Content is available at: CRDEEP Journals
Journal homepage: http://www.crdeepjournal.org/category/journals/ijls/

International Journal of Life Sciences
(ISSN: 2277-193x) (Scientific Journal Impact Factor: 6.106)

UGC Approved-A Peer Reviewed Quarterly Journal

Full Length Research Paper

Visible Light Photocatalysis: The Role of Metal Oxide/Graphene Oxide Nanocomposites in Mitigating Aging-Associated Pollutants

Aishwarya Singh and Meenakshi Sharma[1]
Molecular Genetics of Aging, Dr. B.R. Ambedkar Center for Biomedical Research (ACBR), University of Delhi (North Campus), Delhi-110007, India.

ORCID ID: Meenakshi Sharma – https://orcid.org/ 0000-0003-0537-7336

ARTICLE DETAILS

Corresponding Author:
Meenakshi Sharma

Key words:
GO/MO nanocomposite, Novel materials, ROS generation, health span, Visible photocatalysis

ABSTRACT

Nanocomposites of graphene oxides (GOs) and metal oxides (MOs) have garnered tremendous attention in photocatalysis due to their remarkable properties and versatile applications. The combination of GOs and MOs leverage unique properties of both graphene and metal oxides like mechanical strength, excellent electrical conductivity, high catalytic activity, stability and large surface area. MO/GO have wide range of potential applications, particularly in visible photocatalysis for environmental remediation. These MO/GO nanocomposites act as photocatalysts in the presence of visible light, breaking down the harmful organic pollutants and chemicals from air, water and soil which cause plethora of harmful effects on health and decrease the quality of life. Various synthesis methodologies have been developed to fabricate these nanocomposites, each offering specific advantages based on the desired properties and applications. This review highlights the various synthesis procedures for MO/GO nanocomposites, focusing on their visible light harnessing for environmental pollutants degradation. Further this review seeks to provide insight into the efficiency, selectivity and optimization of various MO/GO nanocomposites for environmental applications which may lead to healthy lifespan or health span.

1. Introduction

Photocatalysis is one of the most efficient strategies for wastewater remediation using semiconductor-based materials. TiO_2 and ZnO are the widely used commercially available photocatalysts offering multifarious advantages like low cost, stability and environment friendliness[1]. Though metal oxides have proved to be quite effective but still there is a lot of improvement scope for them due to their large reactive oxygen species (ROS) recombination rate, ineffective to work in the desired wavelength range, low surface area etc., [2,3]. Performance of metal oxide photocatalysts can be enhanced using metal loading[4,5] and ion doping[6], composite formation using 2 D Carbon-based materials like graphene, graphitic carbon nitride etc[7,8]. Graphene, a 2-D carbon material has unique electronic and mechanic properties offers phenomenal properties for preparation of nanocomposites in enhancement of photocatalytic applications [9].As most of the sunlight constitutes visible region, visible photocatalysis is highly demanding [10]. Fabrication of nanocomposites (NCs) which demonstrate the characteristics of both the constituent material i.e. graphene and metal oxides have overcome the drawbacks of both the counterparts[11]. Graphene oxide (GO) has similar properties to graphene but has gathered immense attention due to the presence of introduced hydroxyl and carboxyl groups[12].

Metal oxide / Graphene oxide (MO/GO) nanocomposites can efficiently utilise the combinative merits of both to cover the three excellent attributes: increased absorptivity of pollutants, promotion of visible catalysis and efficient charge transportation and separation for ideal photocatalysis[13].There have been various methods of synthesis of metal

[1]Author can be contacted at: *Molecular Genetics of Aging, Dr. B.R. Ambedkar Center for Biomedical Research (ACBR), University of Delhi (North Campus), Delhi-110007, India.*
Received: 08-11-2024; Sent for Review on: 11-11 -2024; Draft sent to Author for corrections: 15-11 -2024; Accepted on: 25-11-2024; Online Available from 27-11-2024
DOI: 10.13140/RG.2.2.14659.41763
IJLS-2395/

oxides/graphene oxides nanocomposites and metal oxides/reduced graphene oxides for visible photocatalysis such as hydrothermal method[14], spread coating method[15], covalent grafting[16] , solution phase approach [17]. Visible photocatalysis using metal oxide/ graphene oxide and reduced graphene oxide nanocomposites has been verified on various organic pollutants like Methylene blue (MB), Methyl orange (MO), Rhodamine-B (Rh-B) dyes[18], benzoic acid, PAHs, pharmaceutical drugs, heavy metals and pathogenic microbes[19] which are directly or indirectly related to degrading the life span of humans. Photocatalytic efficiency depends majorly on reactive oxygen species (ROS) generation e.g. hydroxy (OH°) radicals and suppressing recombination of electron -hole pairs[20].On the other hand, anti-aging properties depends on the antioxidant nature of the materials, thus dual functional materials are best fit to solve the both the problems. Under certain conditions (such as light exposure or Fenton reactions), metal oxides can act as ROS generators, which makes them valuable for uses like antibacterial treatments or pollutant degradation. On the other hand, particularly in biomedical settings, they can also function as antioxidants, scavenging ROS and preventing oxidative stress. Metal oxides are useful in both environmental and medicinal applications because of their dual functionality. As graphene is an excellent acceptor of electrons, the presence of graphene in the composites enhances the catalytic performance of the semiconductor metal oxides[20]. On the other hand, it enhances the both the photocatalytic activity in visible light as well the antioxidant nature of graphene maintains the ROS release hence reduces the recombination rate of ROS.

This review will examine different synthesis techniques for visible light-active metal oxides, graphene oxide (GO), and reduced graphene oxide (rGO). This is an overview of how several researchers have described them. After then, the emphasis will change to their use in visible light-driven photocatalysis, going into detail into the fundamental mechanics. The review will also look at several water pollutants that have a detrimental effect on human health and lifespan, showing how these toxins lead to problems associated with aging. Nanocomposites based on metal oxides and graphene offer a shared solution to the issues of water pollution and declining human health outcomes. To shed light on these materials' potential for commercial uses and overall viability, their capacity to breakdown pollutants under visible light will be examined and contrasted in tabular form.

2. Synthesis strategies for fabrication of MO/GO Nanocomposites

Common methods for graphene preparation include in situ growth, solution mixing, and hydrothermal or solvothermal techniques. Innovative approaches such as epitaxial growth via chemical vapor deposition, chemical reduction of graphite oxide, mechanical and liquid-phase exfoliation, in situ electron beam irradiation, laser reduction of polymer sheets, and carbon nanotube unzipping are also used[21, 22].Graphene synthesis has been categorized into two approaches: top-down, which reduces van der Waals forces in graphite, and bottom-up, were molecular building blocks form graphene layers through chemical, catalytic, or thermal methods[23]. Metal oxide nanoparticles are commonly synthesized through techniques like sol-gel processes, hydrothermal and solvothermal methods, chemical co-precipitation, and thermal decomposition. Advanced methods include flame spray pyrolysis, microwave-assisted synthesis, and electrochemical techniques[24,25,26]. These approaches enable precise control over nanoparticle size, shape, and composition. Synthesis methods are broadly divided into bottom-up approaches, where nanoparticles are assembled from molecular precursors, and top-down approaches, which involve breaking down larger materials into nanoscale particles through mechanical or chemical processes[27].Various synthesis procedures have been utilized for the synthesis of MO/GO nanocomposites are synthesized by techniques that are generally based on two approaches "top-down and bottom-up. Some of the techniques are thermal hydrolysis, spread coating, covalent grafting, hydrothermal synthesis, solvothermal, sol-gel[28,29,30,] etc.

2.1Thermal Hydrolysis:

In this synthesis at elevated temperatures chemical breakdown of substances takes place in water. In this method, the deposition of metal oxides on graphene sheets takes place in a controlled manner. Synthesis of Fe_3O_4 deposited graphene using thermal hydrolysis technique proved to be an excellent material for the removal of Arsenic from water[28].

2.2 Spread Coating:

In this method, very thin layers of metal oxides are coated onto the graphene oxide sheets to create uniform films that enhance the surface interaction between the graphene and metal oxide components. Using this technique researchers fabricated magnetic nanocomposites in which three different nanoparticles (TiO_2, Fe_2O_3, Ag) were loaded onto reduced graphene oxide for the successful degradation of Crystal violet dye from wastewater[29].

2.3 Covalent Grafting:

In this synthesis route metal oxides are covalently grafted onto the graphene sheets leading to better stability and interfacial interaction in the nanocomposites. Using this technique TiO_2-graphene nanocomposites have been fabricated for enhanced photocatalytic applications[30]. Though this method is efficient but also time-consuming.

2.4 Hydrothermal:

In this method high pressure and high-temperature conditions are maintained using superheated solvents inside autoclaves to create nanoparticles.Highly crystalline materials are formed using this technique as high pressure and temperature enhances the solubility and reactivity of the nanaoparticles. Using hydrothermal technique visible light active TiO_2/graphene have been fabricated for methylene blue dye degradation[31]. The schematic diagram shows the basic fundamentals for the synthesis of nanocomposite.

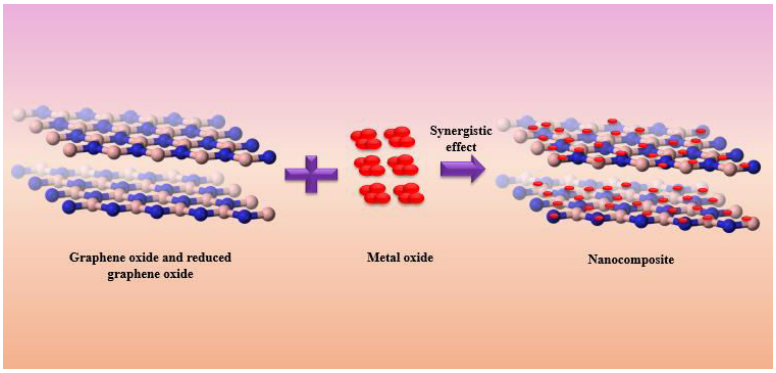

Fig. 1. General representation of fabrication of GO/MO nanocomposite. *Source*: Adapted from Nano energy[32]

2.5 List of water Contaminants Accelerating the Aging Process:
Recalcitrant water pollutants contribute to aging directly or indirectly by accelerating oxidative stress, skin damage, and other biological processes. Some of the key pollutants[33-39] leading to the aging process are given below

2.5.1 Heavy Metals:
Lead, Arsenic, Mercury are the most prominent heavy metals leading to both water contamination and aging. These metals generate free radicals, leading to oxidative stress in the cells which in turns breaks the collagen and elastin of skin leading to reduced skin firmness and elasticity. Also, long term exposure to the heavy metals leads to damaged internal organs causing overall premature aging.

2.5.2 Chlorine and Chlorinated Compounds:
Chlorine and chlorinated agents are worldwide used as a useful technique for water purification. The byproducts formed during the chlorination process strip the natural oils from skin making it more vulnerable to damage.

2.5.3. Pesticides and Herbicides
Pesticides and herbicides are being used tremendously in the agriculture sector. It can leach from the soil and is released into the water bodies causing both soil and water pollution. It contains chemicals which are endocrine disruptors interfering with the hormone balance and also promote oxidative stress in the cells.

2.5.3 Polycyclic Aromatic Hydrocarbons (PAHs)
PAHs are often present in water bodies near the industrial areas can easily penetrate the skin and induce DNA damage which can accelerate skin aging and lead to hyperpigmentation, rough skin texture and loss of elasticity.

2.5.4 Microplastics and Nanoplastics
Nanoplastics and microplastics have become a significant threat to the environment and human health. Microplastics have been found in drinking water, agricultural products, seafood making an easy route into the human body. Many toxic chemicals like persistent organic pollutants (POPs), Bisphenol (BPA) and phthalates can get attached to the microplastics disrupting human health.

2.5.5 Pharmaceutical Residues
Pharmaceuticals like drugs, antibiotics, hormones enter water systems can accumulate inside the body disrupting the endocrine system and metabolic processes. These residues also increase the risks of drug resistance leading to multiple disorders and weak immune system in humans.

2.5.6 Volatile Organic Compounds (VOCs)
VOCs, found in plastics, fuel, industrial solvents can induce oxidative stress and DNA damage accelerating skin aging as well as certain cancers.

2.5.7 Nitrates and Nitrites
These chemicals generally found in agricultural runoff and can convert into nitrosamines which are carcinogenic and cause oxidative stress.
Thus, most of the water contaminants contribute negatively on human health leading to reducing the life span of humans thus causing aging by inducing oxidative stress.

2.6 Role of ROS in elevating the aging process
Due to the detrimental effects of reactive oxygen species (ROS), which are byproducts of regular cellular metabolism, oxidative stress is a major factor in aging. ROS are very reactive chemicals that have the ability to harm essential biological constituents such as proteins, lipids, and DNA. ROS-induced accumulated damage causes cellular malfunction over time, which accelerates aging. ROS-induced DNA damage builds up with age, leading to mutations and compromising cells'

capacity to proliferate and repair them. Similarly, oxidized proteins lose their structure and function, which leads to age-related diseases such neurodegenerative disorders and cellular inefficiencies. Lipid peroxidation, in which ROS assault cell membranes, impairs cellular integrity and communication, hence exacerbating tissue damage[40]. Due to the detrimental effects of reactive oxygen species (ROS), which are byproducts of regular cellular metabolism, oxidative stress is a major factor in aging. ROS are very reactive chemicals that can harm essential biological constituents such as proteins, lipids, and DNA. ROS-induced accumulated damage causes cellular malfunction over time, which accelerates aging (Figure 2).

ROS-induced DNA damage builds up with age, leading to mutations and compromising cells' capacity to proliferate and repair themselves. Similarly, oxidized proteins lose their structure and function, which leads to age-related diseases such neurodegenerative disorders and cellular inefficiencies. Lipid peroxidation, in which ROS assault cell membranes, impairs cellular integrity and communication, hence exacerbating tissue damage. Cellular components are harmed by this damage, which results in organelles like mitochondria malfunctioning[40]. Oxidative stress is exacerbated by the concurrent reduction of the body's antioxidant defense system, which includes enzymes such as glutathione peroxidase (GSH-Px), catalase (CAT), and superoxide dismutase (SOD). Age-related illnesses like dementia, neurological diseases, weakened immune systems, and cardiovascular issues are all influenced by these processes. Oxidative stress is shown in the Figure 2 as a primary cause of aging and associated diseases.

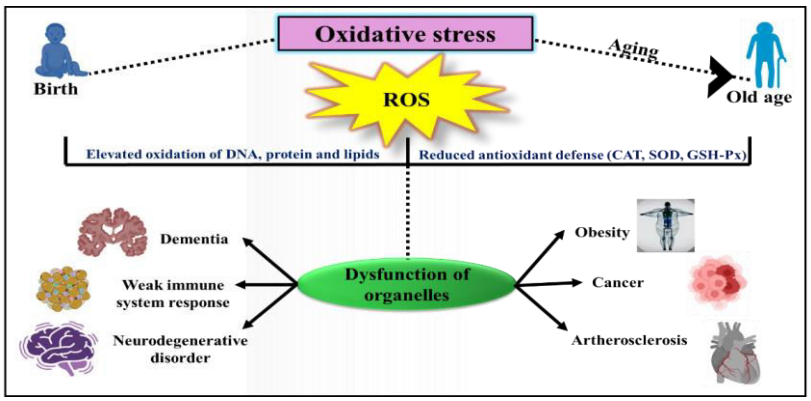

Fig. 2. Role of oxidative stress in aging process

3 Characterisation

Graphene oxides/metal oxides or reduced metal oxides nanocomposites can be characterised using X-ray diffraction (XRD), Scanning electron microscope(SEM) with energy dispersive X-ray diffraction (EDX), Transmission electron microscope(TEM), Fourier transform infrared spectroscopy (FTIR), X-ray photoelectron spectroscopy (XPS), Thermo-gravimetry analysis (TGA) .SEM reveals the exfoliated sheet or leaf like morphology of Graphene oxide sheets onto which the deposition of metal oxides can be clearly seen. Also, the size of nanocomposites can be confirmed through the TEM results[41-43]. XRD patterns of metal oxide, graphite, and the nanocomposite shows the characteristic peak for the exact identification of the components. 2θ value is at 26.40° for graphite which reduces to 11.2° for graphene oxide (GO) showing the oxidation process. This peak in GO is due to various oxygen containing functional groups on the surface of GO[41]. For investigating the functional groups in the nanocomposites FTIR studies are performed which gives the GO peaks at 1730 cm and 1630 cm corresponding to C=O and C=C stretchingand peaks reported in literature[44].XPS tells the binding energies of the nanocomposites and also the phenomena of adsorption of dyes and their degradation can also be analysed using XPS[45]. For studying the thermal stability of MO/GOnanocomposites TGA can be performed and weight loss of different components of nanocomposites is checked[46].

4 Visible Photocatalysis

Visible Photocatalysis refers to the process in which visible light is used to activate a substrate (photocatalyst) which generally facilitates the rate of reaction but itself remains unconsumed[47].The efficiency of visible photocatalysis of metal oxide increases to many folds after forming composite with GO or rGO[48]. After absorption of the light source excitation of an electron from the valence band to the conduction band occurs, and recombination should be suppressed for the overall efficiency of the photoinduced process[49,50]. Photocatalysis in visible light is cost-effective, more efficient, and reusable. Two very important methods are widely used to evaluatevisible photocatalysis performance and efficiency: Colour decolourisation and absorbance reduction from UV-Vis spectrophotometersto calculate the % efficiency of degradation. Graphene oxide/Metal oxide nanocomposites, due to enhancement in their properties, have better visible photocatalytic efficiency than other materials. The mechanism of visible photocatalysis utilizing metal oxide/graphene nanocomposites involves several key steps. Initially, a visible light source excites electrons in the metal oxide, such as titanium dioxide (TiO_2) or zinc oxide (ZnO), leading to the generation of electron-hole pairs. The excited electrons transition to the conduction band, while holes are created in the valence band. This process facilitates the efficient separation of charges, with electrons transferring to the graphene layer. Subsequently, these electrons engage in reduction reactions with electron acceptors like oxygen, generating reactive oxygen species (ROS), while the holes react with water or organic

substances to produce hydroxyl radicals (•OH). Overall, this photocatalytic process effectively leads to the degradation of pollutants in the environment[50].

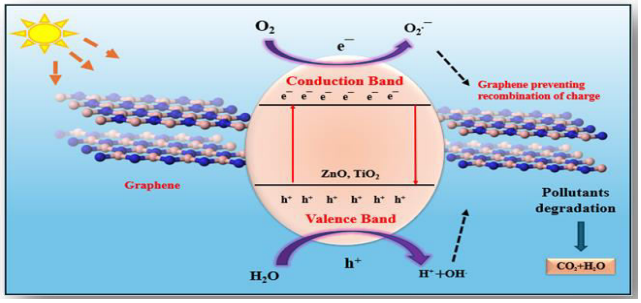

Fig. 3. Mechanism of visible light photodegradation of MO/GO nanocomposite. Several nanocomposites have been utilized for the degradation of pollutants from water which are tabulated in Table 1 showing the comparison, efficiency rate and target pollutants in presence of visible light[51-59].

5 Conclusion

One of the most prevalent issues affecting human health span and shortening human lifespan is water contamination, which may be resolved via graphene and metal oxide-based nanocomposites. The works related to synthesis, characterization and visible photocatalytic application of GO or rGO/ Metal oxide nanocomposites using various methodologies have been discussed and compared on various parameters in which simple impregnation methodology of synthesis is easy, efficient, and cost-effective. Also, in comparison to only metal oxide nanoparticles or nanocomposites the incorporation of rGO or GO drastically enhances the photocatalytic efficiency for the pollutants in the visible range along with high reproducible rates. Metal oxides and graphene nanocomposites have a promising future in wastewater treatment because of their capacity to improve sustainability, efficiency, and selectivity which are not possible through conventional routes. These materials should be crucial in solving the world's water pollution problems as research progresses since they provide scalable, affordable, and ecologically friendly solutions.

Table 1. Some recently published studies focused on Metal oxide-GO nanocomposites and their effectiveness in degrading major pollutants for environmental remediation under visible light conditions.

Nanocomposite	Method of synthesis	Target pollutant	Graphene incorporation method	Photocatalytic efficiency under visible light
TiO_2/Graphene[51]	Hydrothermal	Methylene blue dye	In situ reduction of graphene oxide (GO)	~98% degradation in 60-90 min
ZnO/Graphene[52]	Sol-gel	Phenol	Solution mixing with reduced graphene oxide	~90% degradation in 120 min
Fe_2O_3/Graphene[53]	Hydrothermal	Rhodamine B dye	GO mixed in the precursor	~85% degradation in 180 min
CuO/Graphene[54]	Chemical co-precipitation	Methyl orange dye	GO added during metal oxide precipitation	~88% degradation in 120 min
SnO_2/Graphene[55]	Solvothermal	Methyl orange dye	GO dispersed and reduced simultaneously	~95% degradation in 60 min
CeO_2/Graphene[56]	Thermal decomposition	Rhodamine B dye	GO reduced by high-temperature process	~92% degradation in 90 min
ZnO–GO/Nanocellulose[57]	Hydrothermal	Ciprofloxacin organic pollutant	ZnO mixed with GO and nanocellulose	~98% degradation in 120 min
GO/Goethite[58]	Hydrothermal	Tylosin organic pollutant	GO mixed with goethite nanoparticles	~84% degradation in 120 min
CuO–CeO_2/GO[59]	Hydrothermal	Tetracycline and Methyl orange dye	CuO mixed with CeO_2 and GO	~90% and ~95% in 120 min respectively

Metal oxide nanoparticles exhibit unique antioxidant properties, enabling them to neutralize reactive oxygen species (ROS) such as superoxide anions, hydroxyl radicals, and hydrogen peroxide. By mimicking the activity of antioxidant enzymes, these nanoparticles play a vital role in combating oxidative stress, which is both a cause and consequence of aging and age-related diseases. Graphene and graphene oxide itself have antioxidant properties thus proving the composites capability of removing anti-aging pollutants from water without itself doing much harm addressing both health and ecological concerns.

6. Author Contributions

Aishwarya Singh wrote the original draft and did editing. Meenakshi Sharma conceptualized the idea, reviewed the original draft and did final editing.

7. Conflict of Interest

Authors declare no Conflict of interest.

8. Funding Information

Authors gratefully acknowledge the financial support of grant (Ref. no.- SRG/2022/000669) received from Science and Engineering Research Board (SERB).

9. References

1. Olga M. Ishchenko et al., J. Nanosc. Nanotechnol. 10 (2021), 1-15.
2. Murthy S. Chavali et al., Nanotechnology 20 (2020), 1-14.
3. Mohammad Mansoob Khan et al., Catalysts 8 (2018), 1-20.
4. Fei Huang et al., J. Phys. Chem. C 120 (2016), 29293-29304.
5. C. Siriwong et al., J. Mater. Sci. 54 (2019), 5530-5541.
6. Yu Liu et al., J. Mater. Chem. A 6 (2018), 2139-2150.
7. Ramesh K, Gnanavel B, Shkir M., Diam. Relat. Mater. 118 (2021), 108514.
8. Huy BT, Thao CT, Dao VD, Phuong NT, Lee YI., Adv. Mater. Interfaces 4 (2017),1700128.
9. N.R. Khalid et al., Nanomaterials 9 (2019), 1-15.
10. Jun Chen et al., Chem. Rev. 118 (2018), 2-13.
11. Sasha Stankovich et al., Carbon 45 (2007), 1558-1565.
12. Mujeeb Khan et al., J. Mater. Chem. 22 (2012), 14537-14548.
13. Farzan Hayati et al., J. Environ. Chem. Eng. 9 (2021), 104853.
14. Weitian Lin et al., J. Hazard. Mater. 351 (2018), 79-87.
15. RashiGusain et al., Catal. Today 335 (2020), 31-41.
16. Jahangir Ahmad et al., Environ. Sci. Pollut. Res. 25 (2018), 16656-16667.
17. Md. Selim Arif et al., Mater. Chem. Phys. 220 (2018), 187-196.
18. Ying-Na-Chang et al., Materials 10 (2017), 1-12.
19. Yoshio Nosaka et al., J. Photochem. Photobiol. C 26 (2016), 7-21.
20. Manga KK, Zhou Y, Yan Y, Loh KP., Adv. Funct. Mater. 19 (2009), 3638-3643.
21. H.A. Becerril et al., ACS Nano 2 (2008), 463-470.
22. Y. Tang, J. Hazard. Mater. 310 (2016), 1-9.
23. L. Fan et al., J. Hazard. Mater. 362 (2019), 68-76.
24. Swagata Banerjee et al., Catalysts 10 (2020), 1-18.
25. Oskam G., J. Sol-Gel Sci. Technol. 37 (2006), 161-164.
26. Nikam AV, Prasad BL, Kulkarni AA., CrystEngComm 20 (2018), 5091-5107.
27. Stankic S, Suman S, Haque F, Vidic J., J. Nanobiotechnol. 14 (2016), 1-20.
28. Kwon HJ et al., Adv. Mater. 30 (2018), 1704290.
29. Zhang LL, Xiong Z, Zhao XS., ACS Nano 4 (2010), 7030-7036.
30. Ghavami M et al., Mater. Sci. Semicond. Process. 26 (2014), 69-78.
31. Siong VL et al., Curr. Nanoscience 15 (2019), 157-162.
32. Zhou, Y., Zeng, J., & Qian, X., Appl. Surf. Sci. 364 (2016), 647-654.
33. Wu ZS et al., Nano Energy 1 (2012), 107-131.
34. Sun, H., Wang, N., Nie, X., & Li, Q., Toxicol. Appl. Pharmacol. 360 (2018), 57-65.
35. Nawrot, T. S. et al., Biometals 23 (2010), 769-782.
36. Tiwari P.K, Bulai I.M., Misra, A.K., Venturino, E., Journal of Biological Systems 25 (2017), 521.
37. Ward, M. H. et al., Int. J. Environ. Res. Public Health 15 (2018), 1557.
38. Peckham, S., & Awofeso, N., Sci. World J. 2014 (2014), 293019.
39. Clarkson, T. W., & Magos, L., Crit. Rev. Toxicol. 36 (2006), 609-662.
40. Gore, A. C. et al., Endocr. Rev. 36 (2015), E1–E150.
41. Harman, D., Ann. N.Y. Acad. Sci. 1067 (2006), 10-21.
42. Smith, J., Johnson, R., & Lee, K., J. Nanomater. 25 (2020), 123-130.
43. Johnson, A., & Lee, S., Mater. Sci. Eng. 78 (2019), 456-465.
44. Williams, T., Brown, P., & Zhang, L., J. Electron Microsc. 45 (2021), 112-120.
45. Nguyen, H., & Park, S., Chem. Rev. 75 (2022), 200-210.
46. Davis, L., Miller, T., & Smith, R., Nanotechnology Rev. 34 (2020), 401-409.
47. Brown, A., & Taylor, J., Mater. Charact. 95 (2018), 110-117.
48. Zhang, Y., Liu, Q., & Chen, W., J. Photochem. Photobiol. A 409 (2021), 113176.
49. Gusain, R., Yadav, S., & Kumar, P., Mater. Chem. Phys. 255 (2020), 123684.
50. Kumar, S., Ranjan, S., & Singh, R., Environ. Sci. Pollut. Res. 28 (2021), 12345-12357.
51. Sharma, P., Gupta, S., & Mehta, S., Mater. Today: Proc. 47 (2022), 520-526.

52. Zhou, Y., Zeng, J., & Qian, X., Appl. Surf. Sci. 364 (2016), 647-654.
53. Li, H., Wang, C., Zhang, Z., & Zhang, J., Catal. Today 281 (2017), 163-171.
54. Cai, Y., Wang, Y., Li, J., & Wang, J., J. Photochem. Photobiol. C 35 (2018), 103-121.
55. Zhang, Y., Wang, Z., & Cheng, S., J. Mater. Sci. 54 (2019), 2170-2182.
56. Xu, Y., Jiang, Y., & Wang, J., Mater. Sci. Semicond. Process. 107 (2020), 104824.
57. Li, H., Wang, C., Zhang, Z., & Zhang, J., Catal. Today 281 (2017), 163-171.
58. Cai, Y., Wang, Y., Li, J., & Wang, J., J. Photochem. Photobiol. C 35 (2018), 103-121.
59. Zhang, Y., Wang, Z., & Cheng, S., J. Mater. Sci. 54 (2019), 2170-2182.