742-6596/1879/3/032110
65. Dalal Hassan and Ahmed Hashim Ah-yasari, *Bulletin of Electrical Engineering and Informatics*, **8**, Iss. 1: 52 (2019); doi:10.11591/eei.v8i1.1019
66. Dalal Hassan and Ahmed Hashim, *Bulletin of Electrical Engineering and Informatics*, **7**, Iss. 4: 547 (2018); doi:10.11591/eei.v7i4.969
67. 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