Chapter 5
Potential of Biogenic Plant-Mediated Copper and Copper Oxide Nanostructured Nanoparticles and Their Utility

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5.1 Introduction

Nanotechnology is the technology to control matter at nanoscale and deals with the science and engineering to create functional materials or nanodevices (1–100 nm). Metal and metal oxide nanoparticles are of much interest due to their unique mechanical, electrical, optical, electronic, and magnetic properties and utilized as magnetic storage media, solar energy, bioelectronics, nanobiosensors, and catalyst. Metal nanoparticles are utilized in every sphere of science including medical fields which are still very interesting to the scientists to explore new dimensions due to their small sizes. The metal nanoparticles are synthesized by physicochemical methods using toxic chemicals as reducing agents and later on showed various biological risks when

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utilized. To solve this problem, biological approaches are utilized by using green syntheses, i.e., biological molecules which are derived from plant sources for the metal nanoparticle synthesis. The alkaloids, flavonoids, and proteins present in the plant extract are responsible for nanoparticle stabilization, non-agglomeration, and biologically active characteristics (Singh 2016; Singh et al. 2011, 2012; Prasad 2014; Prasad et al. 2018; Joshi et al. 2018).

The development of nanobionic plants is facilitated by the passive assembly of high-zeta-potential nanomaterials within the chloroplast photosynthetic machinery. Single-walled carbon nanotubes (SWNTs) have the potential for increasing chloroplast carbon capture by promoting chloroplast solar energy harnessing and electron transport rates. SWNT real-time sensing of nitric oxide (NO) in extracted chloroplasts and leaves could also be extended to detect a wide range of plant signaling molecules and exogenous compounds such as pesticides, herbicides, and environmental pollutants. Nanomaterials offer a promising way to engineer plant function, but the absorption, transport, and distribution of nanoparticles within photosynthetic organisms remain poorly understood. This nanobionic approach to engineer plant function will lead to a new research field at the interface of nanotechnology and plant biology. Giraldo et al. (2014) have reported the interactions of plant cell organelles and nanomaterials, i.e., non-biological nanostructure nanomaterials, which have potentialities to enhance functionality of chloroplast manyfolds. The single-walled carbon nanotubes (SWNTs) have capability to passively transport and irreversibly localize within the lipid membrane of extracted plant chloroplasts, which promote over three times higher photosynthetic activity than that of controls, and enhance maximum electron transport rates. Furthermore, they reported that the SWNT-chloroplast assemblies also enable higher rates of leaf electron transport *in vivo* and concentrations of reactive oxygen species (ROS) inside extracted chloroplasts are significantly suppressed by delivering poly(acrylic acid)-nanoceria or SWNT-nanoceria complexes. They demonstrated that plant can function as a photonic chemical sensor. Finally, they speculated that nanobionic engineering of plant function may contribute to the development of biomimetic materials for light harvesting and biochemical detection with regenerative properties and enhanced efficiency (Dhas et al. 1998).

Plant extracts (derived from herbs, shrubs, and trees) may act as biological system for the synthesis of metal and metal oxide nanoparticles, which have been emerged as new simple, eco-friendly, cost-effective, and robust or fast technique. This technique is also known as green chemistry methodology and could be much more efficient rather than using microorganisms and physicochemical methods for synthesis of the same. The plant parts from underground, i.e., root, to aerial, i.e., stem, leaves, flowers, fruits, and seeds, are having phytochemical entities or constituent types of plant resources which provide an efficient platform for metal and metal oxide nanoparticles with lack of toxic chemicals, i.e., nontoxic, and additionally provide natural reducing, stabilizing, chelating, and capping agents. Besides this it reduces the cost of timing of identification, isolation, and culture media preparation for microorganisms when compared with plant resources, i.e., cost competitive feasibility. Apart from these, plants are easily available and safely handled and consist of a wide variability of phytochemicals or biomolecules and secondary metabolites, namely, alkaloids, flavonoids, terpenes, sterols, saponins, glucose, fructose, ascorbic acid, alcohols, carboxylic acids, amino acids, proteins, enzymes, etc. All these are playing a crucial role for the synthesis of metal and metal oxide nanoparticles as reducing agents, stabilizing agents, and capping agents. However, plants show complex networks of antioxidants and enzymes, which together counter the oxidative stress or damage to cellular constituents. Coenzymes and cofactors could play an important role in the reduction of desired starting precursor for the nanoparticle formation, whereas enzyme and protein contents, i.e., reductases, are involved in the biological reduction of substrate, i.e., metal salts, into their corresponding nanoparticles. It had been established that few plants could uptake and bioreduce metal ions from soil containing corresponding salts or minerals or ores by detoxification process and ultimately converted into nanoparticles (Mittal et al. 2013; Singh and Choi 2010).

This chapter highlights the biogenic approach for the synthesis of Cu and CuO nanoparticles which are simple, cost-effective and eco-friendly, highly stable, and reproducible using different plant extracts as stabilizing, capping, and reducing agents. The biosynthesized Cu and CuO NPs have been used for various applications for the betterment of human health as anticancer, antimicrobial, and antioxidant activity, etc.

5.2 Biosensing

The synthesis of morphologically different metal oxide nanoparticles is made from iron, manganese, titanium, copper, zinc, zirconium, cobalt, nickel, tungsten, silver, and vanadium. It also covers respective composites and their function and application in the field of electrochemical and photoelectrochemical sensing of chemical and biochemical species. The proper incorporation of chemical functionalities into these nanomaterials warrants effective detection of target molecules including DNA hybridization and sensing of DNA or the formation of antigen/antibody complexes. Di Tocco et al. (2018) reported the development of an electrochemical biosensor for the determination of triglycerides in serum samples based on a lipase/magnetite-chitosan/copper oxide nanoparticles/multi-walled carbon nanotubes/pectin composite. Lavanya et al. (2018) reported an electrochemical determination of purine and pyrimidine bases using copper-doped cerium oxide nanoparticles. DNA is a primary unit of heredity in all living organisms. The abnormalities related to four bases will have significant influence on disease diagnosis, crime detection, and biocomputing applications. Identification and quantification of DNA bases are important for diagnosis of genetic diagnosis and disorders. The developed sensor had exhibited good repeatability, reproducibility, sufficient stability, and good anti-interference ability, and was applied for simultaneous detection of AD, GU, TY, and

CY in denatured DNA sample. Liu et al. (2018b) reported an ultrasensitive cathode photoelectrochemical immunoassay based on TiO_2 photoanode-enhanced three-dimensional (3D) Cu_2O nanowire array photocathode and signal amplification by biocatalytic precipitation. They showed a low limit of detection (0.037 pg mL^{-1}) with a wide linear range (from 0.1 pg mL^{-1} to 50 ng mL^{-1}) for carcinoembryonic antigen (CEA) detection. Li et al. (2018c) reported a novel electrochemiluminescence (ECL) signal-off strategy based on CuS in situ grown on reduced graphene oxide (CuS-RGO) quenching luminol/H_2O_2 system. Luminol was grafted on the surface of Au@Fe_3O_4-$Cu_3(PO_4)_2$ nanoflowers (Luminol-Au@Fe_3O_4-$Cu_3(PO_4)_2$) which exhibited catalytic effect toward the reduction of H_2O_2 to enhance the ECL intensity of luminol. Dai et al. (2018) reported morphology-dependent electrochemical behavior of 18-facet Cu_7S_4 nanocrystal-based electrochemical sensing platform for hydrogen peroxide and prostate-specific antigen (PSA), and Cu_7S_4 nanocrystal holds great promising application in electrochemical sensors. Wang et al. (2018a) reported DNA-hosted copper nanoclusters/graphene oxide-based fluorescent biosensor for protein kinase activity detection. Moreira et al. (2018) reported redox probe-free readings of a beta-amyloid-42 plastic antibody sensory material assembled on copper@carbon nanotubes. The carbon nanotubes were modified with copper nanoparticles (CNT-CuO) and casted on the carbon area and showed a unique potential for on-site application in medical research and clinical diagnosis. Wu et al. (2018a) reported an efficient capture, rapid killing, and ultrasensitive detection of bacteria by a nano-decorated multifunctional electrode sensor using Zn-CuO nanoparticles and graphene oxide (GO) nanosheets on a Ni porous electrode showing good bacterial capture efficiency toward the applications in portable medical devices for on-the-spot diagnosis and also for simultaneous therapy of diseases caused by bacterial infections. Wang et al. (2018b) reported an electrochemiluminescent competitive immunosensor based on polyethyleneimine-capped SiO_2 nanomaterials as labels to release $Ru(bpy)_3^{2+}$ fixed in 3D Cu/Ni oxalate for the detection of aflatoxin B1. They have proposed immunosensor to provide a promising approach for ultrasensitive detection of other mycotoxins. Bhat et al. (2018) reported the fully nozzle-jet printed nonenzymatic electrode for biosensing application like printing of silver (Ag) precursor and copper oxide nanoparticle (CuO NP) inks by nozzle-jet technique to glucose biosensor on flexible polyethylene terephthalate (PET) substrate, i.e., CuO NPs/Ag/PET electrodes. This electrode fabrication using nozzle-jet printing would be regarded as a potential technique, i.e., biochemical sensor devices. Li et al. (2018d) reported the synthesis of MoS_2@Cu_2O-Pt nanohybrid as enzyme-mimetic label for the detection of the hepatitis B surface antigen. The nanocomposites (molybdenum disulfide @ cuprous oxide-platinum)

Demonstrated uniform coral morphology having specific surface area for loading the secondary antibody and the number of catalytically active sites, which increased the electrical conductivity. These findings are promising toward clinical applications. Yang et al. (2018b) reported an ultrasensitive sandwich-type electrochemical immunosensor based on the signal amplification strategy of echinoidea-shaped Au@Ag-Cu_2O nanoparticles for prostate-specific antigen detection to determine tumor markers which play an important role in early diagnosis of cancer.

The gold nanoparticles functionalized nitrogen-doped graphene quantum dots (Au@N-GQDs) was fabricated and has enhanced conductivity, specific electrode surface area, and quantity of immobilized primary antibodies (Ab1), and echinoidea-shaped nanocomposites (Au@Ag-Cu_2O) composed of Au@Ag core-shell nanoparticles and disordered cuprous oxide were prepared success fabricated to label the secondary antibodies (Ab2) with biocompatibility and high specific surface area. Due to the synergetic effect of Au, Ag, and Cu_2O, the nanocomposites exhibited excellent electrocatalytic activity toward the reduction of hydrogen peroxide (H_2O_2) for the amplified detection of PSA. Chen et al. (2018a) reported an electrochemical aptasensor for thrombin using co-catalysis of hemin/G-quadruplex DNAzyme and octahedral Cu_2O-Au nanocomposites for signal amplification. The proposed aptasensor exhibited good sensitivity, high specificity, and reproducibility and could be applied in bioassay analysis. Sheta et al. (2018) reported a simple synthesis of novel copper metal-organic framework nanoparticles for the biosensing and biological applications. Cu-MOF-NPs (C1) showed more enhanced biological activity against various pathogens (five strains of bacteria, Gram positive and Gram negative) when compared to an antibacterial agent, and the effectiveness of Cu-MOF-NPs increases with increasing particle dose. Tang et al. (2017a) reported copper oxide coated gold nanorods like a film for electrochemical application. The gold nanorod-copper oxide nanocomposites (Au NRs-CuO nanocomposites) were fabricated and showed excellent electrocatalytic activity toward the oxidation of glucose compared with CuO NPs. Au NRs-CuO nanocomposites are promising candidate for the preparation of modified electrodes and electrochemical sensors. Hu et al. (2017) reported the self-cascade reaction catalyzed by CuO nanoparticle-based dual-functional enzyme mimics. The cupric oxide nanoparticle as oxidase mimics for the aerobic oxidation of cysteine to cystine with the generation of hydrogen peroxide was proposed, coupling this property with the peroxidase-like activity of CuO nanoparticles. They constructed a self-organized cascade reaction system based on a single-component nanozyme, which includes the oxidation of cysteine to yield cystine and hydrogen peroxide and the hydrogen peroxide-mediated oxidation of terephthalic acid to produce a fluorescence change. This platform was utilized for the detection of cysteine in pharmaceutical products and human plasma, which opens up a new route and holds promise for the development and applications of multifunctional nanomaterials as enzyme mimics. Arvand and Sayyar Ardaki (2017) reported poly-L-cysteine/electrospun copper oxide nanofibers-zinc oxide nanoparticles nanocomposite as sensing element of an electrochemical sensor for simultaneous determination of adenine and guanine in biological samples and evaluation of damage to dsDNA and DNA purine bases by ultraviolet (UV) radiation. They have fabricated poly-L-cysteine/zinc oxide nanoparticle-electrospun copper oxide nanofibers (PLC/ZnO-NPs-CuO-NFs) on the surface of the graphite electrode (GE), which enhanced the anodic peak currents of the purine bases. The biosensing platform not only detects DNA damage but also determines DNA oxidative damage. Lan et al. (2017) reported the size-controlled copper(I) oxide nanoparticles influence sensitivity of glucose biosensor. Copper(I) oxide (Cu_2O) is a semiconducting oxide with applications in photovoltaics and biosensing. The precise control of size and shape of Cu_2O nanostructures is possible by the electrodeposition utilizing ethylenediamine (EDA) as a size controlling agent. The large surface area of the Cu_2O NPs is able to immobilizing glucose oxidase for glucose biosensing. Fang et al. (2017) reported flowerlike MoS_2 decorated with Cu_2O nanoparticles for non-enzymatic amperometric sensing of glucose. The flowerlike MoS_2 decorated with Cu_2O nanoparticles had been synthesized as Cu_2O/MoS_2 nanohybrid which showed superior electrocatalysis to the oxidation of glucose due to the synergistic effect of Cu_2O nanoparticles and MoS_2 nanosheets. Buk et al. (2017) reported alginate-copper oxide nano-biocomposite as a novel material for amperometric glucose biosensing. A alginate-CuO-GOD film-based biosensor exhibited good performance with long-term stability and specificity for glucose when compared to possible interfering molecules such as ascorbic acid, uric acid, and acetaminophen. Shabnam et al. (2017) reported the doped graphene/Cu nanocomposite for high sensitivity nonenzymatic glucose sensor in food. The nitrogen-doped graphene with dispersed copper nanoparticles (Cu-NGr) was fabricated on modified glassy carbon electrode for glucose detection. The Cu-NGr composite presented electrocatalytic activity due to the synergetic effect of Cu NPs and nitrogen-doped graphene to detect glucose in food as a complex food material. Fu et al. (2017) reported a dual-potential electrochemiluminescence ratiometric sensor for sensitive detection of dopamine based on graphene-CdTe quantum dots and self-enhanced Ru(II) complex. They have designed dual-potential ratiometric electrochemiluminescence (ECL) sensor for detecting dopamine (DA) based on graphene-CdTe quantum dots (G-CdTe QDs) as the cathodic emitter and self-enhanced Ru(II) composite (TAEA-Ru) as the anodic emitter to biological small molecules.

Li et al. (2017a) reported a sensitive electrochemiluminescence immunosensor based on Ru(bpy)32+ in 3D CuNi oxalate as luminophores and graphene oxide-polyethylenimine as released $Ru(bpy)_3^{2+}$ initiator. Wang et al. (2017) reported the mimicking horseradish peroxidase and NADH peroxidase by heterogeneous Cu^{2+}-modified graphene oxide nanoparticles. Zhao et al. (2017) reported a sub-picomolar assay for protein by using cubic Cu_2O nanocages loaded with Au nanoparticles as robust redox probes and efficient nonenzymatic electrocatalysts. An electrochemical aptasensor for protein (thrombin-TB) in human serum samples was developed using cubic Cu_2O nanocages (Cu_2O-NCs) loaded with Au nanoparticles (AuNPs@ Cu_2O-NCs) as nonenzymatic electrocatalyst redox probes which showed an efficient electrocatalytic capability in the reduction of H_2O_2. This nonenzymatic detection platform would be potential and promising in clinical diagnostics and protein analysis techniques. Li et al. (2017b) reported an ultrasensitive amperometric immunosensor for PSA detection based on Cu_2O@CeO_2-Au nanocomposites as integrated triple signal amplification strategy. The amino functionalized cuprous oxide @ ceric dioxide (Cu_2O@CeO_2-NH_2) core-shell nanocomposites were prepared for the quantitative detection of prostate-specific antigen (PSA). AuNPs (Cu_2O@CeO_2-Au) show better electrocatalytic activity toward the reduction of hydrogen peroxide (H_2O_2). Pino et al. (2016) reported high-performance sensor based on copper oxide nanoparticles for dual detection of phenolic compounds and a pesticide. Liu et al. (2016) reported *in situ* immobilization of copper nanoparticles on polydopamine-coated graphene oxide for H_2O_2 determination. Ma et al. (2016) reported the cubic Cu_2O nanoframes with a unique edge-truncated structure and a good electrocatalytic activity for immunosensor application for the quantitative detection of prostate-specific antigen (PSA). Gold nanoparticles decorated 3-aminopropyltriethoxysilane functionalized graphene sheets (Au@APTES-GS) having a large specific surface area, good biocompatibility, and superior electron transfer ability were developed as the matrix to provide method for the clinical monitoring of tumor markers. Xie et al. (2016) reported a sensitive fluorescent sensor for quantification of alpha-fetoprotein (AFP) in the human serum samples based on immunosorbent assay and click chemistry. Qin et al. (2016) reported a novel signal amplification strategy of an electrochemical aptasensor for determination of kanamycin antibiotic, based on thionine functionalized graphene and hierarchical nanoporous PtCu. The aptasensor uses thionine functionalized graphene (GR-TH) and hierarchical nanoporous (HNP) PtCu alloy as biosensing substrates for the determination of kanamycin in animal-derived food. Uzunoglu and Stanciu (2016) reported novel CeO_2-CuO-decorated enzymatic lactate biosensors operating in low oxygen environments. The detection of the lactate level in blood is useful for the diagnosis of some pathological conditions including cardiogenic or endotoxic shocks, respiratory failure, liver disease, systemic disorders, renal failure, and tissue hypoxia. The CeO_2-CuO-decorated sensor was detecting lactate in human serum with good selectivity and reliability. Feng et al. (2016) reported graphene oxide-supported rhombic dodecahedral Cu_2O nanocrystals for the detection of carcinoembryonic antigen (CEA). The rCu_2O-GO-AuNPs electrode also presents a potential alternative for the diagnostic applications of GO-supported special morphology materials in biomedicine and biosensors. Jimenez-Hernandez et al. (2016) reported 3-mercaptopropionic acid surface modification of Cu-doped ZnO nanoparticles and their properties and peroxidase conjugation. Yin et al. (2016) reported a regular signal attenuation electrochemical aptasensor for highly sensitive detection of streptomycin antibiotic in milk and honey samples. This electrochemical aptasensor is of great practical importance in food safety. Mei et al. (2015) reported novel phenol biosensor based on laccase immobilized on reduced graphene oxide-supported palladium-copper alloyed nanocages. They have fabricated RGO-PdCu NC immobilized laccase for the detection of catechol. Chen et al. (2015) reported the constructing heterostructure on highly roughened caterpillar-like gold nanotubes with cuprous oxide grains for ultrasensitive and stable nonenzymatic glucose sensor. Li et al. (2015) reported selective and sensitive determination of dopamine by the novel molecularly imprinted poly (nicotinamide)/CuO nanoparticle-modified electrode. They have suggested that the proposed sensor exhibited significant promise as a reliable technique for the detection of DA in human serum samples. Sun et al. (2015) reported CuO-induced signal amplification strategy for multiplexed photoelectrochemical immunosensing using CdS-sensitized ZnO nanotube arrays as photoactive material and AuPd alloy nanoparticles as electron sink. They have used cancer antigen 125, prostate-specific antigen, and α-fetoprotein as model analytes for the proposed immunoassay which exhibits excellent precision and sensitivity for the multi-detection of tumor markers. Wen and Ju (2015) reported an ultrasensitive photoelectrochemical immunoassay through tag-induced exciton trapping for the detection of protein. Derkus et al. (2015) reported copper-zinc alloy nanoparticle-based enzyme-free superoxide radical sensing on a screen-printed electrode. They have suggested that the enzyme-free electrode showed good performance with respect to the enzyme containing electrode indicating the superior functionality of enzyme-free electrode for the detection of superoxide radicals. Guo et al. (2015) reported an electrochemical immunosensor for ultrasensitive detection of carbohydrate antigen 199 (CA199) based on Au@CuxOS yolk-shell nanostructures with porous shells as labels. They have proposed immunosensor-based method which provides a new promising platform of clinical immunoassay for other biomolecules. Gao et al. (2015) reported an ultrasensitive electrochemical immunoassay for carcinoembryonic antigen (CEA) through host-guest interaction of β-cyclodextrin functionalized graphene and Cu@Ag core-shell nanoparticles with adamantine-modified antibody. They have fabricated immunosensor which exhibits excellent analytical performance for the measurement of CEA and provides an enormous application prospect in clinical diagnostics. Bajaj et al. (2015) reported controllable one-step copper coating on carbon nanofibers (CNFs) for flexible cholesterol biosensor substrate biosensing applications. Siebman et al. (2015) reported the two-dimensional (2D) algal collection and assembly by combining alternative current (AC) dielectrophoresis with fluorescence detection for contaminant-induced oxidative stress sensing. They have developed an alternative current (AC) dielectrophoretic lab-on-chip setup as a rapid tool of capture and assembly of microalga *Chlamydomonas reinhardtii* in two-dimensional (2D) close-packed arrays and explored the reactive oxygen species (ROS) production and oxidative stress during short-term exposure to several environmental contaminants, including mercury, methylmercury, copper, copper oxide nanoparticles (CuO NPs), and diuron. Hu et al. (2014) reported the fluorescent hydrogen peroxide sensor based on cupric oxide nanoparticles and its application for glucose and l-lactate detection. Lavanya et al. (2014) reported the fabrication of folic acid (FA) sensor based on the Cu-doped SnO_2 nanoparticle-modified glassy carbon electrode. They have fabricated sensor for the determination of FA. Wang et al. (2014) reported the platinum porous nanoparticles hybrid with metal ions as probes for simultaneous detection of multiplex cancer biomarkers. They have developed an electrochemical immunosensor for simultaneous detection of carcinoembryonic antigen (CEA) and alpha-fetoprotein (AFP) and suggested that the proposed electrochemical immunoassay provides a potential application of clinical screening for early-stage cancers. Zhou et al. (2014) reported an ultrasensitive nonenzymatic glucose sensor based on three-dimensional network of ZnO-CuO hierarchical nanocomposites (HNCs) by electrospinning. They have revealed that the ZnO-CuO HNCs composed of the ZnO and CuO showed good synergetic effect in between CuO and ZnO. Song et al. (2013) reported the synthesis of graphene oxide-based CuO nanoparticles composite electrode for highly enhanced nonenzymatic glucose detection. They have showed and suggested an outstanding long-term stability, good reproducibility, excellent selectivity, and accurate measurement in real serum sample. Ahmad et al. (2013) reported a wide linear-range detecting nonenzymatic glucose biosensor based on CuO nanoparticles inkjet-printed on electrodes on silver electrodes. Finally, they have utilized proposed electrode for the determination of glucose in human serum samples. Ma et al. (2013) reported a sensitive and selective chemosensor for oxidized glutathione (GSSG) detection based on the recovered fluorescence of NDPA (naphthalimide-DPA) -Fe_3O_4 at SiO_2-Cu(II) nanomaterial. Wang et al. (2013) reported an electrochemical immunosensor with graphene quantum dots and apoferritin-encapsulated Cu nanoparticles double-assisted signal amplification for detection of avian leukosis virus subgroup J (ALVs-J). Liu et al. (2013) reported graphene-wrapped Cu_2O nanocubes for the nonenzymatic electrochemical sensors for the detection of glucose and hydrogen peroxide with enhanced stability. They have fabricated cubic Cu_2O nanocrystals/graphene hybrid with high sensitivity for the detection of glucose and H_2O_2. Hong et al. (2013) reported the chemiluminescent cholesterol sensor based on peroxidase-like activity of cupric oxide nanoparticles with good selectivity and enhanced sensitivity. They have suggested the applicability of proposed sensor for the determination of cholesterol in milk powder and human serum samples. Ge et al. (2013) reported a disposable immunosensor device for point-of-care test (POCT) of tumor marker based on copper-mediated amplification. They have fabricated a paper-based immunodevice for point-of-care test (POCT) for cancer screening and also suggested good applicability of the proposed multiplex immunoassay in clinical diagnosis. Meng et al. (2013) reported the nonenzymatic biosensor based on CuxO nanoparticles deposited on polypyrrole nanowires for detecting glucose (GLC). They have showed the electrocatalytic activity of CuxO/PPy/Au toward GLC in alkaline conditions and suggested that these excellent performances make CuxO/PPy/Au as a good nonenzymatic GLC sensor. Zhou et al. (2013) reported the sodium dodecyl benzene sulfonate functionalized graphene for confined electrochemical growth of metal oxide nanocomposites for fructose sensing application. They have revealed the sensing properties of (Sodium dodecyl benzene sulfate) SDBS/GR/CuOCu toward fructose and suggested that SDBS/GR/CuOCu electrode is one of the promising electrode materials for electrochemical detection of fructose. Won and Stanciu (2012) reported the Cu_2O and Au/Cu_2O particles for the surface properties and applications in glucose sensing. Peng et al. (2012) reported the functionalization of silver nanowire surfaces with copper oxide for surface-enhanced Raman spectroscopic biosensing. El Khatib and Abdel Hameed (2011) reported the development of Cu_2O/carbon Vulcan XC-72 as nonenzymatic sensor for glucose determination. Bedi and Singh (2010) reported the room-temperature ammonia sensor based on cationic surfactant-assisted nanocrystalline CuO. Jiang and Zhang (2010) reported a highly sensitive nonenzymatic glucose sensor based on CuO nanoparticles-modified carbon nanotube electrode. Wang et al. (2010) reported using flowerlike polymer-copper nanostructure composite and novel organic-inorganic hybrid material to construct an amperometric biosensor for hydrogen peroxide. Niu et al. (2009) reported the sensitive DNA biosensor improved by luteolin copper(II) as indicator based on silver nanoparticles and carbon nanotubes-modified electrode for the detection of DNA hybridization. The copper(II) complex of luteolin $C_{30}H_{18}CuO_{12}$ (CuL2) as an electroactive indicator based on silver nanoparticles and multi-walled carbon nanotubes (Ag/MWCNTs)-modified glassy carbon electrode (GCE) was quantified the target ssDNA of the human hepatitis B virus (HBV). Zhang et al. (2009) reported the fixture-reduced method for the synthesis of Cu_2O/MWCNT nanocomposites and its application as enzyme-free glucose sensor. Cu_2O/MWCNT (multi-walled carbon nanotube) nanocomposites-modified electrode was utilized toward glucose determination, i.e., enzyme-free glucose sensor. Shlyahovsky et al. (2005) reported the optical and electrochemical detection of NADH and of NAD^+-dependent biocatalyzed processes by the catalytic deposition of copper on gold nanoparticles for the sensing of ethanol by the NAD^+-dependent alcohol dehydrogenase.

5.3 Catalysts

Li et al. (2019) reported aBiOCl-CuO photocatalyst based on *p*-*n* heterojunction and its photocatalytic performance under visible light. They suggested that the CuO nanoparticles (NPs) with narrow bandgap and near-infrared (NIR) light response act as the co-catalyst and CuO NPs enhance the photocatalytic performance of BiOCl semiconductor. The heterojunction exhibited photocatalytic activity and photostability to decompose organic pollutants such as acid orange (AO) and bisphenol A (BPA). Duran et al. (2019) reported novel 3D copper nanoparticles/chitosan/nanoporous alumina (CCSA) membranes with catalytic activity to decompose methylene blue (MB). The CCSA membranes were tested in the reduction of methylene blue (MB). Wang et al. (2019a) reported layered copper-manganese oxide (LCMO) for the efficient catalytic carbon monoxide (CO) and volatile organic compound (VOC) oxidation. They suggested that LCMO showed an excellent resistance to H_2O, SO_2, CO_2, and other VOCs. Ghafuri et al. (2019) reported the synthesis and characterization of magnetic nanocomposite Fe_3O_4@TiO_2/Ag,Cu and investigation of photocatalytic activity by degradation of rhodamine B (RhB) under visible light irradiation. They investigated the photocatalytic activity in aqueous solution under visible light irradiation and suggested that the Ag- and Cu-doped nanoparticles have synergistic effect to increase the photocatalytic activity of as-synthesized nanocomposite. Khatibi et al. (2019) reported efficient surface design of reduced graphene oxide, carbon nanotube, and carbon active with copper nanocrystals for enhanced simulated-solar-light photocatalytic degradation of acid orange in water and suggested that photoactivity of Cu/RGO among Cu/MWCNT and Cu/AC is due to a synergistic effect between RGO and Cu nanoparticles. Wang et al. (2019b) reported honeycomb porous carbon (HPC) frameworks from wheat flour as supports for CuxO-CeO_2 monolithic catalysts. They have showed that the small-sized CeO_2 particles on HPC surface having oxygen vacancies, to participate in oxygen activation and oxidation of carbon monoxide and improve the redox reactivity of copper species and ceria. Su et al. (2019) reported for the first time a freestanding and flexible Cu@CuO nanowire (NW) mesh as Fenton-like catalyst and showed an excellent catalytic performance toward the degradation of organic dyes such as rhodamine B (RhB) crystal violet, methylene blue, and rhodamine 6G. Qin et al. (2019) reported the

CuO-ZnO heterojunctions decorated graphitic carbon nitride hybrid nanocomposite for ethanol gas sensing application. They suggested those graphitic carbon nitrides (g-C_3N_4) are used as metal-free catalyst in gas sensing field due to its unique chemical stability and excellent substrate characteristics. The CuO-ZnO/g-C_3N_4 ternary composite exhibited enhanced sensing properties to ethanol. Oh et al. (2019) reported Au/Cu_2O/TiO_2 core-shell nanorods using three-step chemical synthesis technique and suggested that the Au nanoparticles core of Au/Cu_2O performed as the catalytic activity enhancer and the Cu_2O shell acts as a co-catalyst. The Au/Cu_2O/TiO_2 nanorods showed photocatalytic performance, recyclability, and stability to degrade organic pollutants under solar light irradiation, whereas *p-n* junction at the interface of Cu_2O shell and the TiO_2 nanorods contributes to the enhanced catalytic activity. Padikkaparambil et al. (2019) reported a facile preparation of noble metal-free Cu-doped CeO_2 oxidation catalyst suitable for engine exhaust gas treatment and suggested carbon monoxide oxidation reaction without any stabilizing agents. The results indicated the formation of lattice-expanded CeO_2 solid solution as well as highly dispersed copper oxides as the active centers of the catalyst. Zhan (2019) reported a synthetic architecture of integrated nanocatalysts with controlled spatial distribution of metal nanoparticles. Tou et al. (2019) reported the room-temperature oxidation of CO using ozone-assisted catalysis (OAC) over monometallic or bimetallic catalysts supported on γ-Al_2O_3. They have demonstrated monometallic catalysts (Ag, Pd, Fe, Mn, and Cu). Naeimi et al. (2019) reported ultrasonic-assisted fabrication of first MoO_3/copper complex bio-nanocomposite based on *Sesbania sesban* plant for green oxidation of alcohols. They have also reported atom-efficient and selective oxidation of alcohols using hydrogen peroxide catalyzed by NMCS bio-nanocomposite under ultrasonic irradiation. Hu et al. (2019) reported catalytic decomposition of ammonium perchlorate (AP) on hollow mesoporous CuO microspheres. Hollow mesoporous CuO microspheres (CuO-HM) could be described as CuO micro-sized spheres composed of self-assembled nanoparticles, possessing hollow and mesoporous structure which improved catalytic efficiency in AP decomposition due to large surface area, easily accessible porous, and hollow structure. They have also demonstrated that hollow and mesoporous CuO was a promising catalyst for the application in solid-fuel rocket propellants. Duan et al. (2018a) reported the Z-scheme heterojunction between TiO_2 nanotubes and Cu_2O nanoparticles mediated by Ag nanoparticles for enhanced photocatalytic stability and activity under visible light. They have revealed the potential application of noble metal nanoparticles to enhance the Z-scheme heterojunction under visible light-driven photocatalysis and provide new insights to the transition from traditional *p-n* heterojunctions to Z-scheme heterojunctions. Gao and Hensen (2018) reported highly active and stable spinel oxide-supported gold catalyst for gas-phase selective aerobic oxidation of cyclohexanol to cyclohexanone. The Au/$MgCuCr_2O_4$ catalysts have demonstrated very efficient for gas-phase oxidation of cyclohexanol to cyclohexanone due to Au-Cu synergical effect. Fedorov et al. (2018) reported structure and chemistry of Cu-Fe-Al nanocomposite catalysts for CO oxidation. Khoshnamvand et al. (2018) reported response surface methodology (RSM) modeling to improve removal of ciprofloxacin from aqueous solutions in photocatalytic process using copper oxide nanoparticles (CuO/UV). Ciprofloxacin (CIP) is antibiotic and an emerging and biological resistant pollutant. The removal of CIP from synthetic aqueous solutions is needed by photocatalytic process through copper oxide nanoparticles as catalyst (CuO/UV). They have demonstrated that photocatalytic process using copper oxide nanoparticles decomposes CIP in aqueous solutions. Lai et al. (2018) reported copper oxide nanoparticles (CuO NPs) as catalysts or semiconductors and showed an adverse genotoxicity and cytotoxicity effects on various cells. CuONPs have aggravated pulmonary inflammation and apoptosis of epithelial cells due to increased reactive oxygen species (ROS) and promoted collagen accumulation and expression of the progressive fibrosis marker alpha-smooth muscle actin (alpha-SMA, plays an important role in fibrogenesis) in the lung tissues. They also alarm toward an urgent need to prevent the adverse effects of CuO NPs in the human respiratory system. Nirumand et al. (2018) reported copper ferrite nanoparticles supported on MIL-101/reduced graphene oxide as an efficient and recyclable sonocatalyst. The magnetic $CuFe_2O_4$/MIL-101/graphene (CMG) ternary nanocomposite decomposes some organic dyes, namely, methylene blue, rhodamine B, and methyl orange (MO) in water by using H_2O_2 as a green oxidant. Sartin et al. (2018) reported an effect of particle shape and electrolyte cation on CO adsorption to copper oxide nanoparticle electrocatalysts. Cu_2O-derived nanoparticles are efficient catalysts for the electrochemical conversion of CO and CO_2 to multicarbon products. Mahapatra et al. (2018) reported growth, structure, and catalytic properties of ZnO x grown on CuO x/Cu(111) surfaces. ZnO / Cu configuration as a catalyst plays an important role in the synthesis of methanol from CO_2 hydrogenation. Tabakova et al. (2018) reported promotional effect of gold on the (Water-gas shift (WGS) reaction, a well-known industrial process for the production of hydrogen) activity of alumina-supported copper-manganese mixed oxides. Velusamy et al. (2018) reported an electrochemical synthesis of copper oxide nanoparticles decorated graphene-β-cyclodextrin composite for trace-level detection of antibiotic drug metronidazole. The copper oxide nanoparticle (CuO NP) decorated graphene/β-cyclodextrin (GR-β-CD) composites exhibit an excellent catalytic activity and lower reduction potential toward the electrochemical detection of metronidazole (MTZ). Jafarirad et al. (2018) reported an innovative biocapped CuO nano-photocatalysts for a rapid and green method for photocatalytic degradation of 4-nitrophenol. Cobalt nanoparticles (CONPs) acts as nanophotocatalyst which could be photodegraded 4-nitrophenol as an environmental pollutant. The fabrication protocol opens the windows for a large-scale and green approach for generating other metal oxide that are useful as nano-photocatalyst. Gong et al. (2018a) reported *in situ* synthesis of highly dispersed Cu-Co bimetallic nanoparticles for tandem hydrogenation/rearrangement of bioderived furfural in aqueous phase. They reported a synergism between copper and cobalt. Pandas and Fazli (2018) reported nanoparticles (NPs) from lanthanum oxide (La_2O_3) and copper oxide (CuO) with spherical morphology which were synthesized through precursor calcinations of copper and lanthanum carbonate and then using a bioactive shell membrane of eggshell. Janmohammadi et al. (2018) reported copper nanoparticles supported on MoO_3 (Cu NPs/MoO_3) which were prepared by a green method using sun spurge leaf extract for the catalytic activity. Duan et al. (2018b) reported ionic liquid-assisted synthesis of reduced graphene oxide-supported hollow spherical PtCu alloy and its enhanced electrocatalytic activity toward methanol oxidation and suggested that the hollow spherical PtCu alloy supported on RGO will have great potential applications for direct methanol fuel cells. Amirzadeh et al. (2018) reported a nonenzymatic glucose sensor based on a pencil graphite electrode (PGE), a modifier suspension including the conducting polymer poly (3,4-ethylenedioxythiophen e):poly(styrenesulfonate) (PEDOT:PSS) and CuO nanoparticles. The PEDOT:PSS/CuO/MWCNTs-PGE-based sensor exhibited better electrocatalytic activity toward glucose and showed excellent reproducibility, good long-term stability, and excellent anti-interference ability in the existence of common interfering species. Mardani and Ziari (2018) reported the synthesis and characterization of new nanomagnetic coordination composite from Fe_3O_4 and Cu(II) complex as an efficient catalyst in oxidation of benzyl alcohol. Kalimuthu et al. (2018) reported boron carbonitride sheet/Cu_2O composite for an efficient photocatalytic hydrogen evolution. The enhanced photocatalytic activity was due to the influence of Cu_2O on the Boron carbon nitride (BCN) surface and enhanced charge separation in the interface at Cu_2O with BCN. Xie et al. (2018b) reported monodisperse core-shell Cu/In_2O_3 nanoparticles (NPs) to boost efficient and tunable syngas formation via electrochemical CO_2 reduction for the first time. The efficiency and composition of syngas production on the developed carbon-supported Cu/In_2O_3 catalysts are highly dependent on the In_2O_3 shell thickness. Liu et al. (2018a) reported mesoporous CuO/MgO synthesized by a homogeneous-hydrothermal method and its catalytic performance for the ethynylation reaction of formaldehyde and exhibits excellent catalytic activity for the formaldehyde reaction of acetylene. Gong et al. (2018b) reported metal-organic-framework-derived controllable synthesis of mesoporous copper-cerium oxide composite catalysts for the preferential oxidation of carbon monoxide. The as-prepared CuO-CeO_2 catalysts display variable morphologies, crystal structures, and specific surface areas based on different ratios of Cu/Ce and calcination temperature. Rao et al. (2018) reported the hierarchical CuO microstructures' synthesis for visible light-driven photocatalytic degradation of Reactive Black-5 dye. Bao et al. (2018) reported a novel core-shell structured nanocatalyst (Fe_3O_4@SiO_2-NH_2-FeCu nanoparticles) with ultrafine FeCu alloy NPs magnetically immobilized in porous silica showed excellent activity and chemoselectivity for catalyzing the hydrogenation of nitroarenes to corresponding anilines using hydrazine hydrate as the hydrogen source, and the reaction could be carried out smoothly in water, which is an environmentally friendly solvent. The FeCu NPs are magnetically immobilized in the silica spheres (Fe_3O_4@SiO). Rani and Shanker (2018) reported the photocatalytic degradation of toxic phenols from water using bimetallic metal oxide nanostructures, namely, Ni-Cu oxide (NiCuO), Cu-Cr oxide ($CuCr_2O_4$), and Ni-Cr oxide ($NiCrO_3$) using *Aegle marmelos* leaf extract. Yousaf et al. (2018) reported an ultra-low Pt-decorated NiCu bimetallic alloy nanoparticles supported on reduced graphene oxide for electrooxidation of methanol. Zhang et al. (2018a) reported an embedded CuO nanoparticles@TiO_2-nanotube arrays for photoelectrocatalytic reduction of CO_2 to methanol. Yuan et al. (2018) reported copper stearate as a catalyst for improving the oxidation performance of heavy oil in *in situ* combustion process. Hosseini et al. (2018a) reported preparation, characterization, and catalytic behavior of copper oxide nanoparticles on thermal decomposition of ammonium perchlorate particles. Lykaki et al. (2018) reported ceria nanoparticles shape effects on the structural defects and surface chemistry and an implication in CO oxidation by Cu/CeO_2 catalysts. Taleb et al. (2018) reported alumina/graphene/Cu hybrids as highly selective sensor for simultaneous determination of epinephrine, acetaminophen, and tryptophan in human urine. The fabricated sensor is an appropriate candidate for the pharmaceutical applications and clinical investigations. Sati et al. (2018) reported a facile synthesis procedure for nanocomposites consisting of one-dimensional (1D) carbon nanotubes, 2D graphene, and metal oxide nanoparticles (CuO, ZnO) referred as metal oxide dispersed on graphene-wrapped carbon nanotubes (CuO/GC and ZnO/GC) nanocomposites. Hoseini et al. (2018) reported designing of some platinum- or palladium-based nanoalloys as effective electrocatalysts for methanol oxidation reaction. They concluded that these non-precious bi- and trimetallic alloy nanostructured thin films have better electrocatalytic performance than Pt monometallic thin films and other Pt nanostructures due to the geometric, electronic, and stabilizer effect. Gulati et al. (2018) reported a green approach for decarboxylative C(sp3)-H activation of proline amino acid which was accomplished by coupling with aldehydes and alkynes to afford α-alkynylated *N*-substituted pyrrolidines as value-added synthons using reduced graphene oxide-supported copper oxide (RGO@CuO) nanocatalysts. Pham et al. (2018) reported oxidative degradation of the antibiotic oxytetracycline by Cu@Fe_3O_4 core-shell nanoparticles. They demonstrated that Cu@Fe_3O_4 is a novel prospective candidate for the pharmaceutical and personal care products degradation in the aqueous phase. Hemmati et al. (2018) reported the biosynthesis of CuO nanoparticles using *Rosa canina* fruit extract as a recyclable and heterogeneous nanocatalyst for C-N Ullmann coupling reactions. Dong et al. (2018) reported an enhancing photocatalytic activity of titanium dioxide via well-dispersed copper nanoparticles and may provide a new strategy to improve photocatalytic efficiency of TiO_2 without using high-cost noble metals. Ibrahim et al. (2018) reported a novel heterobimetallic coordination polymer as a single source of highly dispersed Cu/Ni nanoparticles for efficient photocatalytic water splitting. They anticipated directing the future development of efficient, low-cost, and noble metal-free semiconductor photocatalysts for solar H_2 production.

Xu et al. (2018) reported design and fabrication of Ag-CuO nanoparticles on reduced graphene oxide for nonenzymatic detection of glucose. Imani et al. (2018) reported unraveling in situ formation of highly active mixed metal oxide $CuInO_2$ nanoparticles during CO_2 electroreduction. Anku et al. (2018) reported Graft Gum Ghatti caped Cu_2O nanocomposite for photocatalytic degradation of naphthol blue-black dye. Pattanayak et al. (2018) reported fabrication of cost-effective non-noble metal supported on conducting polymer composite such as copper/polypyrrole graphene oxide (Cu_2O/PPy-GO) as an anode catalyst for methanol oxidation in Direct methanol fuel cell (DMFC). Ling et al. (2018) reported versatile three-dimensional porous Cu@Cu_2O aerogel networks as electrocatalysts and mimicking peroxidases.

Kosmambetova et al. (2018) reported an effect of ultrasonic treatment of the mechanically mixed nanosized CuO-MgO solids on their catalytic properties in the CO oxidation. Zhang et al. (2018c) reported a facile and efficient one-pot method for the synthesis of well-dispersed hollow $CuFe_2O_4$ nanoparticles (H-$CuFe_2O_4$ NPs) in the presence of cellulose nanocrystals (CNC) as the support and suggested that the ferrite nanoparticles supported on CNC acted as a promising catalyst and exhibited potential applications in numerous ferrite-based catalytic reactions. Selvarajan et al. (2018) reported a novel highly selective and sensitive detection of serotonin based on Ag/polypyrrole/Cu_2O nanocomposite-modified glassy carbon electrode. They showed electrocatalytic activity, repeatability, stability, fast response, and good selectivity against potentially interfering species. Comelli et al. (2018) reported an influence of the synthetic conditions on the composition, morphology of CuMgAl hydrotalcites, and their use as catalytic precursor in diesel soot combustion reactions. Sharma and Dutta (2018) reported Se-doped CuO NPs/H_2O_2/UV as a highly efficient and sustainable photo-Fenton catalytic system for enhanced degradation of 4-bromophenol. Yisilamu et al. (2018) reported preparation of cuprous oxide nanoparticles coated with aminated cellulose for the photocatalytic reduction of carbon dioxide to methanol. Dobrucka (2018) reported antioxidant and catalytic activity of biosynthesized CuO nanoparticles using extract of *Galeopsidis herba* and showed catalytic activity in the reduction of malachite green. Naghdi et al. (2018) reported *Cuscuta reflexa* leaf extract-mediated green synthesis of the Cu nanoparticles on graphene oxide/manganese dioxide nanocomposite and its catalytic activity toward reduction of nitroarenes and organic dyes. Chen et al. (2018b) reported PdCu alloy flowerlike nanocages with high electrocatalytic performance for methanol oxidation and suggested the unique flowerlike nanocage structure with high surface area and the synergic effect of Pd and Cu. Li et al. (2018b) reported nanoporous CeO_2-Ag catalysts prepared by etching the CeO_2/CuO/Ag_2O mixed oxides for CO oxidation. They suggested that the catalytic activity was attributed to the enhancement of interfacial interaction between CeO_2 ligament and Ag particle. Tavella et al. (2018) reported the development of photoanodes for photoelectrocatalytic solar cells based on copper-based nanoparticles on titania thin films of vertically aligned nanotubes. They suggested that the main role of CuO nanoparticles is to act as co-catalyst to improve the H_2 photogeneration rate rather than to promote charge separation or other effects, which promote the photocurrent density. Aparna et al. (2018) reported an Au-Cu_2O/RGO nanocomposite-based electrochemical sensor for selective and simultaneous detection of dopamine and uric acid. Dean et al. (2018) reported design of copper-based bimetallic nanoparticles for carbon dioxide adsorption and activation. Soori and Nezamzadeh-Ejhieh (2018) reported synergistic effects of copper oxide-zeolite nanoparticles composite on photocatalytic degradation of 2,6-dimethylphenol aqueous solution. Hasanpour et al. (2018) reported an ultrasensitive electrochemical sensing of acetaminophen and codeine in biological fluids using CuO/$CuFe_2O_4$ nanoparticles as a novel electrocatalyst. Esmaeilpour et al. (2018) reported dendrimer-encapsulated Cu(Π) nanoparticles immobilized on superparamagnetic Fe_3O_4@SiO_2 nanoparticles as a novel recyclable catalyst for *N*-arylation of nitrogen heterocycles and green synthesis of 5-substituted

1H-tetrazoles. Fe_3O_4@SiO_2 nanoparticles as the magnetic catalyst can be separated by an external magnet bar and is recycled seven times without significant loss of its activity. Zhou et al. (2018) reported an efficient degradation of 2,4-dichlorophenol in aqueous solution by peroxymonosulfate activated with magnetic spinel $FeCo_2O_4$ nanoparticles. They showed that magnetic spinel $FeCo_2O_4$ nanoparticles (NPs) have proposed as a catalyst of peroxymonosulfate (PMS) for the degradation of 2,4-dichlorophenol (2,4-DCP) and revealed that the $FeCo_2O_4$/PMS system shows potential for degrading contaminants in the environment. Chen et al. (2018c) reported an enhanced catalyst activity by decorating of Au on Ag@Cu_2O nanoshell. They showed combination of Au, Ag, and Cu_2O which exhibited excellent catalytic properties. Ag@Cu_2O-Au nanocomposite was used to detect the organic, toxic pollutant, 4-nitrophenol (4-NP), which could be ascertained for water remediation. Cai et al. (2018) reported performance of preformed Au/Cu nanoclusters deposited on MgO powders in the catalytic reduction of 4-nitrophenol in solution. Ma et al. (2018) reported a magnetic hierarchical core-shell structured Fe_3O_4@PDA-Pd@[$Cu_3(btc)_2$] nanocomposite. The Fe_3O_4@PDA-Pd@[$Cu_3(btc)_2$] ($n = 5$) nanocomposite shows ultrahigh catalytic activity for the 4-nitrophenol reduction and also exhibits a synergistic effect in the catalytic system. Zhang et al. (2018b) reported catalytic ozonation of *N*,*N*-dimethylacetamide (DMAC) in aqueous solution using nanoscaled magnetic $CuFe_2O_4$. *N*,*N*-dimethylacetamide (DMAC) is used in chemical industry and could cause reproductive toxicity. The copper ferrite ($CuFe_2O_4$) magnetic nanoparticles (MNPs) were introduced for the degradation of DMAC by catalytic ozonation and showed high catalytic activity, stability, and recyclability. Tada et al. (2018) reported Cu species incorporated into amorphous ZrO_2 with high activity and selectivity in CO_2-to-methanol hydrogenation. Mandal et al. (2018) reported the role of copper oxide in electrochemical CO_2 reduction in real time. Gong et al. (2018c) reported in situ synthesis of Cu_2O/reduced graphene oxide composite as effective catalyst for ozone decomposition. The decomposition of ozone is still technologically challenging in humidity levels. Cu_2O/reduced graphene oxide composite (Cu_2O/RGO) is in situ synthesized by reducing a mixed solution of Cu^{2+} and GO. Tian et al. (2018) reported an ultrasensitive electrochemical detection method to detect MCF-7 circulating tumor cells (CTCs) in breast cancer by using reduced graphene oxide/gold nanoparticles composites (RGO/Au NP composites) as a support material with CuO nanozyme as a catalyst. MCF-7 cells were detected by an electrochemical cytosensor with effective surface recognition between specific mucin 1 protein (MUC-1) over-expressed on the MCF-7 cell membranes and MUC-1 aptamer. Xie et al. (2018a) reported CuO nanoparticles decorated 3D graphene nanocomposite as nonenzymatic electrochemical sensing platform for malathion detection. The CuO NPs/3DGR nanocomposite possesses high affinity toward malathion and showed good recovery, stability, and selectivity. Reddy et al. (2018) reported the catalytic activity of copper oxide nanoparticles dispersed on titanium dioxide in water for one-pot synthesis of a library of hydrazinyl-thiazoles via a three-component reaction of various aldehydes/ketones with thiosemicarbazide and different phenacyl bromides for large-scale applications in pharmaceutical industries and suggested that the reaction begins with the activation of the carbonyl group of both aldehyde/ketone and phenacyl bromide by copper oxide nanoparticles supported on titanium dioxide in water. Rezaei et al. (2018) reported heterogeneous magnetic nanocatalyst, Fe_3O_4@SiO_2-ligand-Cu(II) MNPs, revealed high catalytic performance within the synthesis of propargylamines using the multicomponent coupling reaction of aldehydes, phenylacetylene, and secondary amines in water as a solvent. Suwannapichat et al. (2018) reported the direct synthesis of dimethyl ether (DME) from CO_2 hydrogenation over novel hybrid catalysts containing a Cu-ZnO-ZrO_2 catalyst admixed with WOx/Al_2O_3 catalysts. The activity of the hybrid catalyst attributed a combination of coke deposition, sintering of Cu-based catalyst and WOx/Al_2O_3 catalyst, and strongly adsorbed water molecules. Gu et al. (2018) reported an ultrasound-assisted biosynthesis of CuO NPs using brown alga *Cystoseira trinodis* extracts as an eco-friendly and time-saving process. The photocatalytic studies revealed the activity of the prepared CuO NPs as an efficient catalyst for the degradation of methylene blue (MB) in the presence of UV and sunlight. Finally, they introduced a facile, green, and low-cost method for the synthesis of monoclinic CuO NPs with catalytic, antioxidant, and antibacterial properties. Soleimani and Moghaddami (2018) reported the synthesis, characterization, and thermal properties of poly(methyl methacrylate) (PMMA)/CuO polymeric nanocomposites. The photocatalytic activity of CuO NPs, modified NPs, and PMMA/CuO polymeric nanocomposites (PNCs) was investigated in the degradation of methyl orange (MO) under UV radiation. Pang et al. (2018) reported the direct growth of Cu_2ZnSnS_4 on three-dimensional porous reduced graphene oxide thin films as counter electrode with high conductivity and excellent catalytic activity for dye-sensitized solar cells. Chen et al. (2018d) reported the preparation of Cu_2O@Au yolk/shell structures for efficient photocatalytic activity with a self-generated acid etching method. Cu_2O@Au yolk/shell structures were prepared with self-generated acid etching method at room temperature. The photocatalytic property of Cu_2O@Au yolk/shell structures was studied by degrading MO under the irradiation of visible light at room temperature. Benefiting from the synergistic effect of cavity micro-reactor and electron transfer, the photocatalytic performance of the as-prepared Cu_2O@Au yolk/shell structures was much better than that of pure Cu_2O. They proposed the possible photocatalytic mechanism of the Cu_2O@Au yolk/shell catalysts and suggested that yolk/shell structures have potential applications in photocatalysis for its active sites on the large specific area. Olivo et al. (2018) reported sustainable carbon dioxide photoreduction by a cooperative effect of reactor design and titania metal promotion. They have developed an effective process based on the photocatalytic reduction of CO_2 to face, on the one hand, and the crucial problem of environmental pollution, on the other hand, to propose an efficient way to produce clean and sustainable energy sources. Copper (in the oxide CuO form) or gold (as nanoparticles) was employed as promoting metal. Basumatary et al. (2018) reported a novel Ni-Cu/ZnO@MWCNT anode employed in urea fuel cell to attain superior performances. NiCu alloy nanoparticles loaded onto ZnO-coated multi-walled carbon nanotubes (MWCNTs) were evaluated as anode catalysts in direct urea fuel cells. The Ni-Cu/ZnO@MWCNT catalyst was synthesized by a two-step hydrothermal process. Palomino et al. (2018) reported hydrogenation of CO_2 on ZnO/Cu

(100) and ZnO/Cu (111) catalysts and role of copper structure and metal oxide interface in methanol synthesis. Reaction with CO_2 oxidized the zinc, enhancing its stability over the copper substrates. Pielsticker et al. (2018) reported surface segregation, restructuring, and sintering phenomena in size-selected copper-nickel nanoparticles (NPs) supported on silicon dioxide substrates were systematically investigated as a function of temperature, chemical state, and reactive gas environment. Zedan et al. (2018) reported the tailoring reducibility and catalytic activity of CuO nanoparticles for low-temperature CO oxidation. Venkatesha and Ramesh (2018) reported citric acid-assisted synthesis of nanoparticle copper catalyst supported on an oxide system for the reduction of furfural to furfuryl alcohol in the vapor phase. Hassan et al. (2018) reported an exploiting copper-silica-zirconia cooperative interaction for the stabilization of tetragonal zirconia catalysts and enhancement of the visible light photodegradation of bisphenol A. Kim et al. (2018) reported the mesoporous SiO_2-supported Cu_2O nanoparticles as an eggshell-type catalyst. The obtained Cu_2O/SiO_2 eggshell nanocatalyst had a large surface area and narrow pore size distribution, and the catalytic performance can be attributed to the synergistic advantages of mesoporous structure and monodispersed Cu_2O nanoparticles. Jeong et al. (2018) reported copper catalysts for the electrochemical reduction of carbon dioxide. Cu is the only metallic electrode capable of electrochemically converting CO_2 into hydrocarbons and alcohols with significant faradaic efficiencies. Ghadari et al. (2018) reported the synthesis of graphene oxide-supported copper-cobalt ferrite material functionalized by arginine amino acid as a new high-performance catalyst. $Cu_{0.5}Co_{0.5}Fe_2O_4$@Arg-GO catalytic system was prepared in which ferrite moiety acts as an oxidation catalyst and arginine has the role of base catalyst. Also, arginine amino acid was used to modify the surface of graphene oxide nanosheets which the prepared support can improve dispersion and uniform loading of nanoparticles. The prepared $Cu_{0.5}Co_{0.5}Fe_2O_4$@Arg-GO nanocomposite was used as an efficient catalyst for one-pot tandem oxidative synthesis of 2-phenylbenzimidazole derivatives in good yields. Abbas et al. (2018) reported the shape- and size-controlled synthesis of Cu nanoparticles wrapped on RGO nanosheet catalyst and their outstanding stability and catalytic performance in the hydrogenation reaction of dimethyl oxalate. Hou et al. (2018) reported in situ characterization of Cu-Fe-Ox catalyst for water-gas shift reaction. Jiang et al. (2018) reported three-dimensional Mn-Cu-Ce ternary mixed oxide networks prepared by polymer-assisted deposition for formaldehyde (HCHO) catalytic oxidation. These ternary mixed oxide networks will have good potential to be applied in various catalytic reactions. The polymer-assisted deposition approach could be further employed to develop a remarkably broad range of composite metal oxide materials for technical applications. Mohd Zabidi et al. (2018) reported the synthesis and characterization of Cu/ZnO catalyst on carbon nanotubes and Al_2O_3 supports. Cu/ZnO catalyst was synthesized on multi-walled carbon nanotubes (MWCNTs) and Al_2O_3 supports via incipient wetness impregnation method. Products obtained from the CO_2 hydrogenation reaction in the presence of these catalysts were methanol, ethanol, methyl formate, and methane. Hasan et al. (2018) reported *in situ* formation of graphene stabilizes zero-valent copper nanoparticles and significantly enhances the efficiency

of photocatalytic water splitting and suggested a novel method for metallic copper stabilization which illustrates the effect of metallic copper as a catalyst for the *in situ* formation of RGO. Chen et al. (2018e) reported thermally stable and highly active Pt/CeO_2@SiO_2 catalysts with a porous/hollow structure. They were proposed an efficient way to acquire thermally stable and highly active Pt/CeO_2@SiO_2 catalysts with a porous/hollow structure which exhibit high catalytic activity and remarkable durability toward CO oxidation. Ahmed et al. (2018) reported molten salts-derived copper tungstate nanoparticles as bifunctional electrocatalysts for electrolysis of water and supercapacitor applications. They investigated the potential for industrial applications and stability of the electrodes. Hosseini et al. (2018b) reported the CuO nanoparticles supported on three-dimensional nitrogen-doped graphene as a promising catalyst for thermal decomposition of ammonium perchlorate. CuO@3D-(N)GF was used as a promising catalyst for thermal decomposition of ammonium perchlorate (AP) as one of the most common oxidizers in composite propellants. Gupta et al. (2018) reported the copper chalcogenide nanoparticles (Cu_7S_4) supported on graphene oxide (GO), synthesized for the first time from Cu_2S, and used as highly efficient heterogeneous catalysts for oxidative orthoselective C-H aminomethylation of phenols with *N*,*N*-dimethylbenzylamines. Shahrokhian and Rezaee (2018) reported vertically standing Cu_2O nanosheets promoted flower-like PtPd nanostructures supported on reduced graphene oxide for methanol electro-oxidation. The PtPd-NFs/Cu_2O-NSs/RGO exhibited an outstanding electrocatalytic activity, lower onset potential, and high level of poisoning tolerance toward methanol oxidation in acidic media ascribed to the synergetic effect between bimetallic PtPd, Cu_2O, and RGO. And finally, PtPd-NFs/Cu_2O-NSs/RGO can be considered as a promising anode catalyst in direct methanol fuel cells. Zanganeh et al. (2018) reported sinter-resistant and highly active sub-5 nm bimetallic Au-Cu nanoparticle catalysts encapsulated in silica for high-temperature carbon monoxide oxidation. The gold-copper-based silica-encapsulated mixed metal oxide (MMO) core-shell catalyst Au-Cu@SiO_2 is suitable for its application in automotive combustion engine exhausts. Sartin et al. (2018) reported an effect of particle shape and electrolyte cation on CO adsorption to copper oxide nanoparticle electrocatalysts. Qiu et al. (2018) reported yolk-shell structured Cu_2O as a high-performance cathode catalyst for the rechargeable Li-O_2 batteries with long cycling life and high rate capacity. Muthukumar et al. (2018) reported fabrication of strong bifunctional electrocatalytically active hybrid Cu-Cu_2O nanoparticles in a carbon matrix. Cu-Cu_2O NPs@C has been used as bifunctional electrocatalysts for the oxygen evolution reaction (OER) and hydrogen evolution reaction (HER) and has exhibited a strong bifunctional electrocatalytic response at a high current density with a low catalyst loading among the different Cu-based nanostructured catalysts explored for the water splitting reactions.

Saiadian and Khorshidi (2018) reported the catalytic activity of copper nanostructures in the condensation reaction of selected indoles and aldehydes or ketones. Sheng et al. (2018) reported octahedral Pd nanocages with porous shells converted from $Co(OH)_2$ nanocages with nanosheet surfaces as robust electrocatalysts for ethanol oxidation to boost their large-scale applications for direct ethanol fuel cells.

The catalysts are prepared from the second template of a nanosheet surface of amorphous $Co(OH)_2$ octahedral nanocages, which are prepared from the original template of octahedral Cu_2O. These Pd octahedral nanocages exhibit a porous rough surface, which consists of smaller Pd nanoparticles, endowing them with highly active surface area and many active sites. Lang et al. (2018) reported CO oxidation over MOx (M = Mn, Fe, Co, Ni, Cu) supported on $SmMn_2O_5$ composite catalysts. They demonstrated that the best catalytic performance of the CuOx/Samarium Manganese Oxygen (SMO) composite also stems from the additional CO adsorption on the CuOx sites. Sivaranjan et al. (2018) reported the synthesis of highly active RGO-supported mono- and bimetallic nanocomposites as catalysts for chemoselective hydrogenation of α,β-unsaturated ketone to alcohol. The catalytic activity performances of mono- and bimetallic NC catalysts were studied toward the chemoselective hydrogenation of an α,β-unsaturated ketone to an alcohol. They observed catalytic activity and revealed that the bimetallic Cu-Pd/RGO NC catalyst showed a higher conversion yield, reusability, and good selectivity than Cu-Au/RGO as well as monometallic (Pd/RGO, Au/RGO) NCs. Salabat et al. (2018) reported a microemulsion route to fabrication of mono- and bimetallic Cu/Zn/γ-Al_2O_3 nanocatalysts for hydrogenation reaction. Finally, γ-Al_2O_3 was added to the colloidal systems to make Cu/Al_2O_3 or Cu-Zn/Al_2O_3 nanocatalysts. The prepared nanocatalysts were tested for hydrogenation reaction of an unsaturated aldehyde in a batch reactor and mild condition. Huang et al. (2018) reported an *in situ* strategy to understand the photocatalytic performance of Cu_2O-Ag@RGO nanocomposites through interfacial photocatalysis on an optical microfiber. The photocatalysts were conjugated on the surface of an optical microfiber immersed in an organic solution, forming an interface consisting of photocatalysts and organic molecules between the silica microfiber and the solution, which was within the evanescent field of the optical microfiber. The photodegradation efficiency of Cu_2O-Ag@RGO was almost twice that of Cu_2O, while the degradation rate constant was more than five times larger, because the coupling between the silver nanoparticles and reduced graphene oxide (RGO) enhanced the photocatalytic performance of Cu_2O. Chandel et al. (2018) reported the synthesis of multifunctional $CuFe_2O_4$-reduced graphene oxide nanocomposite used as an efficient magnetically separable catalyst as well as high-performance supercapacitor and first-principle calculations of its electronic structures. $CuFe_2O_4$-RGO nanocomposites have shown the catalytic properties toward the reduction of 4-nitrophenol and the epoxidation reaction. Bouazizi et al. (2018) reported silver nanoparticle-embedded copper oxide as an efficient core-shell for the catalytic reduction of 4-nitrophenol and antibacterial activity improvement. They reported a microporous CuO@Ag^0 core-shell with high catalytic and antibacterial activities. CuO@Ag^0 also exhibited an antibacterial activity against *Staphylococcus aureus*. The antibacterial effects were found to strongly depend on the size, contact surface, morphology, and chemical composition of the catalyst particles. The Ag^0 NPs open promising prospects for their potential applications as a low-cost catalyst in wastewater treatment and antibacterial agent in cosmetics. Chen et al. (2018f) reported a Cu_2Se-Cu_2O film electrodeposited on titanium foil as a highly active and stable electrocatalyst for the oxygen evolution reaction. The hybrid catalyst film composed of Cu_2Se and Cu_2O nanoparticles directly grown on Ti foil (Cu_2Se-Cu_2O/TF) via a cathodic electrodeposition method and resulted in sustained catalytic oxidation of water. Abbasi et al. (2018a) reported a unique combination of deep eutectic solvent (the combination of urea with choline chloride) and magnetic CuO@γ-Fe_2O_3 nanoparticles as a green magnetic nanocatalyst that promotes the synthesis of *N*-acylureas from reaction of carbodiimides with carboxylic acids. Wu et al. (2018b) reported a highly selective conversion of toxic nitrobenzene to nontoxic aminobenzene by $Cu_2O/Bi/Bi_2MoO_6$, a ternary catalyst. They also reported the active interfacial contact between copper oxide/metallic Bi/Bismuth Molybdenum oxide (BM)(Cu_2O/Bi/BM) in the designed sandwich structure facilitated the production and maintained the balance of Bi^{3+}/Bi^0 pairs, contributing to the enhanced activity and excellent stability. Bordbar et al. (2018) reported *Melissa officinalis* L. leaf extract-assisted green synthesis of CuO/ZnO nanocomposite for the reduction of 4-nitrophenol and rhodamine B. They have showed excellent catalytic activity in the degradation of 4-nitrophenol (4-NP) and rhodamine B (RhB) in water at ambient temperature. Yang et al. (2018a) reported CO oxidation on inverse Ce_6O_{12}/Cu (111) catalyst and the role of copper-ceria interactions. Shah et al. (2018) reported catalytic activity analysis of copper nanoparticles (Cu NPs) supported on a zinc oxide-polythiophene (ZnO-PTh) nanocomposite. Cu NPs@ZnO-PTh was used as a heterogeneous catalyst for the synthesis of propargylamine, tetra-substituted propargylamine, and pyrrolo[1,2-a]quinoline using a microwave technique in ethylene glycol as a recyclable, green, and biodegradable solvent with 98% yield. The high catalytic activity of Cu NPs@ZnO-PTh was due to the high surface area and synergetic effect of both the Cu NPs and ZnO-PTh nanocomposites, which make it cost-effective and environmentally benign with high atom economy. Ji et al. (2018) reported a hydrothermal synthesis of Fe_3O_4@C hybrid nanoparticle and magnetic adsorptive performance to remove heavy metal ions in aqueous solution. Advanced core-shell material with a high specific area has been considered as an effective material to remove heavy metal from aqueous solutions. They provide an ideal mode to remove heavy metal ions using core-shell Fe_3O_4@C under the water treatment condition. A new approach is clarified that core-shell nano-/micro-functional materials can be synthesized well on large scales which are used in many fields such as environmental remediation, catalyst, and energy. Yi et al. (2018) reported that nano-metal binary oxides were prepared by the combined method of complexation and impregnation in ultrasonic intervention for low-temperature catalytic oxidation of toluene under microwave radiation. Activity differences of prepared samples were evaluated using the removal rate and the mineralization rate as assessment criteria. Khan et al. (2018) reported the green synthesis of ZnO and Cu-doped ZnO nanoparticles from leaf extracts of *Abutilon indicum, Clerodendrum infortunatum*, and *Clerodendrum inerme* and investigation of their biological and photocatalytic activities. They have showed good candidates for the future therapeutic applications. Tabatabaei et al. (2018) reported a novel visible light-driven Cu-based MOFs/Ag_2O composite photocatalysts with enhanced photocatalytic activity toward the degradation of orange G (OG) and their photocatalytic mechanism and optimization study. They synthesized two visible light-driven Cu-based metal organic frameworks (Cu-H_3-btc and Cu-H_2-bdc) composited with Ag_2O nanoparticles to form Cu-H3-btc-Ag_2O-NPs and Cu-H_2-bdc-Ag_2O-NPs, and these are applied for the photocatalytic degradation of orange G (OG) dye in the presence of a blue light-emitting diode (LED). These photocatalytic performances of the as-prepared photocatalysts remain almost constant after reuse or exposure under visible light. Gao et al. (2017) reported designed synthesis CuO hollow microboxes coated with Pd nanosheets and SnO_2 nanoparticles as a highly efficient Rochow reaction catalyst. They designed and synthesized CuO/SnO_2/Pd hollow microboxes for dimethyldichlorosilane synthesis via the Rochow reaction. Song et al. (2017) reported encapsulated NdCuOx bimetallic nanoparticles with nitrogen-doped carbon as an efficient electrocatalyst for oxygen reduction reaction (ORR) in alkaline medium. Zhan and Zeng (2017) reported synthetic protocol for preparation of binary multi-shelled hollow materials (MSHMs) and their enhanced oxidation application. The number of layers in binary CuO/ZnO could be controlled by adjusting copper loading, annealing temperature, or heating ramp rate, and binary CuO/ZnO MSHMs exhibited pronounced catalytic activity on the advanced oxidation process (AOP) toward dye wastewater treatment. Narasaiah et al. (2017) reported biosynthesis of copper oxide nanoparticles from *Drypetes sepiaria* leaf extract and their catalytic activity to dye degradation. They performed photocatalytic activity to examine the photocatalytic degradation efficiency of CuO NPs to Congo Red and colloidal solutions of CuO NPs showed good catalytic activity. Mu et al. (2017) reported the composite catalysts of Cu/CuxO nanoparticles supported on the carbon fibers were prepared for styrene oxidation reaction. Bae et al. (2017) reported colloidal zinc oxide-copper(I) oxide nanocatalysts for selective aqueous photocatalytic carbon dioxide conversion into methane. Gopiraman and Chung (2017) reported highly active and cost-effective CuO-based carbon nanocomposite with unique morphology for catalytic synthesis of imines under solvent-free conditions. Yan et al. (2017) reported in situ integration of ultrathin PtCu nanowires with reduced graphene oxide nanosheets for efficient electrocatalytic oxygen reduction. Clarizia et al. (2017) reported an effect of surface properties of copper-modified commercial titanium dioxide photocatalysts on hydrogen production through photoreforming of alcohols. Dai et al. (2017) reported hollow zeolite-encapsulated Fe-Cu bimetallic catalysts for phenol degradation. Dante et al. (2017) reported polymeric carbon nitride was synthesized from urea and doped with Cu and Fe to act as co-catalysts. The material doped with Fe was a new composite material composed of Fe(III) oxides (acting as a co-catalyst) wrapped by the polymer layers and amorphous carbon. Hsiao and Lin (2017) reported growth of a superhydrophobic multi-walled carbon nanotube forest on quartz using flow-vapor-deposited copper catalysts. Xie et al. (2017) reported recent advances in Cu-based nanocomposite photocatalysts for CO_2 conversion to solar fuels. Li et al. (2017c) reported preparation of ultrafine $Cu_{1.5}Mn_{1.5}O_4$ spinel nanoparticles and its application in *p*-nitrophenol reduction. Wu et al. (2017) reported one-pot method for the fabrication of reduced graphene oxide (RGO)/metal (oxide) (e.g., RGO/Au, RGO/Cu_2O, and RGO/Ag) composites using glucose as the reducing agent and the stabilizer. The glucose not only reduced GO effectively to RGO but also reduced the metal precursors to form metal (oxide) nanoparticles on the surface of RGO. These developed nanomaterials were utilized as an electrode catalyst to simultaneous electrochemical analysis of L-ascorbic acid, dopamine, and uric acid. Dong et al. (2017) reported synthesis, characterization, and application of CuO-modified TiO_2 electrode exemplified for ammonia electro-oxidation. CuO-TiO_2 catalyst was synthesized using the coprecipitation method with $Cu(NO_3)_2$ as the active component for the electrochemical oxidation (ECO) of ammonia (NH_3). Mateo et al. (2017) reported photoassisted CO_2 methanation which can be carried out efficiently at 250 °C using Cu_2O nanoparticles supported on few layer graphene (Cu_2O/G) as a photocatalyst. Vimala Devi et al. (2017) reported the synthesis, defect characterization, and photocatalytic degradation efficiency of Tb-doped CuO nanoparticles. They have demonstrated the photocatalytic performance of undoped and Tb-doped CuO on degradation of methylene blue (MB) and methyl orange (MO). Ghosh et al. (2017) reported amberlite resin formate (ARF) with a polyionic polar environment is successfully utilized as a unique support for immobilization of stabilized Cu_2O nanoparticles (NPs). Elhamifar et al. (2017) reported magnetic iron oxide-supported copper/Schiff- base complex (Cu/SB-Fe_3O_4) as nanocatalyst for the synthesis of biologically active 3,4-dihydropyrimidinones.

Bondarenko et al. (2017) reported copper$^{(0)}$ nanoparticles supported on Al_2O_3 as catalyst for carboxylation of terminal alkynes for the first time used as heterogeneous catalyst. Ghasemi Estarki (2017) reported simple synthesis of $CuAl_2O_4$ nanoparticles by a new morphological control method and characterization of its photocatalytic activity. The synthesis of semiconducting copper aluminate ($CuAl_2O_4$) nanoparticles using aluminum nitrate and copper nitrate as the starting reagent in the presence of different natural polymers such as polyoxyethylene (80) sorbitan monooleate, ethyl cellulose, and starch through sol-gel methods was reported. The photocatalytic decomposition of methyl orange (MO) pollutant was reported under visible illumination. Shi et al. (2017a) reported phenol hydroxylation over cubic/monoclinic mixed phase CuO nanoparticles prepared by chemical vapor deposition (CVD). CuO/SiO_2 catalysts exhibit a much higher dispersion degree of CuO than those by impregnation and thus much better catalytic performances in phenol hydroxylation to catechol and hydroquinone. Shi et al. (2017b) reported phase-controlled growth of cubic phase CuO nanoparticles by chemical vapor deposition. Cupric oxide has monoclinic, tetragonal, and cubic phases. The cubic phase of CuO was deposited on alumina substrate using $Cu(acac)_2$ as precursor. As catalysts, the cubic CuO on alumina was found to be active and selective in the hydroxylation of phenol to catechol, hydroquinone, and benzoquinone. Zhang et al. (2017a) reported the composite films consisting of graphene and CuPW11 polyoxometalates {GN/CuPW11}*n*. The introduction of CuPW11 improves electrocatalytic activity, stability, and CO-tolerance ability of Pt/graphene composite catalysts toward methanol oxidation. Maham et al. (2017) reported biosynthesis of the CuO nanoparticles using Euphorbia *c*hamaesyce leaf extract and investigation of their catalytic activity for the reduction of 4-nitrophenol. Tang et al. (2017b) reported an effect of particle size and morphology on surface thermodynamics and photocatalytic thermodynamics of nano-Cu_2O. They found that nano-Cu_2O with low surface energy exhibited a high photocatalytic activity. Liu et al. (2017) reported Cu_2O nanoparticles supported on carbon nanofibers as a cost-effective and efficient catalyst for RhB and phenol degradation. Due to the synergistic effect between photocatalytic activity of Cu_2O and excellent adsorption capacity of CNFs, the obtained Cu_2O/CNFs exhibited excellent photocatalytic activity for degradation of rhodamine B (RhB) and phenol. The hybrid composite Cu_2O/CNFs could be applied as catalytic materials for application in the future. Paulose et al. (2017) reported copper oxide alumina composite via template-assisted sol-gel method for ammonium perchlorate decomposition. Ye et al. (2017) reported PdCu alloy nanoparticles supported on reduced graphene oxide as active catalyst for electroless copper plating. PdCu bimetallic alloy nanoparticles on reduced graphene oxide could be used as active agent for electroless copper plating on epoxy board and paper. The as-prepared nanocatalyst was promising for the future development of interconnect technologies in electronic packaging. Ji et al. (2017) reported 3D porous Cu@Cu_2O films supported Pd nanoparticles for glucose electrocatalytic oxidation. They have found enhanced activity of the porous Cu@Cu_2O-Pd nanostructures which might be attributed to the unique hierarchical porous structures with highly exposed active sites and synergetic effect from metal oxide semiconductor Cu_2O and noble metal Pd. Vats et al. (2017) reported pristine graphene-copper(II) oxide nanocatalyst, a novel and green approach in CuAAC reactions. They have introduced a quick and green route to synthesize CuO nanocomposites using pristine graphene as a support material by microwave-assisted hydrothermal reaction. The pristine graphene in the nanocomposite increases the catalytic activity due to its better conductivity and ability to adsorb reactants through π-π interaction than RGO. The pristine graphene-CuO nanocomposite showed good recyclability. The CuAAC reactions were using water as a green solvent with pristine graphene-CuO nanocomposite as catalyst and sodium ascorbate as co-catalyst. Abbasi et al. (2017) reported copper oxide supported on magnetic nanoparticles (CuO@γ-Fe_2O_3), an efficient and magnetically separable nanocatalyst for addition of amines to carbodiimides toward synthesis of substituted guanidines.

5.4 Optoelectronics

Zhang et al. (2018d) reported preparation of bilayer graphene utilizing CuO as nucleation sites by CVD method. Graphene is an attractive 2D material for optoelectronics applications. Litvin et al. (2017) reported colloidal quantum dots for optoelectronic devices, photovoltaic cells, photodetectors, and LEDs. In addition, we analyze recent advances in charge transport layers, blocking layers, nanostructured photoanode fabrication, and the importance of QD surface treatments. Throughout, we emphasize the use of hybrid composite materials including combinations of QDs with metal oxides, plasmonic nanoparticles, graphene, and others. Finally, this review provides an analysis of prospects of these important selected quantum dot-based optoelectronic devices. Park et al. (2016b) reported transversally extended laser plasmonic welding for oxidation-free copper fabrication toward high-fidelity optoelectronics. They have reported physical/chemical properties of fabricated Cu conductors and showed durability in terms of bending and adhesion. They have also demonstrated a single-layer Cu-mesh-based touch screen panel (TSP) on thermally sensitive polymer film. Bian et al. (2014) reported a nanocomposite superstructure of metal oxides with effective charge transfer interfaces. Metal oxide mesocrystals have potentially tunable electronic, optical, and magnetic properties useful for applications to catalysis to optoelectronics and sensing to energy storage and conversion. Zhang et al. (2013) reported the deterministic growth of AgTCNQ and CuTCNQ nanowires on large-area reduced graphene oxide films for flexible optoelectronics. They were showed measurements of the optoelectronic properties of RGO/metal-TCNQ hybrid films which exhibit substantial photoconductivity and highly reproducible photoswitching behaviors, and this approach may open the door to the versatile and deterministic integration of functional nanostructures into flexible conducting substrates and producing low-cost and high-performance soft electronic and optoelectronic devices. Heusing et al. (2008) reported the development of printed indium tin oxide (ITO) coatings on PET and polyethylene naphthalate (PEN) foil for flexible organic photodiodes. They have demonstrated the performance of the photodiodes with printed ITO on plastic substrates by the deposition of a PEDOT/PSS layer (Baytron® P) on the ITO-coated foils.

5.5 Wastewater Removal and Its Purification

Wan et al. (2018) reported that manganese oxide nanoparticles impregnated graphene oxide aggregates for cadmium and copper remediation. Kostic et al. (2018) reported the synthesis of mesoporous triple-metal nanosorbent from layered double hydroxide as an efficient new sorbent for removal of dye from water and wastewater. They have carried out coprecipitation synthesis of the mesoporous triple-metal nanosorbent from Fe, Cu, Ni layered double hydroxide (FeCuNi-LDH). Obtained FeCuNi-280 material showed the ability for efficient removal of dye Reactive Blue 19 (RB19) from wastewater of textile industry in wide range of pH. Zhang et al. (2018e) reported the green and size-specific synthesis of stable Fe-Cu oxides as earth-abundant adsorbents for malachite green removal. A green and sustainable pathway is described using Virginia creeper (*Parthenocissus quinquefolia*) leaf extract in the presence of oxalic acid for the synthesis of earth-abundant Fe- and Cu-based nanoparticle adsorbents. This optimized green method could produce Fe- and Cu-based nanoparticles with a remarkably high maximum adsorptive capacity for aqueous malachite green (MG) removal. They were suggested that not only promotes the use of natural, earth-abundant, and renewable resources in synthesizing novel and efficient absorbents but also provides a simple, convenient, and cost-effective strategy for the purification of dye-laden wastewater. Hosseinzadeh and Ramin (2018) reported an effective removal of copper from aqueous solutions by modified magnetic chitosan/graphene oxide nanocomposites. Ursino et al. (2018)

reported the progress of nanocomposite membranes for water treatment. The nanocomposite membranes for water treatment applications such as wastewater treatment, water purification, and removal of microorganisms, chemical compounds, heavy metals, etc., have been established. The different nanofillers, such as carbon nanotubes, zinc oxide, graphene oxide, silver and copper nanoparticles, and titanium dioxide, have provided great advances for water treatment applications. Zhang et al. (2017b) reported comparison and distribution of copper oxide nanoparticles and copper ions in activated sludge reactors. Under equal Cu concentration, copper ions were more toxic toward microorganisms compared to CuO NPs. CuO NPs were removed effectively from wastewater due to a greater biosorption capacity of CuO NPs onto activated sludge, when compared to the copper ions. The decrease in live/dead ratio after 5 h of exposure of CuO NPs and Cu^{2+} indicated the loss of cell viability in sludge flocs. Piplai et al. (2017) reported the removal of mixture of ZnO and CuO nanoparticles (NPs) from water using activated carbon in batch kinetic studies. They were suggested that as there is a need for removing NPs from wastewater, removal of NPs using an AC-based adsorptive-filter might become a promising method. Zhang et al. (2017c) reported the combined impacts of nanoparticles on anammox granules and the roles of ethylenediaminetetraacetic acid (EDTA). Previous studies investigating the risk of engineered nanoparticles (NPs) to biological wastewater treatment have tested NPs individually, but limited data are available on the impact of NPs on the anaerobic ammonium oxidation (anammox) process. They were suggested that the toxicity of NPs was dependent on the amount of active metal reaching the anammox cells and provided insights into the combined toxicity of NPs on anammox biomass. Miao et al. (2016) reported aggregation and removal of copper oxide (CuO) nanoparticles in wastewater environment and their effects on the microbial activities of wastewater biofilms. The have investigated the transport behaviors of copper oxide (CuO) NPs in wastewater matrix and their possible impacts on microbial activities of stable wastewater biofilms cultivated in a lab scale rotating biological contactor (RBC). Extracellular polymeric substance (EPS)-adsorbed copper accounted for a large proportion of the total copper accumulated in biofilms. Biofilms secreted more EPS in response to the nano-CuO stress, with higher production of proteins when compared to polysaccharides. Swain et al. (2016) reported the sustainable valorization processes for selective recovery of pure copper nanopowder from indium tin oxide (ITO) etching wastewater by various wet chemical reduction processes. Phul et al. (2018) reported ascorbic acid-assisted synthesis, characterization, and catalytic application of copper nanoparticles showed degradation of RhB in the dark and light. They found enhancement in the catalytic efficiency of Cu nanoparticles.

5.6 Anticancer Activity

Abbasi et al. (2018b) reported the three new mononuclear Schiff-base complexes which were synthesized, characterized, and used as a precursor for preparation of metal oxide nanoparticles. In vitro cell proliferation via (3-(4,5-Dimethylthiazol-2-yl)-2,5-Diphenyltetrazolium Bromide) (MTT) assay was studied to calculate the cytotoxicity of complexes and metal oxide nanoparticles against gastric cancer cell line (MKN-45) and suggested that all three compounds have anticancer activity with dose-response dependency. Muzammil et al. (2018) reported nanoantibiotics for the future nanotechnologies to combat antibiotic resistance. Metal and metal oxide nanoparticles have been established as better alternatives but the combination of antibiotics and metal oxide nanoparticles decrease the toxicity and enhance the antibacterial, antiviral, and anticancer efficacy. Kalaiarasi et al. (2018) reported copper oxide nanoparticles induce anticancer activity in A549 lung cancer cells by inhibition of histone deacetylase (HDACs). They have copper oxide nanoparticles (CuO NPs) promoting anticancer activity. A549 cells treated with CuO NPs downregulated oncogenes and upregulated tumor suppressor protein expression. Sulaiman et al. (2018) reported biogenic synthesis of copper oxide nanoparticles using *Olea europaea* leaf extract and evaluation of their toxicity activities and findings suggest that Cu NPs may have the potential to be anticancer agents. Afzali et al. (2018) reported square wave voltammetric determination of anticancer drug flutamide using carbon paste electrode modified by CuO/GO/PANI nanocomposite. The electrochemical behavior of flutamide was investigated using a carbon paste electrode (CPE) modified by CuO nanoparticles/graphene oxide/polyaniline (CuO/GO/PANI) nanocomposite. The modified electrode was applied for the determination of flutamide in human urine and pharmaceutical samples with satisfying results. Dey et al. (2018) reported *Azadirachta indica* leaves-mediated green-synthesized copper oxide nanoparticles induce apoptosis through activation of TNF-α and caspases signaling pathway against cancer cells. They were suggested that green synthesized CuO NPs might be beneficial for its application as an anticancer drug in in vivo and in vitro mice model. Khan et al. (2018) reported green synthesis of ZnO and Cu-doped ZnO nanoparticles from leaf extracts of *Abutilon indicum*, *Clerodendrum infortunatum*, and *C. inerme* and investigation of their biological and photocatalytic activities. They have carried out green synthesis and determination of the antioxidant, antibacterial, antifungal, anticancer, and photocatalytic properties of the resultant Cu-doped zinc oxide nanoparticles (NPs). Cu-doped ZnO NPs showed antimicrobial, antioxidant, and antifungal potential, and they are good candidates for therapeutic applications. Sriram et al. (2017) reported CuO-loaded hydrophobically modified chitosan as hybrid carrier for curcumin delivery and anticancer activity. The drug-loaded chitosan-phendione and chitosan with CuO nanoparticles were used for anticancer activities toward the cell lines M19-MEL, MCF-7, and HeLa. Gnanavel et al. (2017) reported biosynthesis and characterization of copper oxide nanoparticles and its anticancer activity on human colon cancer cell lines (HCT-116). They have biosynthesized the stable copper oxide nanoparticles (CuO NPs) from the leaves of *Ormocarpum cochinchinense* to demonstrate anticancer cytotoxicity on human colon cancer cell lines (HCT-116). Rehana et al. (2017) reported an evaluation of antioxidant and anticancer activity of copper oxide nanoparticles synthesized using medicinally important plant extracts, i.e., using different plant extracts obtained from the leaves of *Azadirachta indica, Hibiscus rosa-sinensis, Murraya koenigii, Moringa oleifera*, and *Tamarindus indica*. The leaf extracts showed the presence of carbohydrates, flavonoids, glycosides, phenolic compounds, saponins, tannins, proteins, and amino acids. They have evaluated the cytotoxicity of copper oxide nanoparticles against four cancer cell lines such as human breast (MCF-7), cervical (HeLa), epithelioma (Hep-2) and lung (A549), and one normal human dermal fibroblast (NHDF) cell line. Alishah et al. (2017) reported the green synthesis of starch-mediated CuO nanoparticles using starch extracted from *Solanum tuberosum* and its preparation, characterization, antimicrobial activities, and in vitro MTT assay against MCF-7 cell line. They have evaluated antibacterial activity of copper oxide nanoparticles tested against Gram-positive and Gram-negative bacteria. Peng et al. (2017) reported biocompatible CuS-based nanoplatforms for efficient photothermal therapy and chemotherapy. CuS nanoparticles were coated with mesoporous silicon dioxide (SiO_2) and further loaded with anticancer drug doxorubicin (DOX), i.e., CuS@MSN-DOX. The infrared thermal imaging of CuS@MSN-DOX exploited as a multifunctional platform for combined photothermal therapy (PTT) and chemotherapy at the cell level and in a mice model and also demonstrated that synergistic effect of chemo-photothermal therapy, i.e., combined therapy of cancer. Nagajyothi et al. (2017) reported copper oxide nanoparticles (CuO NPs) which were synthesized by a green route using an aqueous black bean extract and showed anticancer activity of copper oxide nanoparticles against human cervical carcinoma cells. They have showed that the CuO NPs can induce apoptosis and suppress the proliferation of HeLa cells. Giannousi et al. (2016) reported the synthesis and biological evaluation of PEGylated CuO nanoparticles against tumor formation, development, and progression. They have evaluated anticancer activity of the NPs on human cervical carcinoma HeLa cells by using human immortalized embryonic kidney 293 FT cells as a control. Ramaswamy et al. (2016) reported the potentiating effect of eco-friendly synthesis of copper oxide nanoparticles using brown alga for antimicrobial and anticancer activities. The anticancer activity of brown algae-mediated copper oxide nanoparticles was determined against the cell line (MCF-7). Gopinath et al. (2016) reported *in vitro* toxicity, apoptosis, and antimicrobial effects of phyto-mediated copper oxide nanoparticles. The synthesis CuO NPs use the aqueous dried fruit extract of *Tribulus terrestris* and assess their potential in vitro cytotoxicity and antibacterial activity for pharmaceutical applications. Baskar et al. (2016) reported *in vitro* cytotoxicity of copper oxide nanobiocomposites synthesized by *Catharanthus roseus* flower extract against breast cancer cell line. The anticancer activity of copper oxide *nanobiocomposite* against MCF-7 cancer cell lines was reported. Sankar et al. (2014) reported anticancer activity of *Ficus religiosa* engineered copper oxide nanoparticles. Sivaraj et al. (2014) reported biosynthesis and characterization of *Acalypha indica*-mediated copper oxide nanoparticles and evaluation of its antimicrobial and anticancer activity. Copper oxide nanoparticles showed antibacterial and antifungal effect against *Escherichia coli, Pseudomonas fluorescens*, and *Candida albicans*. The cytotoxicity activity of *A. indica*-mediated copper nanoparticles was evaluated against MCF-7 breast cancer cell lines and confirmed that copper oxide nanoparticles have cytotoxicity activity. Germi et al. (2014) reported the copper oxide nanoparticles which showed excellent antitumor activity against two kinds of cancer cells that are AGS (human gastric carcinoma) cells and HeLa (human cervix carcinoma) cells. Hou et al. (2013) reported a facile synthesis of water-dispersible Cu_2O nanocrystal-reduced graphene oxide hybrid as a promising cancer therapeutic agent. They have also reported a Cu_2O nanocrystal-reduced graphene oxide hybrid has anticancer activity and showed safe and applicable cancer therapy agents.

5.7 Antimicrobial/Antibacterial Activity

Bhushan et al. (2019) reported thedevelopment of inorganic nanoparticles-based novel antibiotic. Inorganic nanoparticles have the potential of being used as bactericidal agent due to their effective antimicrobial activity, colloidal aqueous stability, and comparatively low toxic profile. The antibacterial activities of the samples were established against pathogenic strains of bacteria such as *E. coli, B. subtilis, S. aureus*, and *S. typhi*. Wang et al. (2019c) reported photovoltaic and antimicrobial potentials of electrodeposited copper nanoparticle. They were fabricated ITO/CuNP/CuI/Cu (indium tin oxide/copper nanoparticle/copper iodide/copper) substrate solid-state photovoltaic cell by CuNP electrodeposition on the CuI substrate. Kumar et al. (2018) reported efficacious fungicidal potential of composite derived from nano-aggregates of Cu-diclofenac complexes and ZnO nanoparticles. They have reported the synergistically enhanced antifungal activity of the composite developed from self-assembled nano-aggregates of copper complexes of nonsteroidal anti-inflammatory drug, diclofenac (Cu-Dc) in combination with zinc oxide (ZnO) nanoparticles. They have showed increased zones of inhibition in agar well-diffusion method against a human pathogenic fungus (*Candida albicans*) and three plant pathogenic fungi (*Penicillium funiculosum*, *Aspergillus niger*, and *Fusarium oxysporum*). Hong et al. (2018) reported antibacterial activity of Cu_2O and Ag comodified rice grains like ZnO nanocomposites. Cu_2O-Ag/ZnO, Cu_2O/ZnO, and Ag/ZnO nanocomposites showed a synergistic effect on antibacterial activity and antimicrobial activity against *Escherichia coli* and *Staphylococcus aureus*. Markovic et al. (2018) reported antibacterial activity of Cu-based nanoparticles synthesized on the cotton fabrics modified with polycarboxylic acids. The fabrication of antimicrobial textile nanocomposite has provided maximum reduction of Gram-negative bacterium *E. coli* and Gram-positive bacterium *S. aureus*. Singh et al. (2018) reported green synthesis of metals and their oxide nanoparticles for the applications in environmental remediation. The green synthesis is regarded as an important tool to reduce the destructive effects associated with the traditional methods of synthesis for nanoparticles commonly utilized in laboratory and industry. Metal and metal oxide [e.g., gold (Au), silver (Ag), copper oxide (CuO), and zinc oxide (ZnO)] nanoparticles use natural extracts containing phytochemicals (e.g., flavonoids, alkaloids, terpenoids, amides, and aldehydes) as reducing agents and solvent systems.

Duffy et al. (2018) reported investigation into the antibacterial activity of silver, zinc oxide, and copper oxide nanoparticles against poultry-relevant isolates of *Salmonella* and *Campylobacter*. Ebrahim-Saraie et al. (2018) reported promising antibacterial effect of copper oxide nanoparticles against several multidrug-resistant uropathogens. Pugazhendhi et al. (2018) reported photocatalytic properties and antimicrobial efficacy of Fe-doped CuO nanoparticles against the pathogenic bacteria and fungi. They have reported for the first time showing both antibiofilm and antibacterial activities of Fe-doped CuO NPs against bacterial and fungal pathogens. El-Nahhal et al. (2018) reported the efficacy of surfactants in stabilizing coating of nanostructured CuO particles onto the surface of cotton fibers and their antimicrobial activity. The CuO NPs-coated cotton materials have also showed an excellent inhibition for the growth of the medically relevant *Staphylococcus aureus* and *Escherichia coli*. Chung et al. (2018) reported production of bioactive compounds and gene expression alterations in hairy root cultures (HRCs) of Chinese cabbage elicited by copper oxide nanoparticles. Chinese cabbage is an important vegetable and rich source of phytochemicals such as glucosinolates (GSLs) and phenolic compounds (PCs) that are used in pharmaceutical industries. CuO NPs-elicited HRCs offered an efficient and promising in vitro technique to induce secondary metabolites (GSLs and PCs) for possible nutraceutical and pharmaceutical uses. Zare Khafri et al. (2018) reported synthesis of CuS and $ZnO/Zn(OH)_2$ nanoparticles and their evaluation for in vitro antibacterial and antifungal activities. The antimicrobial activity of the CuS NPs and the $ZnO/Zn(OH)_2$ NPs against *Klebsiella pneumonia* (ATCC 1827), *Acinetobacter baumannii* (ATCC 150504), *Escherichia coli* (ATCC 33218), and *Staphylococcus aureus* (ATCC 25293) has been reported. Almasi et al. (2018) reported fabrication of novel nanohybrids by impregnation of CuO nanoparticles into bacterial cellulose and chitosan nanofibers . They have observed a synergistic effect between CuO and CHNF on the antimicrobial activity of CuO-CHNF nanohybrid, and also they have demonstrated the potential of fabricated nanohybrids in water purification and food packaging applications. Ruey Ong et al. (2018) reported an influence of CuO nanoparticle on palm oil-based alkyd resin preparation and its antimicrobial activity. They have found that the CuO speeded up the reaction rate and played antimicrobial role. Vaseghi et al. (2018) reported rapid biosynthesis of novel Cu/Cr/Ni trimetallic oxide nanoparticles with antimicrobial activity. The trimetallic oxide Cu/Cr/Ni nanoparticles (NPs) have been developed using the aqueous leaf extracts of *Eryngium campestre* (*E. campestre*) and *Froriepia subpinnata* (*F. subpinnata*) as bioreducing and capping agents. Safaei and Taran (2018) reported optimized synthesis, characterization, and antibacterial activity of an alginate-cupric oxide bio-nanocomposite. They have showed the alginate-CuO nanocomposite fabrication and ability to act as an antimicrobial agent against Gram-negative and Gram-positive bacteria. Gajalakshmi et al. (2018) reported guar gum (GG)-stabilized copper oxide nanoparticles with enhanced thermal and antimicrobial properties. Alzahrani et al. (2018) reported antibacterial activity of trimetal (CuZnFe) oxide nanoparticles. They have showed that the antibacterial activity of the trimetal oxide NPs was greater against *E. coli* than against *E. faecalis*. Zhang et al. (2018f) reported the effects of copper nanoparticles in porous TiO_2 coatings on bacterial resistance and cytocompatibility of osteoblasts and endothelial cells. Copper (Cu) has showed excellent antimicrobial activity and playing roles in human metabolism. Tran et al. (2017) reported biocompatible copper oxide nanoparticle composites from cellulose and chitosan as antimicrobial activity also known to have bactericidal activity. The composites exhibited antimicrobial activity against bacteria and fungi, including methicillin-resistant

Staphylococcus aureus; vancomycin-resistant Enterococcus; and highly resistant *Escherichia coli, Streptococcus agalactiae, Pseudomonas aeruginosa*, *Stenotrophomonas maltophilia*, and *Candida albicans*. Shobha et al. (2017) reported plant pathovar inhibition from copper-based nanoparticles synthesized from leaf extract of *Flacourtia montana*. The Cu_2O showed remarkable antibacterial activity against *Xanthomonas vesicatoria* and antifungal activity against *Alternaria solani.* Babaei et al. (2017) reported the bactericidal effect of copper oxide nanoparticles on *Shigella sonnei* and *Salmonella typhimurium*. Manyasree et al. (2017) reported CuO nanoparticles' synthesis, characterization, and their bactericidal efficacy against *Escherichia coli, Proteus vulgaris*, *Staphylococcus aureus*, and *Streptococcus mutans*. The copper oxide is a good antibacterial agent against both Gram-positive and Gram-negative organisms. Pourbeyram et al. (2017) reported green synthesis and characterization of ultrafine copper oxide/reduced graphene oxide (CuO/RGO) nanocomposite. Hosseinzadeh et al. (2017) reported the green synthesis of copper oxide nanoparticles using aqueous extract of *Convolvulus persicus* L. as reusable catalysts in cross-coupling reactions and their antibacterial activity. Pansambal et al. (2017) reported phytosynthesis and biological activities of fluorescent CuO nanoparticles using *Acanthospermum hispidum* L. extract. Oun and Rhim (2017) reported carrageenan-based hydrogels and films: effect of ZnO and CuO nanoparticles on the physical, mechanical, and antimicrobial properties. Giannousi et al. (2017) reported copper-based nanoparticles as antimicrobials. El-Batal et al. (2017) reported melanin production by *Streptomyces cyaneus* and synthesis of copper oxide nanoparticles using gamma radiation. Melanin pigment is used in medicine, food, and cosmetic. *Streptomyces cyaneus* is utilized for the synthesis of melanin. Copper oxide nanoparticles (CuO NPs) exhibited antimicrobial activity against foodborne Gram-positive and Gram-negative bacteria and fungi; they can find potential applications for the food packaging approach. Ijaz et al. (2017) reported the green synthesis of copper oxide nanoparticles using *Abutilon indicum* leaf extract as antimicrobial, antioxidant, and photocatalytic dye degradation activities and also indicate that they are good candidates for future therapeutic applications. Muthulakshmi et al. (2017) reported preparation and properties of cellulose nanocomposite films with in situ generated copper nanoparticles using *Terminalia catappa* leaf extract. They have shown that the cellulose/CuNP composite films exhibited good antibacterial activity against *E. coli* bacteria. Albalawi et al. (2017) reported an effect of Ag, Cu, and ZnO nanoparticle suspensions on the antimicrobial activity of *Tribulus terrestris* herbal extracts against *E. coli, Proteus sp.*, *Morganella sp.*, *Entrococcus faecalis, Staphylococcus aureus*, and *Candida albicans*. Peszke et al. (2017) reported a unique property of silver and copper-silica-based nanocomposites as antimicrobial agents. The metallic silica-based nanostructure (Ag/SiO_2, Cu/SiO_2) has revealed inhibition of growth of Gram-positive and Gram-negative bacteria as well as microscopic fungi. Altikatoglu et al. (2017) reported the green synthesis of copper oxide nanoparticles using *Ocimum basilicum* extract which is found to have antibacterial activity against pathogenic bacterial strains *E. coli* and *S. aureus.* Syame et al. (2017) reported the synthesis of copper-chitosan nanocomposites and their applications in treatment of local pathogenic isolate bacteria.

Ong et al. (2016) reported the influence of CuO nanoparticle on non-edible rubber seed oil-based alkyd resin preparation and its antimicrobial activity. Moshalagae Motlatle et al. (2016) reported chemical synthesis, characterization, and evaluation of antimicrobial properties of Cu and its oxide nanoparticles. They have showed excellent antimicrobial activity of Cu_2O/CuO nanoparticles against a mixture of bacterial strains (*S. aureus, E. coli*, and *P. aeruginosa*), indicating that the size as well as oxidation state of Cu contributes to the antibacterial efficacy. Shaffiey and Shaffiey (2016) reported silver oxide-copper oxide nanocomposite preparation and antimicrobial activity as a source for the treatment of fish diseases. The antimicrobial activities of Ag_2O/CuO nanoparticles (NPs) provide application of Ag_2O/CuO nanoparticles as disinfectant and/or antibiotic in the fishery industry. Jayandran et al. (2016a) reported the green synthesis, characterization, and antimicrobial activity studies of salicylalchitosan biofunctionalized copper oxide nanoparticles. They observed that antimicrobial activities of biofunctionalized copper oxide nanoparticles have higher inhibition activity than the non-functionalized nanoparticles and salicylalchitosan against standard microbial species. Park et al. (2016a) reported copper oxide nanoparticles aggravate airway inflammation and mucus production in asthmatic mice via mitogen-activated protein kinase (MAPK) signaling. CuO NPs markedly increased inflammatory cell infiltration into the lung and mucus secretions and exhibited toxicity on the respiratory system. CuO NPs' exposure has a potential toxicity in humans with respiratory disease. Ramaswamy et al. (2016) reported potentiating effect of eco-friendly synthesis of copper oxide nanoparticles using brown alga as antimicrobial and anticancer activities. Jayandran et al. (2016b) reported the green synthesis, characterization, and antimicrobial activity studies of curcuminaniline biofunctionalized copper oxide nanoparticles. Biofunctionalization of nanoparticles is the recent and advanced technology in the fields of nanoscience and biotechnology which produces the environmentally benign and more efficient antimicrobial agents. Baskar et al. (2016) reported *in vitro* cytotoxicity of copper oxide nanobiocomposites synthesized by *Catharanthus roseus* flower extract against breast cancer cell line. The anticancer activity of synthesized copper oxide nanobiocomposite against MCF-7 cancer cell lines was established. Pathania et al. (2016) reported the fabrication, characterization, and cytotoxicity of guar gum/copper oxide nanocomposite and efficient removal of organic pollutant. The GG/CuO nanocomposite was nontoxic for the CHO-K1 cells, oral cancer cells KB, and rat glioma C6 cells. Katwal et al. (2015) reported electrochemical synthesized copper oxide nanoparticles for enhanced photocatalytic and antimicrobial activity. The CuO NPs were used as excellent photocatalyst for the degradation of different organic dyes like methylene blue. The antimicrobial efficiency of CuO NPs was investigated against bacterial strains (*E. coli* and *S. aureus*) and fungal strains (*Aspergillus niger* and *Candida albicans*). Singh et al. (2015) reported antibiofilm and membrane-damaging potential of cuprous oxide nanoparticles against *Staphylococcus aureus* with reduced susceptibility to vancomycin. Cu_2O NPs exert their action by disruption of the bacterial cell membrane and can be used as effective antistaphylococcal and antibiofilm agents in diverse medical devices. Thampi et al. (2015) reported functionalization of fabrics with PANI/CuO nanoparticles by precipitation route for antibacterial applications. Malka et al. (2013) reported the eradication of multidrug-resistant bacteria by a novel Zn-doped CuO nanocomposite. Melegari et al. (2013) reported evaluation of toxicity and oxidative stress induced by copper oxide nanoparticles in the green alga *Chlamydomonas reinhardtii*. Karthik and Geetha (2013) reported the synthesis of copper precursor, copper and its oxide nanoparticles by green chemical reduction method and its antimicrobial activity. The antimicrobial properties of copper nanoparticles were investigated using *Streptococcus pyogenes*, *Pseudomonas aeruginosa*, *Escherichia coli*, and *Staphylococcus aureus*. Perreault et al. (2012) reported polymer coating of copper oxide nanoparticles increases nanoparticles uptake and toxicity in the green alga *Chlamydomonas reinhardtii*. Mallick et al. (2012) reported iodine-stabilized Cu nanoparticle chitosan composite for antibacterial applications. Liang et al. (2012) reported the polyaniline/$Cu_{0.05}Zn_{0.95}O$ (PANI/CZO) nanocomposites which were prepared by in situ inverse microemulsion method and used against *Staphylococcus aureus*, *Escherichia coli*, and *Candida albicans* and exhibited excellent antibacterial activity against the growth of microorganisms. Delgado et al. (2011) reported polypropylene (PP) with embedded copper metal or copper oxide nanoparticles as a novel plastic antimicrobial agent.

Yang et al. (2019) reported long-term antibacterial stable reduced graphene oxide nanocomposites loaded with cuprous oxide nanoparticles. Bashiri Rezaie et al. (2018) reported environmentally friendly low-cost approach for nano-copper oxide functionalization of cotton designed for antibacterial and photocatalytic applications. Arun et al. (2018) reported influence of transition metal ion Ni^{2+} on optical, electrical, magnetic, and antibacterial properties of phyto-synthesized CuO nanostructure. Ghadi et al. (2018) reported phytochemical fabrication, characterization, and antioxidant application of copper and cobalt oxide nanoparticles using *Sesbania sesban* plant. Mersian et al. (2018) reported synthesis of zirconium-doped copper oxide (CuO) nanoparticles by the Pechini route and investigation of their structural and antibacterial properties. Sathiyavimal et al. (2018) reported biogenesis of copper oxide nanoparticles (CuO NPs) using *Sida acuta* and their incorporation over cotton fabrics to prevent the pathogenicity of Gram-negative and Gram-positive bacteria. Sharmila et al. (2018) reported biogenic synthesis of CuO nanoparticles using *Bauhinia tomentosa* leaf extract and showed antibacterial application. Vaidehi et al. (2018) reported antibacterial and photocatalytic activity of copper oxide nanoparticles synthesized using *Solanum lycopersicum* leaf extract. Gu et al. (2018) reported ultrasound-assisted biosynthesis of CuO NPs using brown alga *Cystoseira trinodis*. Jadhav et al. (2018) reported green biosynthesis of CuO and Ag-CuO nanoparticles from *Malus domestica* leaf extract and evaluation of antibacterial, antioxidant, and DNA cleavage activities.

5.8 Antioxidant Activity

Alavi and Karimi (2018) reported antibacterial, total antioxidant, scavenging, reducing power, and ion chelating activities of green synthesized silver, copper, and titanium dioxide nanoparticles using *Artemisia haussknechtii* leaf extract. Mahjouri et al. (2018) reported toxicity impacts of chemically and biologically synthesized CuO nanoparticles on cell suspension cultures of *Nicotiana tabacum*. Koca et al. (2018) reported phytotoxic effects of biosynthesized copper oxide nanoparticle and ionic copper on *Elodea canadensis*. Dobrucka (2018) reported antioxidant and catalytic activity of biosynthesized CuO nanoparticles using extract of *Galeopsidis herba*. The synthesized CuO nanoparticles showed very good catalytic activity in the reduction of malachite green. Kaur et al. (2018) reported DNA interaction and antiproliferative effect of copper oxide nanocolloids prepared from metallosurfactant-based microemulsions acting as precursor, template, and reducing agent. Jadhav et al. (2018) reported green biosynthesis of CuO and Ag-CuO nanoparticles from *Malus domestica* leaf extract and evaluation of antibacterial, antioxidant, and DNA cleavage activities. Pradhan et al. (2016) reported enzymatic biomarkers can portray nanoCuO-induced oxidative and neuronal stress in freshwater shredders. Mohamadifard et al. (2016) reported the effects of copper oxide nanoparticles and hydroalcoholic extracts of *Berberis vulgaris*, *Descurainia sophia*, and *Silybum marianum* on catalase, glutathione peroxidase, and malondialdehyde concentration in male diabetic rats. Antioxidants reduce the occurrence of damages caused by free radicals. They showed that the studied herbal extracts could be used for moderating the effects of oxidative stress, induced by copper oxide nanoparticles. Duman et al. (2016) reported chamomile flower extract (*Matricaria chamomilla*)-directed CuO nanoparticle formation for its antioxidant and DNA cleavage properties. Guin et al. (2015) reported synthesis of copper oxide nanoparticles using *Desmodium gangeticum* aqueous root extract. Udayabhanu et al. (2015) reported *Tinospora cordifolia*-mediated facile green synthesis of cupric oxide nanoparticles and their photocatalytic, antioxidant, and antibacterial properties. CuO NPs exhibit significant bactericidal activity against *Klebsiella aerogenes, Pseudomonas aeruginosa, Escherichia coli*, and *Staphylococcus aureus.* The study reveals robust method for the synthesis of multifunctional CuO nanoparticle employing underutilized medicinal plants. Shaw et al. (2014) reported nano-CuO stress-induced modulation of antioxidative defense and photosynthetic performance of Syrian barley (*Hordeum vulgare* L.). Das et al. (2013) reported synthesis and evaluation of antioxidant and antibacterial behavior of CuO nanoparticles. Vellora et al. (2013) reported the antimicrobial effect of copper oxide nanoparticles using Gum karaya leaves act as reducing agent and phytochemicals reduce copper hydroxide into copper oxide nanoparticles, and they showed antimicrobial activity tested with different Gram-positive and Gram-negative bacterial strains. Awwad et al. (2015) reported using leaves of *Malva sylvestris* to synthesized copper oxide nanoparticles treated with copper chloride dehydrate and finally showed as antimicrobial agents.

5.9 Imaging Agents

Wang et al. (2018c) reported Se atom-induced synthesis of concave spherical Fe_3O_4@Cu_2O nanocrystals for highly efficient magnetic resonance imaging-surface-enhanced Raman scattering (MRI-SERS) imaging-guided NIR photothermal therapy. They have developed multifunctional nanoplatform, which integrates multimodality imaging and therapeutic functions into a single nanocarrier used in biomedicine and nanoscience. $Fe_3O_4@Cu_2O$ nanocrystal (NC) is first reported as a multifunctional diagnostic agent for in vitro magnetic resonance imaging (MRI) and surface-enhanced Raman scattering (SERS) imaging-guided photothermal therapy (PTT) based on Se atom-induced transformation of core-shell $Fe_3O_4@Cu_2O$ NCs. MRI-SERS imaging-guided PTT has great potential for precision theranostic nanomedicines. Shi and Shen (2018) reported integrin αvβ3 receptor targeting PET/MRI dual-modal imaging probe based on the ^{64}Cu labeled manganese ferrite nanoparticles. PET/MRI dual-modal imaging plays more and more important role in the diagnosis of cancers and dreaded diseases. Li et al. (2018a) reported selective growth synthesis of ternary Janus nanoparticles (JNPs) for imaging-guided synergistic chemo- and photothermal therapies in the second NIR window. Multifunctional therapeutic agents in the second near-infrared (NIR-II) window have synergetic properties for cancer therapy. PEG-CuS-Au-MnO_2 ternary JNPs can be regarded as a prospective therapeutic nanoplatform for dual-modal imaging-guided synergistic chemo-photothermal cancer therapy in the NIR-II window. Karimi et al. (2018) reported ^{64}Cu is one of the most beneficial radionuclides that can be used as a theranostic agent in positron emission tomography (PET) imaging. Feng et al. (2018) reported multifunctional nanotheranostic agent with high performance for tumor site-specific generation of singlet oxygen ($1O^2$) as well as imaging guidance is crucial to laser-mediated photodynamic therapy. Copper sulfide-loaded Fe-doped tantalum oxide (Fe-mTa_2O_5@CuS) nanoparticles produced heat and toxic $1O^2$ which can kill tumor cells *in vitro* and *in vivo* effectively. Perlman et al. (2018) reported copper oxide-loaded poly(lactic-co-glycolic acid) (PLGA) nanospheres toward a multifunctional nanoscale platform for ultrasound-based imaging and therapy. CuO-loaded PLGA nanospheres (CuO-PLGA-NS) were prepared by a double emulsion (W/O/W) method with subsequent solvent evaporation. CuO-PLGA-NS constitute a versatile platform useful for combined imaging and therapeutic ultrasound-based procedures. Tan et al. (2018) reported an ultrasmall Cu_2ZnSnS_4 (CZTS) nanocrystal with high near-infrared (NIR) photothermal conversion abilities and peroxidase-mimic properties are synthesized and functionalized with bovine serum albumin (BSA) for rapid clearance multifunctional theranostic platform. Antonoglou et al. (2017) reported elucidation of one-step synthesis of PEGylated CuFe bimetallic nanoparticles and showed antimicrobial activity of CuFe@PEG vs Cu@PEG. Huang et al. (2017) reported design and functionalization of the NIR-responsive photothermal semiconductor nanomaterials for cancer theranostics. Copper chalcogenide semiconductors have emerged as a promising photothermal agent attributed to strong absorbance in the near-infrared (NIR) region and high photothermal conversion efficiency. They have been formulated by integrating the photothermal agents with antitumor drugs, photosensitizers, or radiosensitizers, resulting in a synergistic effect. $Fe_3O_4@Cu_2$-xS and $Cu_9S_5@mSiO_2$ have showed integration of photothermal agents with contrast agents or other anticancer medicines, achieving cancer theranostic and synergistic treatment. They believe that the photothermal technology from the NIR-responsive photothermal semiconductor nanomaterials would be promoted cancer theranostics. Peng et al. (2017) reported biocompatible CuS-based nanoplatforms for efficient photothermal therapy and chemotherapy. Near-infrared (NIR) photothermal therapy (PTT) is a new approach to ablate cancer without affecting normal tissues. The potential of CuS@MSN-DOX utilized as a multifunctional platform for combined PTT and chemotherapy. Ben-Sasson et al. (2016) reported *in situ* surface functionalization of reverse osmosis membranes with biocidal copper nanoparticles. They have demonstrated that *in situ* grafting of Cu NPs on reverse osmosis membranes is a potential alternative to reduce biofouling. Ahir et al. (2016) reported tailored-CuO-nanowire decorated with folic acid-mediated coupling of the mitochondrial-ROS generation and miR425-PTEN axis in furnishing potent anticancer activity in human triple-negative breast carcinoma cells. Gao et al. (2016) reported Fe_3O_4@mSiO_2-FA-CuS-PEG nanocomposites for magnetic resonance imaging and targeted chemo-photothermal synergistic therapy of cancer cells. Fe_3O_4@mSiO_2-FA-CuS-PEG nanocomposite for magnetic resonance imaging (MRI) and targeted chemo-photothermal therapy was fabricated. It has synergistic effect of chemotherapy and photothermal therapy against HeLa cells under irradiation with a 915 nm laser and has a great potential in image-guided therapy of cancers. Perlman et al. (2015b) reported copper oxide nanoparticles as contrast agents for MRI and ultrasound dual-modality imaging. They have offered radiation-free high spatial resolution scans by MRI and cost-effective high temporal resolution scans by ultrasound. Wang et al. (2015) reported electrospray formation and combustion characteristics of iodine-containing Al/CuO nanothermite microparticles. Perlman et al. (2015a) reported preliminary study of copper oxide nanoparticles acoustic and magnetic properties for medical imaging. Zolata et al. (2014) reported radio-immunoconjugated, Dox-loaded, surface-modified superparamagnetic iron oxide nanoparticles (SPIONs) as a bioprobe for breast cancer tumor theranostics. Tian et al. (2013) reported sub-10 nm Fe_3O_4@Cu_2-xS core-shell nanoparticles for dual-modal imaging and photothermal therapy. Barreto et al. (2011) reported synthesis, colloidal stability, and ^{64}Cu labeling of iron oxide nanoparticles bearing different macrocyclic ligands. Glaus et al. (2010) reported in vivo evaluation of ^{64}Cu-labeled magnetic nanoparticles as a dual-modality PET/MR imaging agent. Patel et al. (2010) reported Cu^{2+}-labeled, SPION-loaded porous silica nanoparticles for cell labeling and multifunctional imaging probes. Jarrett et al. (2008) reported synthesis of ^{64}Cu-labeled magnetic nanoparticles for multimodal imaging.

5.10 Drug Delivery Agents

Bhushan et al. (2019) reported the study of synthesis and structural, optical, and magnetic characterizations of iron/copper oxide nanocomposites. They have been used as the potential antibiotic to counter the diseases caused by normal and multidrug-resistant pathogenic bacterial strains. Velusamy et al. (2018) reported novel electrochemical synthesis of copper oxide nanoparticles decorated graphene-β-cyclodextrin composite for trace-level detection of antibiotic drug metronidazole. Bakravi et al. (2018) reported synthesis of gelatin-based biodegradable hydrogel nanocomposite and their application as drug delivery agent. Xue et al. (2018) reported phyto-mediated synthesized multifunctional Zn/CuO NPs hybrid nanoparticles for enhanced activity for kidney cancer therapy: A complete physical and biological analysis. Zhen et al. (2018) reported reduced graphene oxide coated Cu_2-xSe nanoparticles for targeted chemo-photothermal therapy.

Ahmadian et al. (2018) reported synthesis of polyvinyl alcohol/CuO nanocomposite hydrogel and its application as drug delivery agent. Han et al. (2017) reported hollow copper sulfide nanosphere-doxorubicin/graphene oxide core-shell nanocomposite for photothermo-chemotherapy. Giannousi et al. (2016) reported synthesis and biological evaluation of PEGylated CuO nanoparticles. Jha et al. (2016) reported comparative nanoscale interaction of TiO_2/ZnO/Cu with human spermatozoa for biomedical application. Farhoudian et al. (2016) reported a facile synthesis of antibacterial chitosan/CuO bio-nanocomposite hydrogel beads. Delgado et al. (2011) reported polypropylene with embedded copper metal or copper oxide nanoparticles as a novel plastic antimicrobial agent. Yang et al. (2011) reported peptide conjugated Arginylglycylaspartic acid (cRGD)-functionalized, doxorubicin (DOX) an antibiotic-conjugated, and ^{64}Cu-labeled superparamagnetic iron oxide nanoparticles for targeted anticancer drug delivery and PET/MR imaging.

5.11 Diagnosis and Therapeutic Agents

Perlman et al. (2018) reported copper oxide-loaded PLGA nanospheres toward a multifunctional nanoscale platform for ultrasound-based imaging and therapy. Wu et al. (2015) reported rattle-type Fe_3O_4@CuS developed to conduct magnetically guided photoinduced hyperthermia at first and second NIR biological windows. Yugandhar et al. (2018) reported cost-effective green synthesis of copper oxide nanoparticles using fruit extract of *Syzygium alternifolium* (Wt.) Walp. Logpriya et al. (2018) reported the preparation and characterization of ascorbic acid-mediated chitosan-copper oxide nanocomposite for antimicrobial, sporicidal, and biofilm inhibitory activity. Jadhav et al. (2018) reported green biosynthesis of CuO and Ag-CuO nanoparticles from *Malus domestica* leaf extract which acts as a good stabilizing agent and evaluation of antibacterial, antioxidant, and DNA cleavage activities. The synthesized CuO and Ag-CuO nanoparticles using *Malus domestica* leaf-capped nanoparticles have exhibited interesting antibacterial activity with both Gram-positive and Gram-negative bacteria at microgram concentrations, and these greenly synthesized NPs act as a potent therapeutic agent. Bhuvaneshwari et al. (2018) reported green synthesis of copper oxide nanoparticles for biological applications. The nanometer-sized materials known as nanomaterials have unique physical, chemical, and biological properties. Among them nano-copper oxide has potential applications in many fields like heterogeneous catalysts, photocatalysts, antimicrobial agent, antioxidants, imaging agents, and drug delivery agents. A nanoparticle (NP) with biomolecules is useful in diagnosis and therapeutic. Sundaramurthy and Parthiban (2015) reported that CuO NPs have glorious potency to degrade methylene blue below solar irradiation. The green-synthesized CuO NPs were confirmed as economical catalysts with increased rates of textile dye decolourization. The CuO NPs can also suppress cell viability using several mechanisms, such as apoptosis and necrosis. Cell suicide mechanism which controls cell numbers is apoptosis. Two types of pathway are involved in apoptosis. Finally, CuO NPs have been used as photocatalyst, antimicrobial agent, and better anticancer compound with minimal side effects. CuO NPs can also act as efficient antibacterial agent when incorporated in coatings, plastics, and textiles (Yallappa et al. 2013; Kwak and Chongyoup 2005; Manoranjan and Gitisudha 2016). Nagajyothi et al. (2017) reported copper oxide nanoparticles (CuO NPs) were synthesized by a green route using an aqueous black bean extract and the cytotoxic effect of the CuO NPs was determined by sulforhodamine-B assay. They showed that the CuO NPs can induce apoptosis and suppress the proliferation of HeLa cells. Kumar et al. (2017) reported biofabrication of copper oxide nanoparticles (CuO NPs) using Andean blackberry fruit (ABF) and leaf (ABL) which showed antioxidant activity. They also suggested that green CuO NPs could be used in future biomedical application. Sangeetha et al. (2012) reported the synthesis of nanostructured copper oxide particles by green chemistry approach and aloe extract.

Ghidan et al. (2016) reported copper oxide nanoparticle (CuO NP) synthesis by green method using *Punica granatum* peel extract. Rajeshwari et al. (2014a) reported biogenic copper oxide nanoparticle synthesis using *Tabernaemontana divaricata* leaf extract and its antibacterial activity against urinary tract pathogen. Rajeshwari et al. (2014b) reported biosynthesis and characterization of *Acalypha indica*-mediated copper oxide nanoparticles and evaluation of its antimicrobial and anticancer activity. Sharma et al. (2015) reported green synthesized copper oxide (CuO) nanoparticles (NPs) as electrocatalytic materials for the fabrication of counter electrode in dye-sensitized solar cells (DSSCs) using the leaves extract of *Calotropis gigantea* plant in aqueous medium through green synthesis. Gnanavel et al. (2017) reported biosynthesis and characterization of copper oxide nanoparticles and its anticancer activity on human colon cancer cell lines (HCT-116). Shrikant et al. (2012) reported a novel route for rapid biosynthesis of copper nanoparticles using aqueous extract of *Calotropis procera* L. latex and their cytotoxicity on tumor cells. The progresses of green chemistry in the synthesis of nanoparticles with the use of plants have a great attention. Yallappa et al. (2013) reported microwave-assisted rapid synthesis and biological evaluation of stable copper nanoparticles using *T. arjuna* bark extract, and Cu NPs show very good antioxidant property. Udayabhanu et al. (2015) reported the green synthesis of copper oxide nanoparticles (CuO NPs) by a solution combustion method using *Tinospora cordifolia* water extract and found nanoparticles have spongelike structure and sizes which were found to be ~6–8 nm. These CuO NPs showed photocatalytic activity to degrade methylene blue (MB) in the presence of UV and sunlight and also reported significant bactericidal activity against *Klebsiella aerogenes*, *Pseudomonas aeruginosa*, *Escherichia coli*, and *Staphylococcus aureus*.

Green synthesis by using plant resources has been a simple and effective approach for the synthesis of various forms of nanoparticles. They possess strong biological activities in terms of antioxidant, anti-inflammatory, antidiabetic, and antibacterial potentialities which could be utilized in various biological applications by the cosmetic, food, and biomedical industries. Nanoparticles with antimicrobial activity, especially as a new class of biomedical materials for use in increasing the level of public health in daily life, have emerged.

Biological methods for nanoparticle synthesis using microorganisms, enzymes, and plants or plant extracts have been suggested as possible eco-friendly alternatives to chemical and physical methods. The nature acts like a large "bio-laboratory" comprising plants, algae, fungi, yeast, etc. which are composed of biomolecules. These naturally occurring biomolecules have been identified to play an active role in the formation of nanoparticles with distinct shapes and sizes, thereby acting as a driving force for the designing of greener, safe, and environmentally benign protocols for the synthesis of nanoparticles. The present review targets the comparative biogenic synthesis and mechanisms of nanoparticles using algae and waste materials (agro-waste in the presence of biomolecules). The use of waste materials not only reduces the cost of synthesis but also minimizes the need of using hazardous chemicals and stimulates "green synthesis." It also focuses on the computational aspects of binding of biomolecules to nanoparticles and some of the applications of the biosynthesized nanoparticles in biomedical, catalysis, and biosensor fields (Kuppusamy and Mashitah 2016).

The field of nanotechnology mainly encompasses with biology, physics, chemistry, and material sciences, and it develops novel therapeutic nanosized materials for biomedical and pharmaceutical applications. The biological syntheses of nanoparticles are being carried out by different macro-microscopic organisms such as plant, bacteria, fungi, seaweeds, and microalgae. The biosynthesized nanomaterials have been effectively controlling the various endemic diseases with less adverse effect. Plant contains abundant natural compounds such as alkaloids, flavonoids, saponins, steroids, tannins, and other nutritional compounds. These natural products are derived from various parts of plant such as leaves, stems, roots, shoots, flowers, barks, and seeds. Recently, many studies have proved that the plant extracts act as a potential precursor for the synthesis of nanomaterial in non-hazardous ways. Since the plant extract contains various secondary metabolites, it acts as reducing and stabilizing agents for the bioreduction reaction to synthesized novel metallic nanoparticles. The non-biological methods (chemical and physical) are used in the synthesis of nanoparticles, which has a serious hazardous and high toxicity for living organisms. In addition, the biological synthesis of metallic nanoparticles is an inexpensive, single-step, and eco-friendly methods. The plants are used successfully in the synthesis of various greener nanoparticles such as cobalt, copper, silver, gold, palladium, platinum, zinc oxide, and magnetite. Also, the plant-mediated nanoparticles are potential remedy for various diseases such as malaria, cancer, HIV, hepatitis, and other acute diseases. The biofabricated silver nanoparticles are extensively used in environmental, biotechnological, and biomedical applications. The synthesis of SNPs has been carried out by using the filtrate extract of novel fungal strain *Penicillium atramentosum* KM. The synthesized SNPs showed antimicrobial activity against bacterial strains (Narayanan and Sakthivel 2011).

The size, shape, and controlled dispersity of nanoparticles play a vital role in determining the physical, chemical, optical, and electronic properties attributing its applications in environmental, biotechnological, and biomedical fields. Various physical and chemical processes have been exploited in the synthesis of several inorganic metal nanoparticles by wet and dry approaches, viz., ultraviolet irradiation, aerosol technologies, lithography, laser ablation, ultrasonic fields, and photochemical reduction techniques. However, these methodologies remain expensive and involve the use of hazardous chemicals. Therefore, there is a growing concern for the development of alternative environment-friendly and sustainable methods. Increasing awareness toward green chemistry and biological processes has led to a necessity to develop simple, cost-effective, and eco-friendly procedures. Phototrophic eukaryotes such as plants, algae, and diatoms and heterotrophic human cell lines and some biocompatible agents have been reported to synthesize greener nanoparticles like cobalt, copper, silver, gold, bimetallic alloys, silica, palladium, platinum, iridium, magnetite, and quantum dots. Owing to the diversity and sustainability, the use of phototrophic and heterotrophic eukaryotes and biocompatible agents for the synthesis of nanomaterials is yet to be fully explored. This review describes the recent advancements in the green synthesis and applications of metal nanoparticles by plants, aquatic autotrophs, human cell lines, biocompatible agents, and biomolecules.

5.12 Future Perspectives

Metal and metal oxide NPs have been widely utilized in various biomedical applications, such as detection, diagnosis, imaging, and therapy and provide a perspective for future evolution of this field. CO_2 conversion via photocatalysis is a solution to address global warming and energy shortage. Photocatalysis can directly utilize the inexhaustible sunlight as an energy source to catalyze the reduction of CO_2 to useful solar fuels such as CO, CH_4, CH_3OH, and C_2H_5OH. Cu-based photocatalysts are the most attractive for CO_2 conversion. Cu-based photocatalysts for CO_2 conversion, which includes metallic copper, copper alloy nanoparticles (NPs), copper oxides, and copper sulfide photocatalysts, provide insight into the nature of potential active sites for the catalysts with much-enhanced energy conversion efficiency and production rates. Microbial infectious diseases are a global threat to human health and excess and improper use of antibiotics has created antimicrobial-resistant microbes that can resist clinical treatment. The metal oxide nanoparticles have fight against microbes resistant to use of various classes of antibiotics. The mechanisms of action of MO NPs against microorganisms, safety concerns, challenges, and future perspectives are potentially important. The challenges and perspective on nanomaterials toward drug delivery, imaging, and photothermal agents for diagnosis and therapy of diseases are alarming and potentially important to tackle. The size, size distribution, morphology, polymorphic nature, crystallinity, biocompatibility, biodegradability, drug elution profiles, and aggregation propensity are important issues for the future development of MNPs that address the present challenges and lead to new opportunities in nanomedicine and nanobiotechnology (Tseng et al. 2015; Sun and Yang 2014; Raghunath and Perumal 2017; Xie et al. 2017; George et al. 2018).

5.13 Conclusions

Copper and copper oxide nanoparticles can be fabricated by plant extracts. The shape and size may be controlled by maintaining the temperature, pH, and concentration of the reacting components. Their cytotoxicity varies with shape such as spherical, beads, and rods and has great potential for use in instruments and medical devices, as drug carrier, and in the treatment of many diseases. The plant extracts containing alkaloids, flavonoids, saponins, ketones, aldehydes, and phenols or reducing acids like citric acid and ascorbic acids can be used for nanoparticle synthesis. CuONPs can be used for removal of dyes, in wastewater treatment, purification of ground water and also used as a catalyst, biosensing, antibacterial, antimicrobial, anticancer activity and as an antioxidant.

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