Наносистеми, наноматеріали, нанотехнології
Nanosistemi, Nanomateriali, Nanotehnologii
2024, т. 22, № 1, сс. 167–176
https://doi.org/10.15407/nnn.22.01.167

PACS numbers: 72.80.Tm, 77.22.Ch, 77.22.Gm, 77.55.+f, 77.84.Lf, 81.07.Pr, 82.35.Np

Boosting the Dielectric Properties of PVA/In_2O_3/SiC Nanostructures for Electronics Nanodevices

Ahmed Hashim and M. H. Abbas

College of Education for Pure Sciences,
Department of Physics,
University of Babylon,
Hillah, Iraq

The present work aims to prepare of the indium oxide (In_2O_3)–silicon carbide (SiC) nanostructures doping the polyvinyl alcohol (PVA) to use in different electronics fields. The dielectric properties of PVA–In_2O_3–SiC nanocomposites are examined. The results demonstrate that the dielectric constant and dielectric loss of the PVA–In_2O_3–SiC nanocomposites are decreased with an increase in the frequency, while the electrical conductivity is increased as frequency is increased. The dielectric constant, dielectric loss, and electrical conductivity of PVA are increased with an increase in the In_2O_3–SiC nanoparticles' (NPs) concentration. Finally, the obtained results for the dielectric properties indicate that the PVA–In_2O_3–SiC nanocomposites can be suitable in various electronics fields.

Метою даної роботи є виготовлення наноструктур оксиду індію (In_2O_3)–карбіду кремнію (SiC), що леґують полівініловий спирт (ПВС), для використання в різних галузях електроніки. Досліджено діелектричні властивості нанокомпозитів ПВС–In_2O_3–SiC. Результати показують, що діелектрична проникність і діелектричні втрати нанокомпозитів ПВС–In_2O_3–SiC зменшуються зі збільшенням частоти, тоді як електропровідність зростає зі збільшенням частоти. Діелектрична проникність, діелектричні втрати й електропровідність ПВС зростають зі збільшенням концентрації наночастинок In_2O_3–SiC. Нарешті, одержані результати стосовно діелектричних властивостей показують, що нанокомпозити ПВС–In_2O_3–SiC можуть бути придатними у різних галузях електроніки.

Key words: polyvinyl alcohol, SiC, In_2O_3, nanocomposites, dielectric properties, conductivity.

Ключові слова: полівініловий спирт, SiC, In_2O_3, нанокомпозити, діелектричні властивості, електропровідність.

(Received 30 June, 2023; in revised form, 28 July, 2023)

1. INTRODUCTION

Ongoing progress is being made toward the manufacture of more flexible dielectric nanocomposites, which can lead to distinctive designated technologies. The nanocomposites films were created by dispersing nanosize inorganic additives in an organic polymeric matrix. Those composites have been employed in a variety of implementations, such supercapacitors as well as stretchy electrodes. Composite films with distinct structural as well as dielectric properties are used as substances for electrical energy storage instruments. The composite films are important because they merge the polymers' machinability, longevity, as well as ductile qualities with the thermal stability as well as electric conductivities of the nanoadditive [1].

Silicon carbide (SiC) is used as a heat exchanger module, as it is a promising material for increasing corrosion resistance. In addition, SiC has excellent characteristics, including its low density and high specific thermal conductivity. It is well known that SiC has excellent thermal stability and corrosion resistance [2].

Indium oxide (In_2O_3) is an important functional semiconductor material, having direct band gap of $\cong 3.6$ eV and indirect band gap of $\cong 2.6$ eV, which has drawn much research interest in both fundamental and experimental research fields due to its ultrasensitive gas sensing characteristics, photocatalytic properties and extensive applications in sensors, flat panel displays, optoelectronic devices *etc.* [3].

Polyvinyl alcohol (PVA) is characterized by carbon chain backbone linked with hydroxyl groups. The hydroxyl groups, OH groups, are considered as a source of hydrogen bonding; therefore, it helps to form the polymer blends or polymer complexes. PVA is water-soluble and biocompatible polymer and is vastly used in the preparation of polymer blends due to its excellent physical and chemical properties. Therefore, the applications of PVA can be increased more and more by adding different dopant materials into PVA matrix [4].

There many studies on nanocomposites to employ in various fields like sensors [5, 6], electronics and optoelectronics [7–20], antibacterial [21–26], radiation shielding and bioenvironmental [27–32], optical fields [33–42], and energy storage [43–45].

This paper deals with fabrication of PVA–In_2O_3–SiC nanocomposites and investigating the dielectric properties to apply in different industrial fields.

2. MATERIALS AND METHODS

Films of PVA/In_2O_3/SiC nanocomposites were prepared by casting process. The film of pure PVA was fabricated by dissolving of 1 gm of PVA in distilled water (30 ml). The In_2O_3–SiC NPs were added to the PVA with contents of 1.2%, 2.4%, 3.6%. The dielectric characteristics of PVA–In_2O_3–SiC nanocomposites were measured within the frequency (f) range from 100 Hz to $5\cdot10^6$ Hz by using LCR meter (HIOKI 3532-50 LCR HI TESTER). The dielectric constant, ε', was determined by [46]:

$$\varepsilon' = C_p d/\varepsilon_0 A, \quad (1)$$

where C_p is the capacitance, d is thickness, and A in [cm^2].

Dielectric loss, ε'', was given by [47]:

$$\varepsilon'' = \varepsilon' D, \quad (2)$$

where D represents the dispersion factor.

The A.C. electrical conductivity was found by [48]:

$$\sigma_{A.C.} = 2\pi f \varepsilon' D \varepsilon_0. \quad (3)$$

3. RESULTS AND DISCUSSION

The behaviours of dielectric constant and dielectric loss with frequency and content of In_2O_3–SiC NPs are shown in Figs. 1–4. The

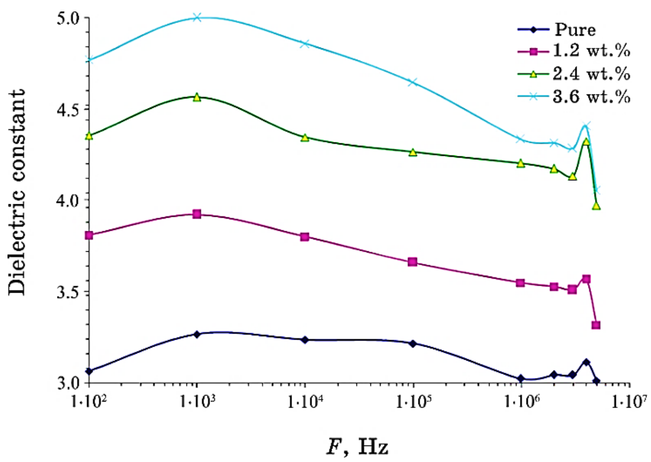

Fig. 1. Behaviour of dielectric constant with frequency for the PVA–In_2O_3–SiC nanocomposites.

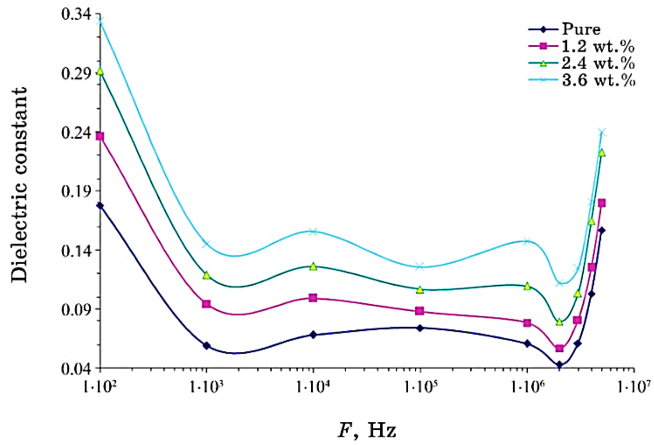

Fig. 2. Dielectric loss performance with frequency for the PVA–In_2O_3–SiC nanocomposites.

dielectric constant and dielectric loss are reduced with frequency while increased with content of In_2O_3–SiC NPs. These behaviours of both dielectric constant and dielectric loss due to the high contribution of charge accumulation in the nanocomposites assigned to the effect of polarization effect. The dielectric constant and dielectric loss are increased when the In_2O_3–SiC NPs content increases due to increase of charge-carriers' numbers [49–57].

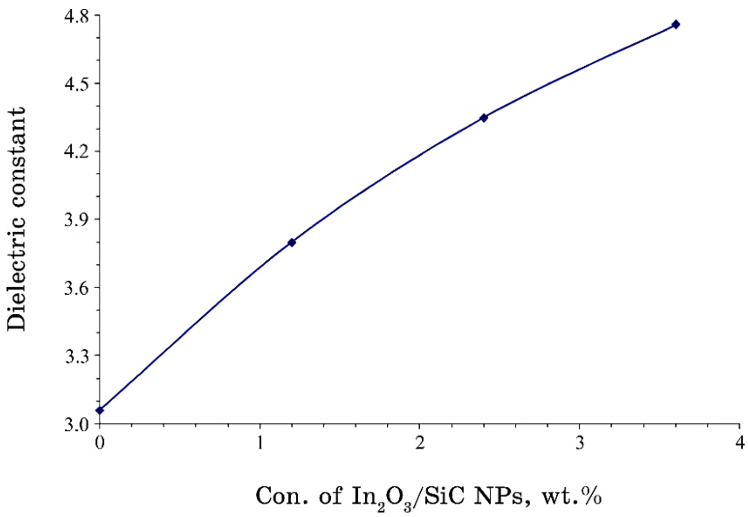

Fig. 3. Variation of dielectric constant of PVA with content of In_2O_3–SiC NPs.

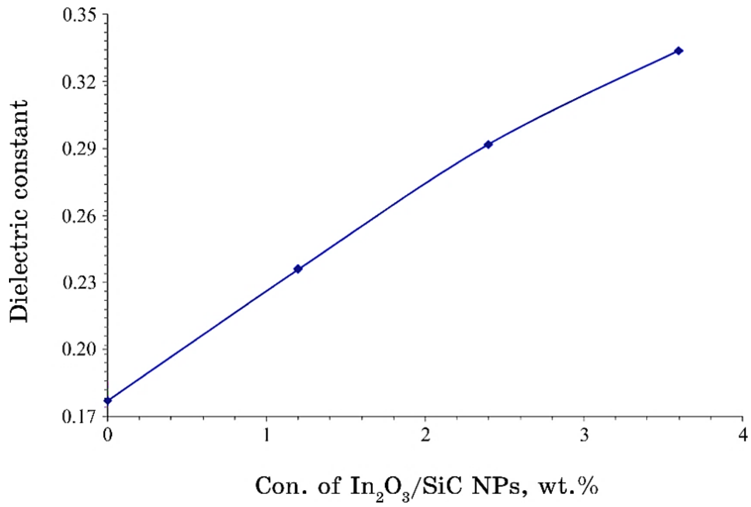

Fig. 4. Dielectric loss variation of PVA with content of In_2O_3–SiC NPs.

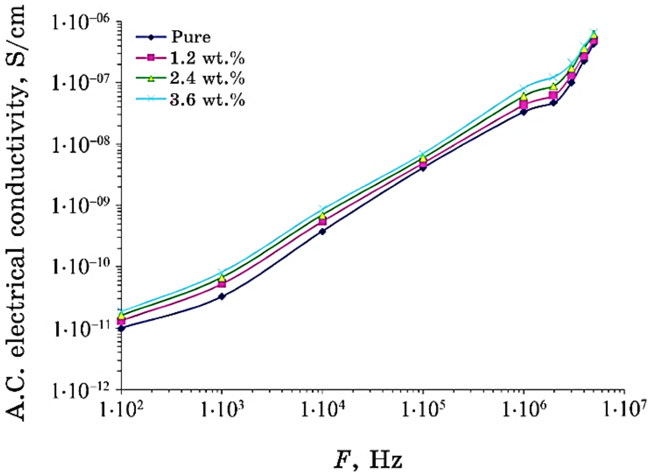

Fig. 5. Variation of A.C. electrical conductivity for PVA–In_2O_3–SiC nanocomposites with frequency.

Figures 5 and 6 demonstrate the variation of A.C. electrical conductivity for PVA–In_2O_3–SiC nanocomposites with frequency and content of In_2O_3–SiC NPs. As the In_2O_3–SiC NPs ratio is increased, the inorganic filler molecules start bridging the gap separating the two localized states and lowering the potential barrier between them, thereby, facilitating the transfer of charge carriers between two localized states; hence, the conductivity increases as a result of increase the charges carrier numbers. The frequency-dependent

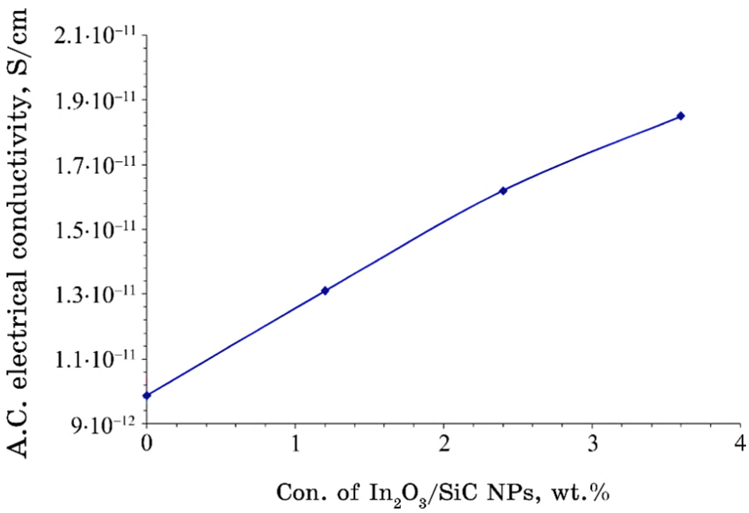

Fig. 6. Behaviour of A.C. electrical conductivity for PVA with content of In_2O_3–SiC NPs.

conductivity is caused by the hopping of charge carriers in the localized state. The term hopping refers to the sudden displacement of charge carriers from one position to another neighbouring site and, in general, includes both jumps over a potential barrier and quantum mechanical tunnelling [58–68].

4. CONCLUSIONS

In this study, PVA–In_2O_3–SiC nanocomposites were synthesised to utilize in various electronics approaches.

The dielectric properties of PVA–In_2O_3–SiC nanocomposites were tested. The results showed the dielectric constant and dielectric loss of PVA–In_2O_3–SiC nanocomposites decreased with rising frequency while the electrical conductivity increased as frequency increased. The dielectric constant, dielectric loss and electrical conductivity of PVA increased with increasing of the In_2O_3–SiC NPs concentrations. The final results for dielectric properties showed that the PVA–In_2O_3–SiC nanocomposites might be appropriate in many electronics approaches.

REFERENCES

1. B. M. Alotaibi, H. A. Al-Yousef, A. Atta, and F. A.Taher, *Journal of Ovonic Research*, **19**, No. 2: 175 (2023);

https://doi.org/10.15251/JOR.2023.192.175
2. A. Ichinose, K. Kuwata, T. Esaki, T. Matsuda, and N. Kobayashi, *J. of Mater. Sci. and Chem. Eng.*, **8**: 23 (2020); https://doi.org/10.4236/msce.2020.811002
3. M. A. M. Khan, R. Siwach, S. Kumar, J. Ahmed, and M. Ahamed, *J. of Alloys and Compounds*, **846**: 1 (2020); https://doi.org/10.1016/j.jallcom.2020.156479
4. T. Fahmy, A. Sarhan, and Z. M. Elqahtani, *Int. J. of Eng. Res. and Techno.*, **13**, No. 3: 454 (2020); https://dx.doi.org/10.37624/IJERT/13.3.2020.454-461
5. H. Ahmed and A. Hashim, *International Journal of Scientific & Technology Research*, **8**, Iss. 11: 1014 (2019).
6. B. Mohammed, H. Ahmed, and A. Hashim, *Nanosistemi, Nanomateriali, Nanotehnologii*, **20**, No. 1: 187 (2022); https://doi.org/10.15407/nnn.20.01.187
7. 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
8. A. Hashim and Z. S. Hamad, *Nanosistemi, Nanomateriali, Nanotehnologii*, **18**, Iss. 4: 969 (2020); https://doi.org/10.15407/nnn.18.04.969
9. A. Hazim, A. Hashim, and H. M. Abduljalil, *Egypt. J. Chem.*, **64**, No. 1: 359 (2021); doi:10.21608/EJCHEM.2019.18513.2144
10. H. Ahmed and A. Hashim, *Journal of Molecular Modeling*, **26**: 1 (2020); doi:10.1007/s00894-020-04479-1
11. H. Ahmed and A. Hashim, *Silicon*, **14**: 4907 (2022); https://doi.org/10.1007/s12633-021-01258-2
12. A. Hashim, *Opt. Quant. Electron.*, **53**: 1 (2021); https://doi.org/10.1007/s11082-021-03100-w
13. H. Ahmed and A. Hashim, *Trans. Electr. Electron. Mater.*, **23**: 237 (2022); https://doi.org/10.1007/s42341-021-00340-1
14. H. Ahmed and A. Hashim, *Silicon*, **14**: 7025 (2021); https://doi.org/10.1007/s12633-021-01465-x
15. A. Hazim, A. Hashim, and H. M. Abduljalil, *Trans. Electr. Electron. Mater.*, **21**: 48 (2019); https://doi.org/10.1007/s42341-019-00148-0
16. A. F. Kadhim and A. Hashim, *Opt. Quant. Electron.*, **55**: 432 (2023); https://doi.org/10.1007/s11082-023-04699-8
17. H. Ahmed and A. Hashim, *Opt. Quant. Electron.*, **55**: 280 (2023); https://doi.org/10.1007/s11082-022-04528-4
18. G. Ahmed and A. Hashim, *Silicon*, **15**: 3977 (2023); https://doi.org/10.1007/s12633-023-02322-9
19. M. H. Meteab, A. Hashim, and B. H. Rabee, *Opt. Quant. Electron.*, **55**: 187 (2023); https://doi.org/10.1007/s11082-022-04447-4
20. B. Mohammed, H. Ahmed, and A. Hashim, *Nanosistemi, Nanomateriali, Nanotehnologii*, **21**, Iss. 1: 113 (2023); https://doi.org/10.15407/nnn.21.01.113
21. A. Hashim, I. R. Agool, and K. J. Kadhim, *Journal of Bionanoscience*, **12**, No. 5: 608 (2018); doi:10.1166/jbns.2018.1580
22. 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
23. 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
24. O. B. Fadil and A. Hashim, *Nanosistemi, Nanomateriali, Nanotehnologii*, **20**, Iss. 4: 1029 (2022); https://doi.org/10.15407/nnn.20.04.1029
25. W. O. Obaid and A. Hashim, *Nanosistemi, Nanomateriali, Nanotehnologii*, 20, Iss. 4: 1009 (2022); https://doi.org/10.15407/nnn.20.04.1009
26. 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
27. A. Hashim and N. Hamid, *Journal of Bionanoscien*ce, **12**, No. 6: 788 (2018); doi:10.1166/jbns.2018.1591
28. A. Hashim and Z. S. Hamad, *Journal of Bionanoscience*, **12**, No. 4: 488 (2018); doi:10.1166/jbns.2018.1551
29. A. Hashim and Z. S. Hamad, *Journal of Bionanoscience*, **12**, No. 4: 504 (2018); doi:10.1166/jbns.2018.1561
30. 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
31. K. H. H. Al-Attiyah, A. Hashim, and S. F. Obaid, *Journal of Bionanoscience*, **12**: 200 (2018); doi:10.1166/jbns.2018.1526
32. 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
33. H. Ahmed and A. Hashim, *Silicon*, **14**: 6637 (2022); https://doi.org/10.1007/s12633-021-01449-x
34. H. Ahmed and A. Hashim, *Silicon*, **13**: 4331 (2020); https://doi.org/10.1007/s12633-020-00723-8
35. H. Ahmed and A. Hashim, *Transactions on Electrical and Electronic Materials*, **22**: 335 (2021); https://doi.org/10.1007/s42341-020-00244-6
36. 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
37. H. Ahmed and A. Hashim, *Opt. Quant. Electron.*, **55**: 1 (2023); https://doi.org/10.1007/s11082-022-04273-8
38. W. O. Obaid and A. Hashim, *Silicon*, **14**: 11199 (2022); https://doi.org/10.1007/s12633-022-01854-w
39. O. B. Fadil and A. Hashim, *Silicon*, **14**: 9845 (2022); https://doi.org/10.1007/s12633-022-01728-1
40. H. Ahmed and A. Hashim, *Silicon*, **15**: 2339 (2023); https://doi.org/10.1007/s12633-022-02173-w
41. H. B. Hassan, H. M. Abduljalil, and A. Hashim, *Nanosistemi, Nanomateriali, Nanotehnologii*, **20**, No. 4: 941 (2022); https://doi.org/10.15407/nnn.20.04.941
42. H. A. Jawad and A. Hashim, *Nanosistemi, Nanomateriali, Nanotehnologii*, **20**, Iss. 4: 963 (2022); https://doi.org/10.15407/nnn.20.04.963
43. Abbas Sahi Shareef, Farhan Lafta Rashid, Aseel Hadi, and Ahmed Hashim, *International Journal of Scientific & Technology Research*, **8**, Iss. 11: 1041 (2019); https://www.researchgate.net/publication/337315854_Water-

Polyethylene_Glycol_Sic-
Wc_And_Ceo2WcNanofluids_For_Saving_Solar_Energy
44. A. Hadi, A. Hashim, and D. Hassan, *Bulletin of Electrical Engineering and Informatics*, **9**, No. 1: 83 (2020); doi:10.11591/eei.v9i1.1323
45. H. Ahmed and A. Hashim, *Nanosistemi, Nanomateriali, Nanotehnologii*, **20**, Iss. 4: 951 (2022); https://doi.org/10.15407/nnn.20.04.951
46. S. Ishaq, F. Kanwal, S. Atiq, M. Moussa, U. Azhar, and D. Losic, *Materials*, **13**: 1 (2020); doi:10.3390/ma13010205
47. T. A. Abdel-Baset and A. Hassen, *Physica B*, **499**: 24 (2016); http://dx.doi.org/10.1016/j.physb.2016.07.002
48. C. S. Rani and N. J. John, *Int. J. of Innovative Techno. and Exploring Eng.*, **8**, Iss. 11: 1285 (2019).
49. A. M. Ismail, Mohamed H. El-Newehy, Mehrez E. El-Naggar, A. Meera Moydeen, and A. A. Menazea, *Journal of Materials Research and Technology*, **9**, Iss. 5: 11178 (2020); h1ttps://doi.org/10.1016/j.jmrt.2020.08.013
50. Z. S. Hamad and A. Hashim, *Nanosistemi, Nanomateriali, Nanotehnologii*, **20**, Iss. 1: 159 (2022); https://doi.org/10.15407/nnn.20.01.159
51. A. Hashim and Z. S. Hamad, *Nanosistemi, Nanomateriali, Nanotehnologii*, **20**, Iss. 1: 165 (2022); https://doi.org/10.15407/nnn.20.01.165
52. A. Hashim and A. Jassim, *Nanosistemi, Nanomateriali, Nanotehnologii*, **20**, No. 1: 177 (2022); https://doi.org/10.15407/nnn.20.01.177
53. A. Hashim and Z. S. Hamad, *Nanosistemi, Nanomateriali, Nanotehnologii*, **20**, Iss. 2: 507 (2022); https://doi.org/10.15407/nnn.20.02.507
54. B. Mohammed, H. Ahmed, and A. Hashim, *Journal of Physics: Conference Series*, **1879**: 1 (2021); doi:10.1088/1742-6596/1879/3/032110
55. D. Hassan and A. H. Ah-Yasari, *Bulletin of Electrical Engineering and Informatics*, **8**, Iss. 1: 52 (2019); doi:10.11591/eei.v8i1.1019
56. D. Hassan and A. Hashim, *Bulletin of Electrical Engineering and Informatics*, **7**, Iss. 4: 547 (2018); doi:10.11591/eei.v7i4.969
57. A. Hashim, M. H. Abbas, N. AH. Al-Aaraji, and A. Hadi, *J. Inorg. Organomet Polym.*, **33**: 1 (2023); https://doi.org/10.1007/s10904-022-02485-9
58. R. Divya, M. Meena, C. K. Mahadevan, and C. M. Padma, *Journal of Engineering Research and Applications*, **4**, Iss. 5: 1 (2014).
59. 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
60. M. H. Meteab, A. Hashim, and B. H. Rabee, *Silicon*, **15**: 1609 (2023); https://doi.org/10.1007/s12633-022-02114-7
61. 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
62. M. H. Meteab, A. Hashim, and B. H. Rabee, *Silicon*, **15**: 251 (2023); https://doi.org/10.1007/s12633-022-02020-y
63. A. Hashim, A. Hadi, and M. H. Abbas, *Opt. Quant. Electron.*, **55**: 642 (2023); https://doi.org/10.1007/s11082-023-04929-z
64. A. Hashim, A. Hadi, and M. H. Abbas, *Silicon*, **15**: 6431 (2023); https://doi.org/10.1007/s12633-023-02529-w
65. H. A. J. Hussien and A. Hashim, *J. Inorg. Organomet. Polym.*, **33**: 2331 (2023); https://doi.org/10.1007/s10904-023-02688-8
66. A. Hashim, A. Hadi, N. A. H. Al-Aaraji, and F. L. Rashid, *Silicon*, **15**: 5725 (2023); https://doi.org/10.1007/s12633-023-02471-x

67. A. F. Kadhim and A. Hashim, *Silicon*, **15**: 4613 (2023); https://doi.org/10.1007/s12633-023-02381-y
68. H. A. Jawad and A. Hashim, *Nanosistemi, Nanomateriali, Nanotehnologii*, **21**, No. 1: 133 (2023); https://doi.org/10.15407/nnn.21.01.133