Наносистеми, наноматеріали, нанотехнології
Nanosistemi, Nanomateriali, Nanotehnologii
2024, т. 22, № 1, сс. 177–186
https://doi.org/10.15407/nnn.22.01.177

© 2024 ІМФ (Інститут металофізики
ім. Г. В. Курдюмова НАН України)
Надруковано в Україні.

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

Tailoring the Dielectric Properties of PS/In_2O_3/SiC Nanocomposites for Nanoelectronics Fields

Ahmed Hashim[1] and Aseel Hadi[2]

[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

In this article, fabrication of polystyrene (PS)–indium oxide (In_2O_3)–silicon carbide (SiC) nanocomposites with low weight, low cost and high corrosion resistance is investigated. The dielectric properties of PS–In_2O_3–SiC nanocomposites are studied. The experimental results show that the dielectric constant and dielectric loss of PS–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 PS are increased with an increase in the In_2O_3–SiC-nanoparticles' concentration. The final results for dielectric properties show that the PS–In_2O_3–SiC nanocomposites may be useful in different electronics applications.

У цій статті було досліджено виготовлення нанокомпозитів полістирол (ПС)–оксид індію (In_2O_3)–карбід кремнію (SiC) з низькою вагою, низькою вартістю та високою корозійною стійкістю. Було досліджено діелектричні властивості нанокомпозитів PS–In_2O_3–SiC. Експериментальні результати показують, що електрична проникність і діелектричні втрати нанокомпозитів ПС–In_2O_3–SiC зменшуються зі збільшенням частоти, тоді як електропровідність зростає зі збільшенням частоти. Діелектрична проникність, діелектричні втрати й електропровідність ПС зростають зі збільшенням концентрації наночастинок In_2O_3–SiC. Остаточні результати стосовно діелектричних властивостей показують, що нанокомпозити ПС–In_2O_3–SiC можуть бути корисними в різних застосуваннях для електроніки.

Key words: In_2O_3, SiC, polystyrene, nanocomposites dielectric properties,

conductivity.

Ключові слова: In_2O_3, SiC, полістирол, нанокомпозити, діелектричні властивості, провідність.

(Received 28 June, 2023)

1. INTRODUCTION

Polymer nanocomposites have captured the interest of many researchers owing to their high performance, remarkable mechanical and thermal properties. They possess outstanding properties, such as improved mechanical strength and dimensional stability, better optical, magnetic, and electrical properties, enhanced water and oxygen barrier, thermal stability, meaningful flame retardation, chemical resistance, increased anti-scratch and wear resistance properties, *etc.* [1].

Silicon carbide (SiC) is one of the main commonly utilized non-oxide ceramics for many industrial fields relating to its attention the elevated temperature characteristics like good strength, excellent hardness, and elevated resistance for thermal shock and wear. It also has a good resistance for chemical oxidation. The performance of SiC under such great conditions is projected to allow major enhancement to a multiplicity of fields. SiC nanostructures have exposed to display superior characteristics compare to the SiC bulk. It also demonstrates the potential fields in UV photodetectors and diodes relating to a higher efficiency for light emission [1].

Indium oxide (In_2O_3) is an important and well-known transparent conducting oxide of *n*-type semiconductor exhibiting a wide band gap, chemical stability, high electrical conductivity and transparency to visible light. It is frequently used for photovoltaic devices, transparent windows, liquid crystal displays (LCD), light emitting diode (LED), solar cell, gas sensors, and antireflecting coatings [2].

Polystyrene (PS) is an inexpensive, environmentally friendly polymer it is among the most popular materials which has many applications in industry, building and construction, domestic appliances and food packaging. In food packaging, polystyrene can be used in many shapes as monolayer plastic film, plastic sheet, or injection moulded and foamed. Plasticizers usually used in the industry for improving the workability of the polymers by lowering the glass transition temperature (T_g) [4].

There are several studies on nanostructured substances to make use in such fields as electronics and optoelectronics [5–19], radiation shielding and bioenvironmental [20–25], sensors [26, 27], antibacterial [28–33], energy storage [34–36], optical fields [37–46].

This work aims to prepare the PS–In_2O_3–SiC nanocomposites and to study the dielectric properties used in different electronics applications.

2. MATERIALS AND METHODS

Nanocomposites of PS–In_2O_3–SiC were prepared by using solution-casting method. The pure PS film was fabricated by dissolving of 1 gm of this polymer in chloroform (30 ml). The In_2O_3–SiC NPs were added to the PS with contents are 1.2 wt.%, 2.4 wt.%, and 3.6 wt.%. The dielectric properties of PS–In_2O_3–SiC nanocomposites were tested at frequency range (100 Hz–$5\cdot10^6$ Hz) using LCR meter (HIOKI 3532-50 LCR HI TESTER).

The dielectric constant (ε′) was determined by [47]:

$$\varepsilon' = C_p d/\varepsilon_0 A, \tag{1}$$

where C_p is matter capacitance, d is the thickness, A is the area.

Dielectric loss (ε″) was found by [48]:

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

where D is the dispersion factor.

The electrical conductivity was given by [49]:

$$\sigma_{\text{A.C.}} = 2\pi f \varepsilon' D \varepsilon_0. \tag{3}$$

3. RESULTS AND DISCUSSION

Figures 1–4 show the variations of dielectric constant and dielectric loss with frequency and content of In_2O_3–SiC NPs, respectively. The performances of dielectric constant and dielectric loss in the given frequency range as the following, the strong frequencies dispersion of the permittivity is seen at low range of frequency.

The values of dielectric constant and dielectric loss are decreased with increase of frequency due to the relaxation process and may be due to charge accumulation inside the nanocomposites attributed to influence of interfacial polarization on permittivity.

With addition of the filler In_2O_3–SiC, the values of both dielectric constant and dielectric loss increases at the range of lower frequency and nearly the same at the range of the higher frequency attributed to the filler cause more localization of charge carriers along with mobile ions causing higher ionic conductivity. Also, the rise of dielectric constant and dielectric loss with increasing content

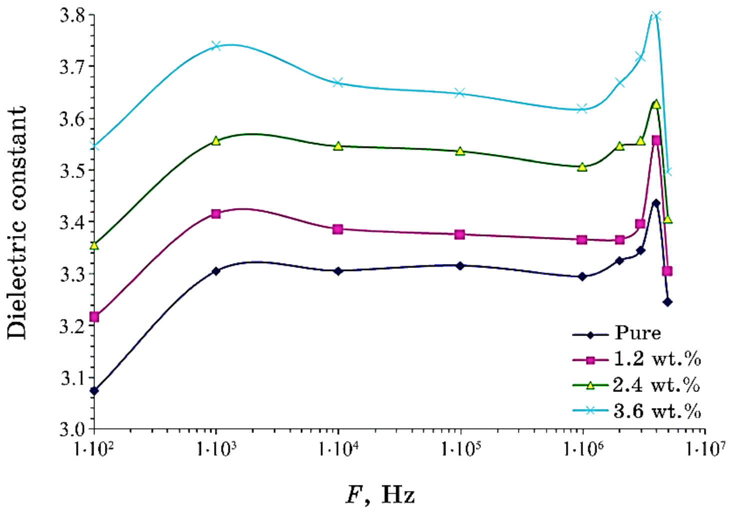

Fig. 1. Variation of dielectric constant for the PS–In_2O_3–SiC nanocomposites with frequency.

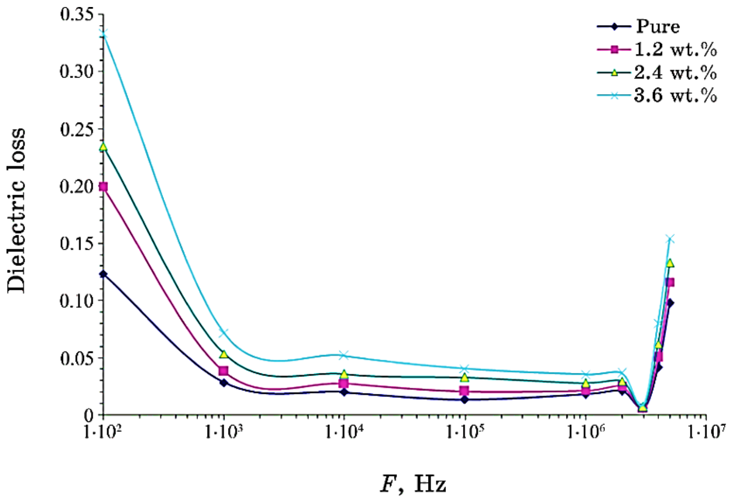

Fig. 2. Behaviour of dielectric loss for the PS–In_2O_3–SiC nanocomposites with frequency.

of In_2O_3–SiC NPs due to increase in the numbers of charges carriers [50–61].

Figures 5 and 6 demonstrate the behaviour of A.C. electrical conductivity with frequency and In_2O_3–SiC NPs content, respectively. As shown in these figures, the A.C. electrical conductivity rises with an increase in the frequency and In_2O_3–SiC NPs content. It

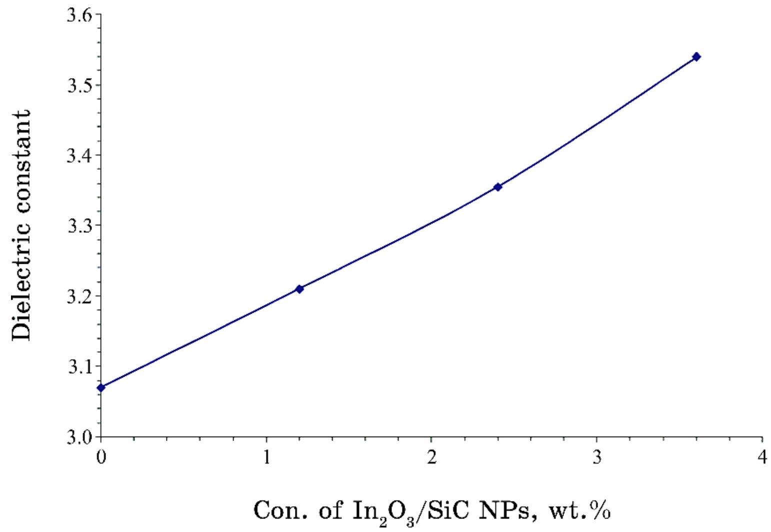

Fig. 3. Behaviour of dielectric constant for PS with content of In_2O_3–SiC NPs.

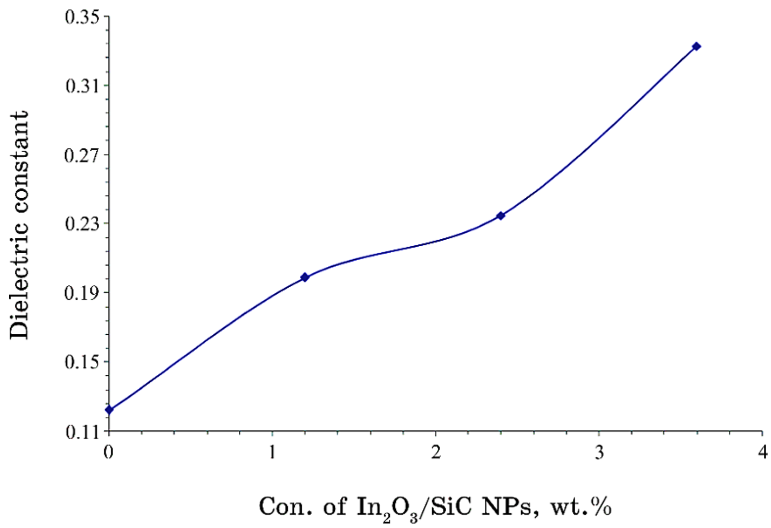

Fig. 4. Dielectric loss performance for PS with content of In_2O_3–SiC NPs.

was also observed that the values of AC electrical conductivity are increased as the concentration of In_2O_3–SiC NPs increased into PS matrix. The increase of conductivity due to increase the mobility and charge-carriers' numbers. Furthermore, these observations could be assigned to space-charge polarization [62–69].

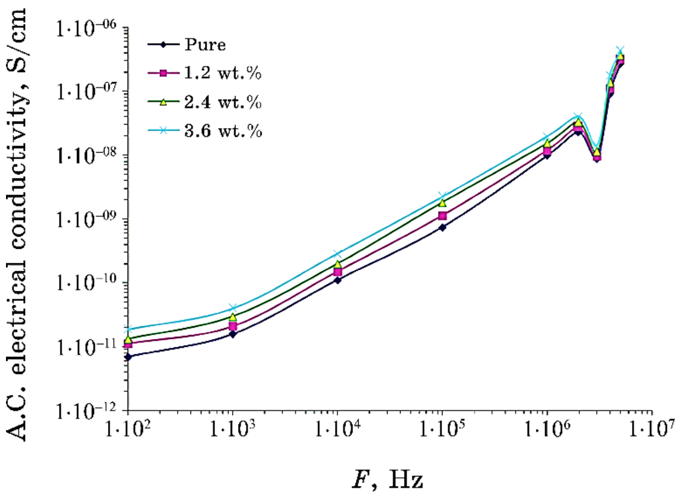

Fig. 5. Behaviour of A.C. electrical conductivity for the PS–In_2O_3–SiC nanocomposites with frequency.

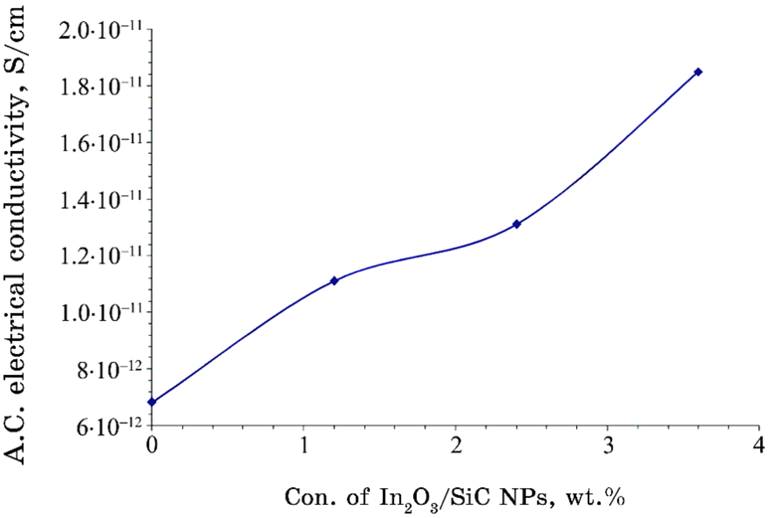

Fig. 6. Performance of A.C. electrical conductivity for PS with In_2O_3–SiC NPs content.

4. CONCLUSIONS

The present work includes manufacture of PS–In_2O_3–SiC nanocomposites with low weight, low cost and high corrosion resistance. The dielectric properties of PS–In_2O_3–SiC nanocomposites were tested. The results showed that the dielectric constant and dielectric loss of

PS–In_2O_3–SiC nanocomposites decreased with an increase in the frequency while the electrical conductivity increased as frequency increased. The dielectric constant, dielectric loss and electrical conductivity of PS increased with an increase in the In_2O_3–SiC nanoparticles concentrations. The final results for dielectric properties showed that the PS–In_2O_3–SiC nanocomposites might be suitable in many electronics fields.

REFERENCES

1. S. U. Rehman, S. Javaid, M. Shahid, I. H. Gul, B. Rashid, C. R. Szczepanski, M. Naveed, and S. J. Curley, *Polymers*, **14**: 1 (2022); https://doi.org/10.3390/polym14173576
2. K. W. Mas'udah, M. Diantoro, and A. Fuad, *IOP Conf. Series: Journal of Physics: Conf. Series.*, **1093**: 1 (2018); doi:10.1088/1742-6596/1093/1/012033
3. A. Attaf, A. Bouhdjar, H. Saidi, Y. Benkhetta, H. Bendjedidi, M. Nouadji, and N. Lehraki, *AIP Conf. Proc.*, **1653**: 1 (2014); doi:10.1063/1.4914207
4. N. A. Kamel, M. A. Saied, R. M. Ramadan, and S. L. Abd El-Messieh, *Egypt. J. Chem.*, **64**: 3111(2021); doi:10.21608/EJCHEM.2021.61000.3309
5. H. Ahmed and A. Hashim, *Silicon*, **14**: 7025 (2021); https://doi.org/10.1007/s12633-021-01465-x
6. A. Hazim, A. Hashim, and H. M. Abduljalil, *Trans. Electr. Electron. Mater.*, **21**: 48 (2019); https://doi.org/10.1007/s42341-019-00148-0
7. A.F. Kadhim and A. Hashim, *Opt. Quant. Electron.*, **55**: 432 (2023); https://doi.org/10.1007/s11082-023-04699-8
8. H. Ahmed and A. Hashim, *Opt. Quant. Electron.*, **55**: 280 (2023); https://doi.org/10.1007/s11082-022-04528-4
9. G. Ahmed and A. Hashim, *Silicon*, **15**: 3977 (2023); https://doi.org/10.1007/s12633-023-02322-9
10. M. H. Meteab, A. Hashim, and B. H. Rabee, *Opt. Quant. Electron.*, **55**: 187 (2023); https://doi.org/10.1007/s11082-022-04447-4
11. B. Mohammed, H. Ahmed, and A. Hashim, *Nanosistemi, Nanomateriali, Nanotehnologii*, **21**, Iss. 1: 113 (2023); https://doi.org/10.15407/nnn.21.01.113
12. A. Hashim, *Nanosistemi, Nanomateriali, Nanotehnologii*, **19**, Iss. 3: 647 (2021); https://doi.org/10.15407/nnn.19.03.647
13. 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
14. A. Hashim and Z. S. Hamad, *Nanosistemi, Nanomateriali, Nanotehnologii*, **18**, Iss. 4: 969 (2020); https://doi.org/10.15407/nnn.18.04.969
15. A. Hazim, A. Hashim, and H. M. Abduljalil, *Egypt. J. Chem.*, **64**, No. 1: 359 (2021); doi:10.21608/EJCHEM.2019.18513.2144
16. H. Ahmed and A. Hashim, *Journal of Molecular Modeling*, **26**: 1 (2020); doi:10.1007/s00894-020-04479-1
17. H. Ahmed and A. Hashim, *Silicon*, **14**: 4907 (2022); https://doi.org/10.1007/s12633-021-01258-2

18. A. Hashim, *Opt. Quant. Electron.*, **53**: 1 (2021); https://doi.org/10.1007/s11082-021-03100-w
19. H. Ahmed and A. Hashim, *Trans. Electr. Electron. Mater.*, **23**: 237 (2022); https://doi.org/10.1007/s42341-021-00340-1
20. A. Hashim and Z. S. Hamad, *Journal of Bionanoscience*, **12**, No. 4: 504 (2018); doi:10.1166/jbns.2018.1561
21. 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
22. K. H. H. Al-Attiyah, A. Hashim, and S. F. Obaid, *Journal of Bionanoscience*, **12**: 200 (2018); doi:10.1166/jbns.2018.1526
23. H. A. J. Hussien, A. Hadi, and A. Hashim, *Nanosistemi, Nanomateriali, Nanotehnologii*, 20, No. 4: 1001 (2022); https://doi.org/10.15407/nnn.20.04.1001
24. A. Hashim and N. Hamid, *Journal of Bionanoscien*ce, **12**, No. 6: 788 (2018); doi:10.1166/jbns.2018.1591
25. A. Hashim and Z. S. Hamad, *Journal of Bionanoscience*, **12**, No. 4: 488 (2018); doi:10.1166/jbns.2018.1551
26. H. Ahmed and A. Hashim, *International Journal of Scientific & Technology Research*, **8**, Iss. 11: 1014 (2019).
27. B. Mohammed, H. Ahmed, and A. Hashim, *Nanosistemi, Nanomateriali, Nanotehnologii*, **20**, Iss. 1: 187 (2022); https://doi.org/10.15407/nnn.20.01.187
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, No. 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. A. Hashim, I. R. Agool, and K. J. Kadhim, *Journal of Bionanoscience*, **12**, No. 5: 608 (2018); doi:10.1166/jbns.2018.1580
33. 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
34. A. Hadi, A. Hashim, and D. Hassan, *Bulletin of Electrical Engineering and Informatics*, **9**, No. 1: 83 (2020); doi:10.11591/eei.v9i1.1323
35. H. Ahmed and A. Hashim, *Nanosistemi, Nanomateriali, Nanotehnologii*, **20**, Iss. 4: 951 (2022); https://doi.org/10.15407/nnn.20.04.951
36. A. S. Shareef, F. Lafta R., A. Hadi, and A. Hashim, *International Journal of Scientific & Technology Research*, **8**, Iss. 11: 1041 (2019).
37. H. Ahmed and A. Hashim, *Silicon*, **15**: 2339 (2023); https://doi.org/10.1007/s12633-022-02173-w
38. 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

39. H. A. Jawad and A. Hashim, *Nanosistemi, Nanomateriali, Nanotehnologii*, **20**, Iss. 4: 963 (2022); https://doi.org/10.15407/nnn.20.04.963
40. H. Ahmed and A. Hashim, *Silicon*, **14**: 6637 (2022); https://doi.org/10.1007/s12633-021-01449-x
41. H. Ahmed and A. Hashim, *Silicon*, **13**: 4331 (2020); https://doi.org/10.1007/s12633-020-00723-8
42. H. Ahmed and A. Hashim, *Transactions on Electrical and Electronic Materials*, **22**: 335 (2021); https://doi.org/10.1007/s42341-020-00244-6
43. 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
44. H. Ahmed and A. Hashim, *Opt. Quant. Electron.*, **55**: 1 (2023); https://doi.org/10.1007/s11082-022-04273-8
45. W.O. Obaid and A. Hashim, *Silicon*, **14**: 11199 (2022); https://doi.org/10.1007/s12633-022-01854-w
46. O. B. Fadil and A. Hashim, *Silicon*, **14**: 9845 (2022); https://doi.org/10.1007/s12633-022-01728-1
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. E. Elbayoumy, N. A. El-Ghamaz, F. Sh. Mohamed, M. A. Diab, and T. Nakano, *Polymers*, **13**, No. 17: 3005 (2021); https://doi.org/10.3390/polym13173005
49. P. Beena and H. S. Jayanna, *Polymers and Polymer Composites*, **27**, No. 9: 619 (2019); doi:10.1177/0967391119856140
50. M. H. Meteab, A. Hashim, and B. H. Rabee, *Silicon*, 15: 251 (2023); https://doi.org/10.1007/s12633-022-02020-y
51. A. Hashim, A. Hadi, and M. H. Abbas, *Opt. Quant. Electron.*, **55**: 642 (2023); https://doi.org/10.1007/s11082-023-04929-z
52. A. Hashim, A. Hadi, and M. H. Abbas, *Silicon*, **15**: 6431 (2023); https://doi.org/10.1007/s12633-023-02529-w
53. A. Hashim, M. H. Abbas, N. AH. Al-Aaraji, A. Hadi, *J. Inorg. Organomet Polym.*, **33**: 1 (2023); https://doi.org/10.1007/s10904-022-02485-9
54. A. Hashim, M. H. Abbas, N. AH. Al-Aaraji, and A. Hadi, *Silicon*, **15**: 1283 1283 (2023); https://doi.org/10.1007/s12633-022-02104-9
55. M. H. Meteab, A. Hashim, and B. H. Rabee, *Silicon*, **15**: 1609 (2023); https://doi.org/10.1007/s12633-022-02114-7
56. 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
57. H. A. J. Hussien and A. Hashim, *J. Inorg. Organomet. Polym.*, **33**: 2331 (2023); https://doi.org/10.1007/s10904-023-02688-8
58. 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
59. A. F. Kadhim and A. Hashim, *Silicon*, **15**: 4613 (2023); https://doi.org/10.1007/s12633-023-02381-y
60. A. A. Menazea, A. M. Ismail, and I. S. Elashmawi, *Journal of Materials Research and Technology*, **9**, Iss. 3: 5689 (2020); https://doi.org/10.1016/j.jmrt.2020.03.093
61. H. A. Jawad and A. Hashim, *Nanosistemi, Nanomateriali, Nanotehnologii*, **21**, Iss. 1: 133 (2023); https://doi.org/10.15407/nnn.21.01.133
62. Z. S. Hamad and A. Hashim, *Nanosistemi, Nanomateriali, Nanotehnologii*,

20, Iss. 1: 159 (2022); https://doi.org/10.15407/nnn.20.01.159
63. A. Hashim and Z. S. Hamad, *Nanosistemi, Nanomateriali, Nanotehnologii*, **20**, Iss. 1: 165 (2022); https://doi.org/10.15407/nnn.20.01.165
64. A. Hashim and A. Jassim, *Nanosistemi, Nanomateriali, Nanotehnologii*, **20**, Iss. 1: 177 (2022); https://doi.org/10.15407/nnn.20.01.177
65. A. Hashim and Z. S. Hamad, *Nanosistemi, Nanomateriali, Nanotehnologii*, **20**, Iss. 2: 507(2022); https://doi.org/10.15407/nnn.20.02.507
66. B. Mohammed, H. Ahmed, and A. Hashim, *Journal of Physics: Conference Series*, **1879**: 1 (2021); doi:10.1088/1742-6596/1879/3/032110
67. D. Hassan and A. H. Ah-Yasari, *Bulletin of Electrical Engineering and Informatics*, **8**, Iss. 1: 52 (2019); doi:10.11591/eei.v8i1.1019
68. D. Hassan and A. Hashim, *Bulletin of Electrical Engineering and Informatics*, **7**, Iss. 4: 547 (2018); doi:10.11591/eei.v7i4.969
69. 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); https://doi.org/10.1016/j.jmrt.2020.08.013