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Synthesis of PMMA/PEO/SiC/$BaTiO_3$ Nanostructures for Antibacterial and Radiation-Shielding Applications

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The current research aims to fabricate the new PMMA/PEO/SiC/$BaTiO_3$ nanostructures (PMMA—poly(methyl 2-methylpropenoate), PEO—polyethylene oxide) to use them in biomedical purposes as the radiation-shielding and in antibacterial applications due to their distinguished chemical and physical properties as well as a good gamma-ray attenuation coefficients and high antibacterial effectiveness. The PMMA/PEO/SiC/$BaTiO_3$ nanostructures are prepared with different weight percentages of silicon carbide (SiC)/barium titanate ($BaTiO_3$) nanoparticles (NPs) and PMMA/PEO blend to obtain nanostructures with low-weight, good flexibility, and good processability. The morphology of films' surface for PMMA/PEO/SiC/$BaTiO_3$ nanostructures is searched by optical microscope (OM) and scanning electron microscope (SEM). The SiC/$BaTiO_3$ NPs are highly homogenous within the PMMA/PEO medium, according to the OM and SEM investigations. The attenuation coefficients are tested using ^{137}Cs sources. The results demonstrate that the attenuation coefficient of PMMA/PEO is enhanced by rising of SiC/$BaTiO_3$ NPs. The antibacterial results show that the PMMA/PEO/SiC/$BaTiO_3$ nanostructures have antibacterial effectiveness for gram-positive and gram-negative organisms. Therefore, the PMMA/PEO/SiC/$BaTiO_3$ nanostructures can be employed as a radiation-shielding material as well as an antibacterial agent for use in the medical and environmental applications.

Поточне дослідження спрямоване на виготовлення нових наноструктур ПММП/ПЕО/SiC/$BaTiO_3$ (ПММА — полі(метил-2-метилпропеноат), ПЕО — поліетиленоксид) для використання їх у біомедичних цілях як захист від радіяції та в антибактеріальних застосуваннях завдяки їхнім відмінним хемічним і фізичним властивостям, а також хорошим коефіцієнтам ослаблення γ-променів і високій антибактеріяльній ефективності. Наноструктури ПММА/ПЕО/SiC/$BaTiO_3$ готуються з різними ваговими відсотками наночастинок (НЧ) карбіду Силіцію (SiC)/титанату

Барію ($BaTiO_3$) та суміші ПММА/ПЕО для одержання наноструктур з низькою вагою, хорошою гнучкістю та хорошою технологічністю. Морфологія поверхні плівок для наноструктур ПММА/ПЕО/SiC/$BaTiO_3$ досліджується за допомогою оптичного мікроскопа (ОМ) та сканувального електронного мікроскопа (СЕМ). Згідно з дослідженнями ОМ і СЕМ, НЧ SiC/$BaTiO_3$ є високогомогенними в середовищі ПММА/ПЕО. Коефіцієнти ослаблення перевіряються з використанням джерел ^{137}Cs. Результати демонструють, що коефіцієнт ослаблення ПММА/ПЕО підвищується за рахунок зростання кількости наночастинок SiC/$BaTiO_3$. Результати антибактеріяльних досліджень показують, що наноструктури ПММА/ПЕО/SiC/$BaTiO_3$ мають антибактеріяльну ефективність для грам-позитивних і грам-неґативних організмів. Таким чином, наноструктури ПММА/ПЕО/SiC/$BaTiO_3$ можна використовувати як матеріял, що екранує випромінення, а також як антибактеріяльний засіб для використання в медицині та навколишньому середовищі.

Key words: PMMA/PEO, SiC, $BaTiO_3$, antibacterial effectiveness, radiation shielding.

Ключові слова: ПММА/ПЕО, SiC, $BaTiO_3$, антибактеріяльна ефективність, захист від радіяції.

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1. INTRODUCTION

Antibacterial substances are essential in many scientific fields, including medicine, manufacturing, food packaging, and water treatment [1]. Antimicrobial activity can be description as a collective term for all active principles (agents) that limit bacterial development, inhibit the generation of microbial colonies, and may even kill microorganisms [2, 3].

Traditional disinfectants made of organic substances are cytotoxic and unhealthy. Therefore, there has been a lot of emphasis paid to the development of inorganic disinfectants [1, 4]. For example, the nanoparticles (NPs) improve antimicrobial activity without creating toxicity to nearby tissues [4]. More importantly, unlike conventional antibiotics, these nanomaterials could have various effects on bacterial growth, making it harder for germs to develop resistance to them [1, 5]. Due to its excellent mechanical, electrical, and thermal properties, such as fracture strength, large elastic modulus, stiffness and toughness, chemical stability, relatively low density and perfect thermal conductivity, as well as low thermal-expansion co-efficient and high resistivity, silicon carbide (SiC) is one of the attractive filler ceramics for elevated temperature structural components [6].

Semi-crystalline-linear polyethylene oxide (PEO) has great heat stability as well as low cost and is useful for enhancing mechanical characteristics. Therefore, PEO is taken in to account for utilisation in antibacterial coatings and the food-packaging field [7, 8]. The PEO polymer has been utilised to create antimicrobial coatings on the surfaces of biomedical systems as an efficient coating approach. Although PEO coating alone can increase a materials' antimicrobial activity, adding nanofiller with strong antibacterial activity to the PEO matrix can increase the antibacterial activity by twofold [9, 10]. Barium titanate $BaTiO_3$ NPs, a perovskite-type ceramic material, offers excellent properties like a high dielectric constant and good ferro-, piezo-, and pyroelectric properties. The production of multilayer ceramic capacitors, thermistors, transducers, infrared detectors, sensors, and electrooptical devices often uses $BaTiO_3$ NPs [11, 12] and may potentially be used in medicinal domains such as tissue engineering, medication delivery, and cancer therapy, according to studies [13–16].

Due to its reduced inflammatory properties, PMMA, one of the most widely used commercial polymeric materials, is nevertheless used for a variety of biomedical applications, including lenses [16]. Silicon and silicon compounds doped polymers were investigated by many studies to apply in optical, electronics and photonics fields [17–21].

The aim of this work is to synthesize the PMMA/PEO/SiC/$BaTiO_3$ nanostructures, which have excellent antibacterial activity against gram-positive and gram-negative bacteria, with low cost and high activity.

2. MATERIALS AND METHODS

The materials used in this work are PMMA/PEO blend as a matrix and SiC/$BaTiO_3$ NPs as fillers. In 40 ml of chloroform, PMMA (75%) and PEO (25%) were dissolved with a magnetic stirrer for 1 hour to get a more uniform solution. Various weight percentages of SiC/$BaTiO_3$ NPs 1.6, 3.2, 4.8, and 6.4 wt.% were added to the PMMA/PEO solution. Nanostructures were prepared by using casting method with thickness of 90 μm. The morphology of films surface for PMMA/PEO/SiC/$BaTiO_3$ nanostructures was explored by optical microscope (OM) and scanning electron microscope (SEM). Nanostructured PMMA/PEO/SiC/$BaTiO_3$ composites are tested as antibacterial for gram-positive (*Staphylococcus aureus*) and gram-negative (*Escherichia coli*) bacteria by using a disc diffusion method. The gamma-ray attenuation properties for various percentages of SiC/$BaTiO_3$ NPs have been examined. The samples were putted in front of a collimated beam hail from gamma-ray sources (Cs-137). The space between the sample and the gamma-ray source was of 2 cm.

3. RESULTS AND DISCUSSION

Figures 1 and 2 show the distribution of $SiC/BaTiO_3$ NPs in the PMMA/PEO matrix with different ratios of $SiC/BaTiO_3$ NPs. At low content, the $SiC/BaTiO_3$ NPs are agglomerated as clusters.

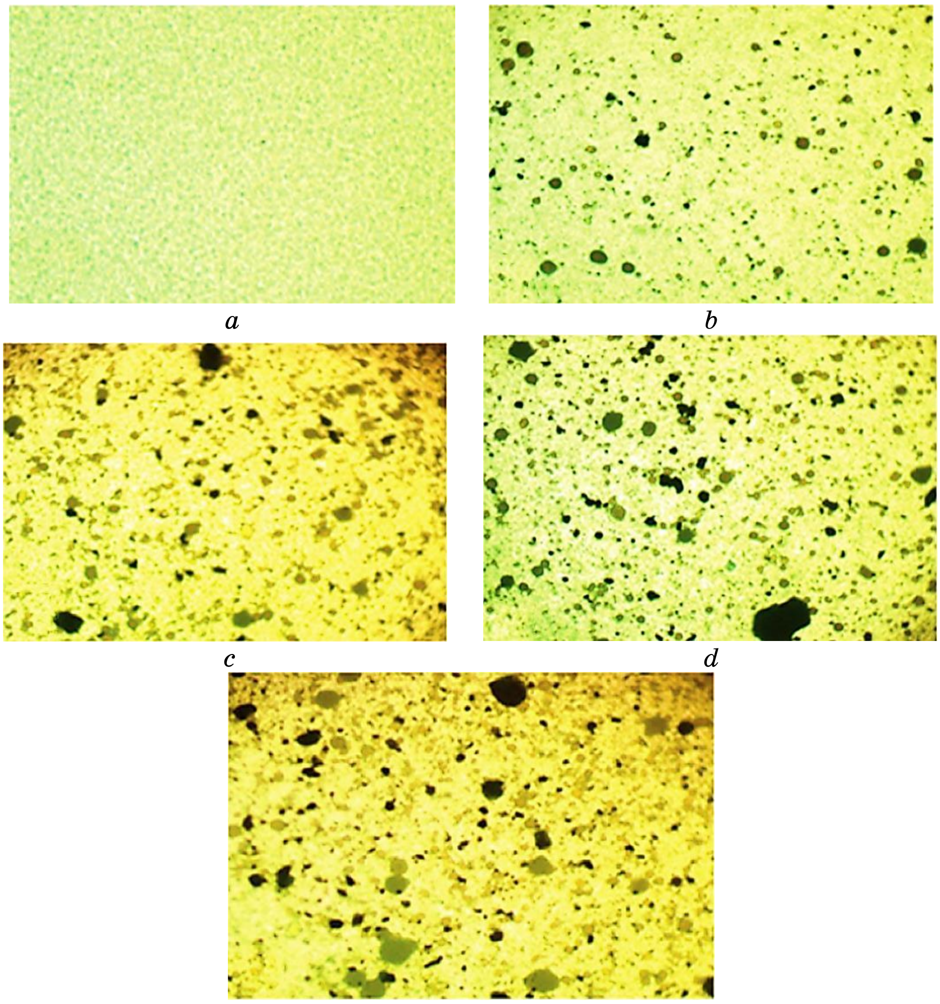

Fig. 1. Optical microscope images (×10) for $PMMA/PEO/SiC/BaTiO_3$ nanostructures: (*a*) blend; (*b*) 1.6 wt.% $SiC/BaTiO_3$ NPs; (*c*) 3.2 wt.% $SiC/BaTiO_3$ NPs; (*d*) 4.8 wt.% $SiC/BaTiO_3$ NPs; (*e*) 6.4 wt.% $SiC/BaTiO_3$ NPs.

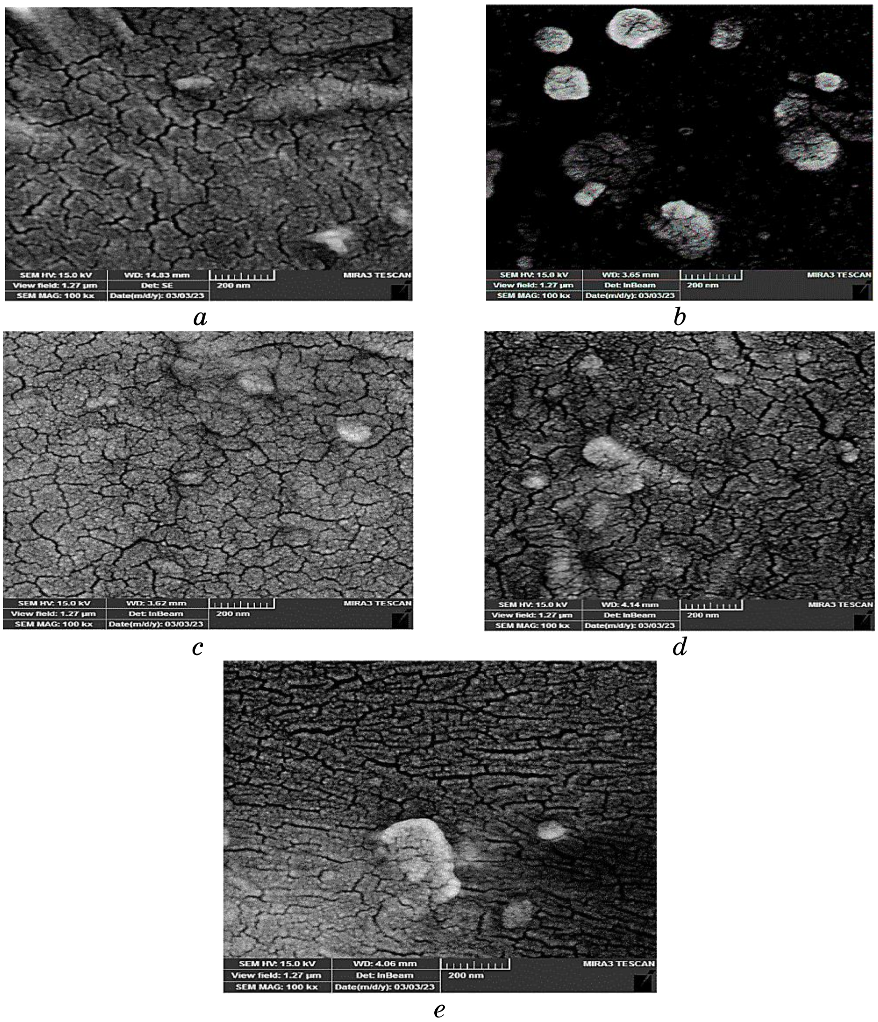

Fig. 2. SEM images for PMMA/PEO/SiC/$BaTiO_3$ nanostructures: (*a*) blend; (*b*) 1.6 wt.% SiC/$BaTiO_3$ NPs; (*c*) 3.2 wt.% SiC/$BaTiO_3$ NPs; (*d*) 4.8 wt.% SiC/$BaTiO_3$ NPs; (*e*) 6.4 wt.% SiC/$BaTiO_3$ NPs.

When the SiC/$BaTiO_3$ NPs ratio increases, the SiC/$BaTiO_3$ NPs form path connect inside the PMMA/PEO matrix.

The SEM images demonstrate that the surface of PMMA/PEO/SiC/$BaTiO_3$ nanostructures' films becomes more softer with a rise of nanoparticles' ratio [22–28].

Figures 3 and 4 represent the antibacterial activity of the PMMA/PEO/SiC/$BaTiO_3$ nanostructures against gram-negative (*Escherichia coli*) and gram-positive (*Staphylococcus aureus*) bacte-

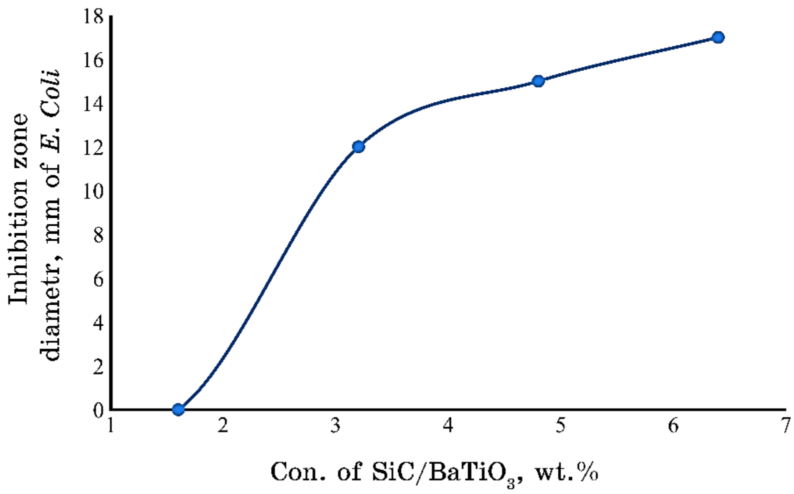

Fig. 3. Inhibition-zone diameter of PMMA/PEO/SiC/$BaTiO_3$ nanostructures against *Escherichia coli*.

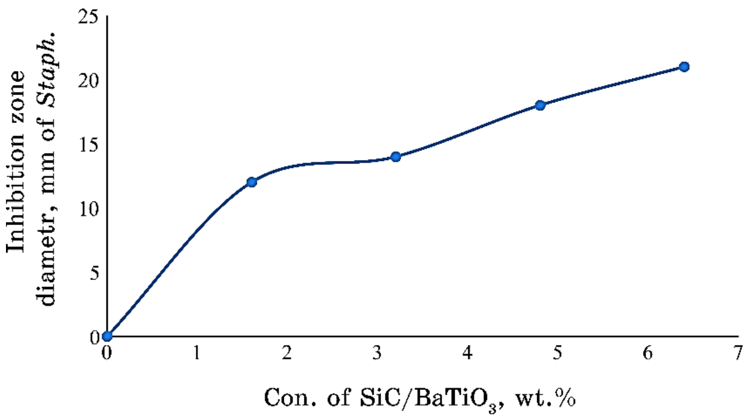

Fig. 4. Inhibition-zone diameter of PMMA/PEO/SiC/$BaTiO_3$ nanostructures against *Staphylococcus aureus*.

ria. The inhibition area enhances with increasing ratio of SiC/$BaTiO_3$ NPs. Polymers can be rendered antimicrobial by various technologies, such as ionizing radiation; however, they can still become polluted by microbes, while being used, melt mixing of polymers with antibacterial chemicals is the favourer method to get antibacterial polymers.

The major method that caused the antibacterial activity of nanostructures by the SiC/$BaTiO_3$ NPs might be through oxidative stress reason by ROS. ROS include radicals like superoxide radicals

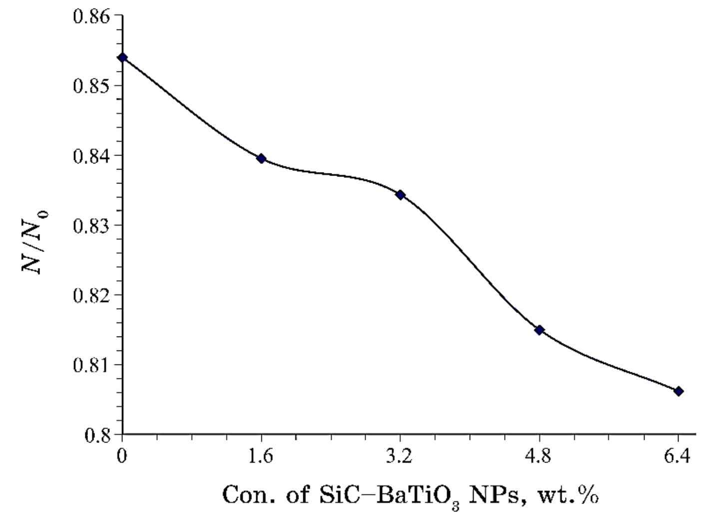

Fig. 5. Variance of N/N_0 for PMMA/PEO medium with different concentrations of SiC/$BaTiO_3$ NPs.

(O^{-2}), hydroxyl radicals (–OH) and hydrogen peroxide (H_2O_2); singlet oxygen ($^1O_2$) could be the cause spoilage the proteins and DNA in the bacteria. ROS could have been generated from the existent the PMMA/PEO/SiC/$BaTiO_3$ leading to the inhibition of most pathogenic bacteria like *Escherichia coli* and *Staphylococcus aureus*. It is found from the results that a high effectiveness of the samples was against gram-positive bacteria (*Staphylococcus aureus*) than gram-negative bacteria (*Escherichia coli*) on nanoparticles. This is because of a thick cell wall of the gram-positive bacteria consist of many layers of peptidoglycan than thin cell wall of gram-negative bacteria including little layers of peptidoglycan [29–39].

Figure 5 illustrates the change of N/N_0 for the PMMA/PEO/SiC/$BaTiO_3$ nanostructures with different amount of SiC/$BaTiO_3$ NPs. The transmission radiation is reduced with the rise of the content of SiC/$BaTiO_3$ NPs that is imputed to the raise of the attenuation radiation.

Figure 6 depicts the attenuation coefficient for the PMMA/PEO/SiC/$BaTiO_3$ nanostructures with various ratios of SiC/$BaTiO_3$ NPs. The attenuation coefficient rises with increasing SiC/$BaTiO_3$ NPs. This is because shielding materials are made of nanostructures, which either absorb or reflect gamma-rays [40–46].

4. CONCLUSIONS

This work includes fabrication of PMMA/PEO/SiC/$BaTiO_3$

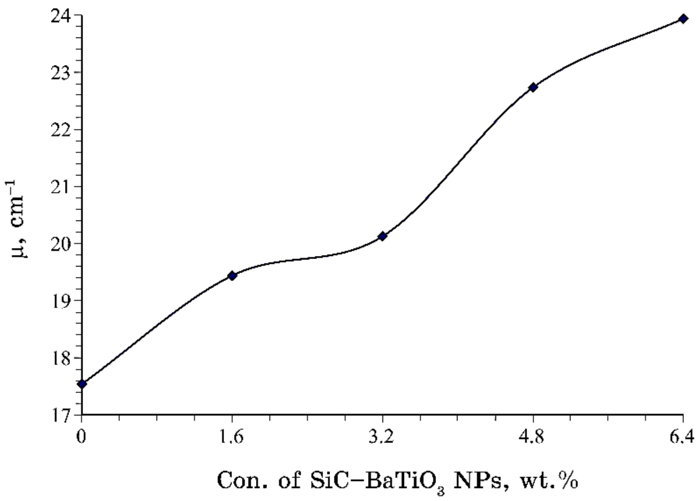

Fig. 6. Variance of attenuation coefficient for the gamma-radiation in PMMA/PEO medium with different concentrations of SiC/$BaTiO_3$ NPs.

nanostructures to use as a radiation shielding and in antibacterial applications with low-weight, good flexibility, good processability, having good gamma-ray attenuation coefficients as well as high effectiveness for antibacterial applications. The results demonstrated that the attenuation coefficient of PMMA/PEO/SiC/$BaTiO_3$ nanostructures enhanced by rising of SiC/$BaTiO_3$ NPs. The antibacterial results show that the PMMA/PEO/SiC/$BaTiO_3$ nanostructures have antibacterial effectiveness for gram-positive and gram-negative organisms. Therefore, the new PMMA/PEO/SiC/$BaTiO_3$ nanostructures can be employed as a radiation shielding material as well as an antibacterial agent for use in medical and environmental applications.

REFERENCES

1. M. J. Hajipour, K. M. Fromm, A. Akbar Ashkarran, D. Jimenez de Aberasturi, I. R. d. Larramendi, T. Rojo, V. Serpooshan, W. J. Parak, and M. Mahmoudi, *Trends in Biotechnology*, **30**, No. 10: 499 (2012); https://doi.org/10.1016/j.tibtech.2012.06.004
2. M. Yousefi, M. Dadashpour, M. Hejazi, M. Hasanzadeh, B. Behnam, M. de la Guardia, N. Shadjou, and A. Mokhtarzadeh, *Materials Science and Engineering: C*, **74**: 568 (2017); https://doi.org/10.1016/j.msec.2016.12.125
3. U. Meyer-Hoffert, M. W. Hornef, B. Henriques-Normark, L. G. Axelsson, T. Midtvedt, K. Pütsep, and M. Andersson, *Gut.*, **57**, No. 6: 764 (2008); doi:10.1136/gut.2007.141481
4. A. Mobed, M. Hasanzadeh, and F. Seidi, *RSC Advances*, **11**, No. 55: 34688

(2021).
5. A. J. Huh and Y. J. Kwon, *Journal of Controlled Release*, **156**, No. 2: 128 (2011); https://doi.org/10.1016/j.jconrel.2011.07.002
6. Z. Li, W. Zhou, X. Su, F. Luo, D. Zhu, and P. Liu, *Journal of the American Ceramic Society*, **91**, No. 8: 2607 (2008).
7. A. Fattah-alhosseini, M. Molaei, N. Attarzadeh, K. Babaei, and F. Attarzadeh, *Ceram. Int.*, **46**, No. 13: 20587 (2020); https://doi.org/10.1016/j.ceramint.2020.05.206
8. M. Farea, A. Abdelghany, and A. Oraby, *RSC Advances*, **10**, No. 62: 37621 (2020).
9. A. E. Tarabiah, H. A. Alhadlaq, Z. M. Alaizeri, A. A. A. Ahmed, G. M. Asnag, and M. Ahamed, *J. of Polymer Research*, **29**, No. 5: 167 (2022); doi:10.1007/s10965-022-03011-8
10. M. O. Farea, A. M. Abdelghany, M. S. Meikhail, and A. H. Oraby, *J. of Mater. Res. and Techno.*, **9**, No. 2: 1530 (2020); https://doi.org/10.1016/j.jmrt.2019.11.078
11. B. Jiang, J. Iocozzia, L. Zhao, H. Zhang, Y.-W. Harn, Y. Chen, and Z. Lin, *Chem. Society Reviews*, **48**, No. 4: 1194 (2019); doi:10.1039/C8CS00583D
12. T. T. M. Phan, N. C. Chu, V. B. Luu, H. Nguyen Xuan, D. T. Pham, I. Martin, and P. Carrière, *J. of Sci.: Adv. Mater. and Dev.*, **1**, No. 1: 90 (2016); https://doi.org/10.1016/j.jsamd.2016.04.005
13. Y. N. Yoon, D.-S. Lee, H. J. Park, and J.-S. Kim, *Scientific Reports*, **10**, No. 1: 2560 (2020); doi:10.1038/s41598-020-59445-x
14. A. Marino, E. Almici, S. Migliorin, C. Tapeinos, M. Battaglini, V. Cappello, M. Marchetti, G. de Vito, R. Cicchi, F. S. Pavone, and G. Ciofani, *J. of Colloid and Interface Sci.*, **538**: 449 (2019); https://doi.org/10.1016/j.jcis.2018.12.014
15. S. Wang, X. Zhao, J. Qian, and S. He, *RSC Advances*, **6**, No. 46: 40615 (2016).
16. Y. Bai, X. Dai, Y. Yin, J. Wang, X. Sun, W. Liang, Y. Li, X. Deng, and X. Zhang, *Int. J. of Nanomedicine*, **14**: 3015 (2019); doi:10.2147/IJN.S197824
17. 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
18. H. Ahmed and A. Hashim, *Silicon*, **13**: 4331 (2020); https://doi.org/10.1007/s12633-020-00723-8
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, *International Journal of Scientific & Technology Research*, **8**, Iss. 11: 1014 (2019).
21. H. Ahmed and A. Hashim, *Silicon*, **14**: 6637 (2022); https://doi.org/10.1007/s12633-021-01449-x
22. W. O. Obaid and A. Hashim, *Silicon*, **14**: 11199 (2022); https://doi.org/10.1007/s12633-022-01854-w
23. O. B. Fadil and A. Hashim, *Silicon*, **14**: 9845 (2022); https://doi.org/10.1007/s12633-022-01728-1
24. M. H. Meteab, A. Hashim, and B. H. Rabee, *Silicon*, **15**: 251 (2023); https://doi.org/10.1007/s12633-022-02020-y
25. A. Hashim, A. Hadi, and M. H. Abbas, *Opt. Quant. Electron.*, **55**: 642

(2023); https://doi.org/10.1007/s11082-023-04929-z
26. A. Hashim, A. Hadi, and M. H. Abbas, *Silicon*, **15**: 6431 (2023); https://doi.org/10.1007/s12633-023-02529-w
27. M. H. Meteab, A. Hashim, and B. H. Rabee, *Opt. Quant. Electron.*, **55**: 187 (2023); https://doi.org/10.1007/s11082-022-04447-4
28. M. H. Meteab, A. Hashim, and B. H. Rabee, *Silicon*, **15**: 1609 (2023); https://doi.org/10.1007/s12633-022-02114-7
29. M.Venkatarayappa, S. Kilarkaje, A. Prasad, and D. Hundekal, *Journal of Materials Science and Engineering. A*, **1**, No. 7A: 964 (2011).
30. S. Sun, Y. Wang, L. Wang, Y. Bai, and L. Ding, *Polymer Science, Series B*, **59**, No. 5: 630 (2017); doi:10.1134/S156009041705013X
31. T. K. Mowade, S. P. Dange, M. B. Thakre, and V. D. Kamble, *J. Adv. Prosthodont.*, **4**, No. 1: 30 (2012); doi:10.4047/jap.2012.4.1.30
32. S. K. Modak, A. Mandal, and D. Chakrabarty, *Polymer Composites*, **34**, No. 1: 32 (2013); https://doi.org/10.1002/pc.22374
33. A. Hashim, I. R. Agool, and K. J. Kadhim, *Journal of Bionanoscience*, **12**, No. 5: 608 (2018); doi:10.1166/jbns.2018.1580
34. 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
35. 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
36. O. B. Fadil and A. Hashim, *Nanosistemi, Nanomateriali, Nanotehnologii*, **20**, Iss. 4: 1029 (2022); https://doi.org/10.15407/nnn.20.04.1029
37. W. O. Obaid and A. Hashim, *Nanosistemi, Nanomateriali, Nanotehnologii*, **20**, Iss. 4: 1009 (2022); https://doi.org/10.15407/nnn.20.04.1009
38. 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
39. 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
40. M. Roy, Bajpai, J. A. K. Bajpai, and R. G. Mahloniya, *Advanced Materials Letters*, **3**, No. 5: 426 (2012); doi:10.5185/amlett.2012.6373
41. G. A. Eid, A. Kany, M. El-Toony, I. Bashter, and F. Gaber, *Arab. J. Nucl. Sci. Appl.*, **46**, No. 2: 226 (2013).
42. A. Hashim and N. Hamid, *Journal of Bionanoscienc*e, **12**, No. 6: 788 (2018); doi:10.1166/jbns.2018.1591
43. A. Hashim and Z. S. Hamad, *Journal of Bionanoscience*, **12**, No. 4: 488 (2018); doi:10.1166/jbns.2018.1551
44. A. Hashim and Z. S. Hamad, *Journal of Bionanoscience*, **12**, No. 4: 504 (2018); doi:10.1166/jbns.2018.1561
45. 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
46. K. H. H. Al-Attiyah, A. Hashim, and S. F. Obaid, *Journal of Bionanoscience*, **12**: 200 (2018); doi:10.1166/jbns.2018.1526