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A Review on Industrial Applications of Zinc Oxide Nanoparticles

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ABSTRACT: Nanotechnology research has gained much attention in recent years as it provides innovative solutions in the field of biomedicine, material science, optics and electronics. Nanostructured ZnO materials have received broad attention due to their excellent performance in electronics, optics and photonics, optoelectronics, sensors, transducers and biomedical sciences. It is a wide band-gap compound semiconductor that is suitable for short wavelength optoelectronic applications. Zinc Oxide Nanoparticles (ZnO NP) are non-biotoxic materials with photo-catalysis and photo-oxidising properties on biological species. ZnO is costless, environmentally friendly with significant physical and chemical stabilities. It is one of the most important metal oxide nanoparticles and one of the most widely used nanoparticles. ZnO NPs are popularly employed in various fields due to their peculiar physical and chemical properties. In this paper, industrial applications of ZnO NPs are highlighted, focusing on the recent progress in research to realize its feasibility in these applications. However, further intensive research on better understanding of the relationship between size, shape and structure of zinc oxide nanoparticles, and how one can tune its capability for various industrial applications is highly recommended.

Key words: Zinc Oxide, Semiconductors, Piezoelectric devices, Gas sensors, solar cells

I. INTRODUCTION

Nanostructured Zinc Oxide (ZnO) materials have received broad attention due to their distinguished performance in electronics, optics and photonics, optoelectronics, sensors, transducers and biomedical sciences. From the 1960s, synthesis of ZnO thin films has been an active field because of their applications as sensors, transducers and catalysts (Dusan & Peter, 2010). ZnO is therefore a key technological material. The lack of a centre of symmetry in its wurtzite structure combined with large electromechanical coupling results in strong piezoelectric and pyroelectric properties and the consequent use of ZnO in mechanical actuators and piezoelectric sensors. In addition, ZnO is a wide band-gap compound semiconductor that is suitable for short wavelength optoelectronic applications (Klinton et al., 2019). The high excited binding energy (60meV) in ZnO crystal can ensure efficient excitonic emission at room temperature. ZnO is transparent to visible light and can be made highly conductive by doping. ZnO is a versatile functional material that has a diverse group of growth morphologies, such as nanocombs, nanorings, nanohelixes, nanosprings, nanobelts, nanowires and nanocages (Zhong, 2004).

Zhiyong and Jia (2005), noted thatZnO offers tremendous potential in future applications of electronic, optoelectronic, andmagnetoelectronic devices. Agnieszka and Teofil (2014) Confirmed that Zinc oxide has applications in various branches of industry: rubber, pharmaceutical, cosmetics, textile, electronic and electrotechnology, photocatalysis etc. Dušan and Petar (2010) noted some advantages of ZnO as low price, good gas sensing properties, photocatalytic activity, antibacterial activity, possibility to prepare structures with interesting optical properties, like photonic crystals, catalytic materials, in small amounts as ZnO is non- toxic. ZnO is odourless and white solid in appearance, with a band gap of 3.3 eV, 1975°C melting point and a density of 5.606 g/cm^3 (Klinton et al., 2019). The wurtzite structure is the most stable at environmental conditions and thus the most common structure of ZnO as shown in figure 1.

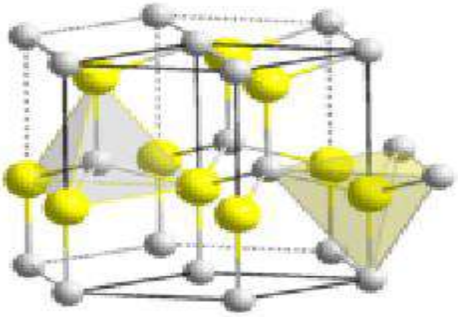

Figure 1: ZnO Wurtzite Structure (Prateek & Kirti, 2016)

1. PREPARATION

There are different methods of ZnO nanostructures preparation, like metal-organic vapour-phase epitaxy (MOVPE), high temperature evaporation, gas spraying, pulsed laser deposition, sputtering, sol-gel, wet chemical, electrochemical methods (Dusan & Peter, 2010), precipitation method, vapour transport method, hydrothermal process (Sidra, et al. 2014), metal-organic, chemical vapour deposition, pulsed laser deposition and chemical vapour transport (Prateek & Kirti, 2016).

2. SEMICONDUCTORS

ZnO remains a promising material for electronic and optoelectronic device applications, despite the difficulties in achieving its p-type conductivity. The difference between the current surge to turn ZnO into a functional semiconductor and past attempts is the availability of better thin-film growth techniques (Anderson & Chris, 2009). ZnO substrates have higher quality and experience has been gained from research on III-nitrides, which posed similar difficulties with respect to controlling the conductivity (Anderson & Chris, 2009). Bedia et al. (2014) reports the experimental and the electrical junction properties analysis of current–voltage characteristics of n-ZnO/p-Si heterostructures and reported that Zinc oxide semiconductor presents n-type conductivity with lowest resistivity. The measured current–voltage (I–V) of the p–n heterostructure show nonlinear diode like behaviour. It also shows great photoelectric effect under power (160W) of lamp illuminate. The solar cell exhibited a short-circuit current density of 4×10^{-3} mA, an open-circuit voltage of 6mV.

According to Ju et al. (2016) a composite containing 10% ZnO with 7% Al displayed a dielectric constant of 18.5 at 100 Hz, twice when compared with the pure ZnO/PVDF (polyvinylidene fluoride) composites. This phenomenon was attributed to ZnO semiconducting properties which can significantly improve the conductive nature of the materials. In the same lane, Juan etal. (2018) reported the successful fabrication of new heterojunction of two 2D hybrid ZnO(SA)/V_2O_5(HDA) semiconductors which exhibited an improved photocatalytic activity than the pristine zinc oxide in the degradation of methylene blue under visible light.

3. LIGHT EMITTING DIODE

LED is an acronym that stands for light emitting diode. It is a semiconductor diode that emits light when voltage is applied to it and that is used especially in electronic devices as an indicator light. White light emitting diodes play an important role in applications, such as in displays, general lighting and automobile headlights (Vivek and Kantisara, 2019). The materials for light-emitting diodes in the visible spectrum (400 - 700 nm) are semiconductors with band gaps between 1.8 and 3.1 eV (Srikant & Clarke, 1998) and ZnO with band gap of 3.1 eV at room temperature falls within the range. This is the reason why the most common application of ZnO is in Laser and LED.

Jiangyong et al. (2015) designed and fabricated a flexible red-emitting quantum dot light emitting diodes (QLEDs) on indium tin oxide/poly(ethylene-terephthalate (ITO/PET) substrates using ZnO NPs as an electron transfer layer (ETL), which display a low turn on voltage and high current and power efficiencies. They reported that the superior performance is as a result of the higher electron mobility of ZnO NPs. Prateek and Kirti (2016) also confirmed that Zinc Oxide (ZnO) nanostructures are perfect photoelectric diode. Mustapha et al. (2018) investigated the optical behaviour of pure and blended conjugated co-polymers with added ZnO nanoparticles and confirmed that the addition of ZnO nanoparticles has greatly improved the fluorescence optical properties. Vivek and Kantisara (2019) developed a method to determine the concentration of Eu^{3+} ions and Tb^{3+} ions (Europium and Terbium) in a thin-film sample of SiO_2 co-doped with ZnO-np to produce a white light emitting material. An emission of white light was observed which was attributed to the energy transfer from the excited ZnO-np to the rare-earth (RE) ions.

4. GASSENSORS

Fan and Lu (2005) in Umit, (2010) declared that, one of the most important parameters of gas sensors is their selectivity and this selectivity is achieved by applying different voltages to the gate of a nanowire FET or by performing measurements at different temperatures since different gas molecules have different activation energies. Wang etal. (2006) observed the high response and good selectivity of ZnO nanorods to low concentrations of H_2S and concluded that the nanorods are promising candidates for detecting extremely low concentrations of H_2S. Umit (2010) stressed that ZnO nanowires have a potential for detecting NO_2, NH_3, NH_4, CO, H_2, H_2O, O_3, H_2S and C_2H_5OH gases. In their efforts to confirm such assertions, Hassan et al. (2015) constructed a novel structures of Nanomaterials gas sensors array using ZnO, and ZnO doped with Al via sol-gel technique with the aim of assessing its gas sensing ability. The highest sensitivity values for both double and quadrature gas sensor devices established for H_2 gas was observed at Zn:Sb=95:5 weight ratio.

Zhezhe et al. (2017) after successfully synthesis and characterization of high crystalline ZnO nanoparticles recommended the nanoparticles as promising gas sensor for n-butanol. Similarly Sanaz etal. (2017) synthesized Indium doped ZnO and ZnO nanoparticles and subjected it to gas sensing measurement whose result showed indium dopant ions improving the gas sensitivity of ZnO for high acetone concentrations effectively. They therefore, suggested that the IZO tablet can act as reliable and low cost gas sensor for acetone detection. Fatemeh et al. (2018) reported that pristine ZnO NPs displayed a high response to hydrogen at a low concentration in air but with poor selectivity

5. BIOSENSORS

Biosensor development is receiving much attention nowadays as it intersects the biological and engineering sciences. Biosensors are analytical devices that comprise a biological recognition element and a suitable transducer which are usually coupled to an appropriate data processing system (fig. 2) (Inbasekaran, et al., 2014). The potential of ZnO nanostructures as nanosized biosensors for detecting different biological molecules has also been explored and reported though in limited number. As in the case of gas sensors, the principle of operation is that the conductance of ZnO nanorod FETs drastically changes when biomolecules are adsorbed. The key factor in most biological processes is the need for a small change of the pH concentration created by the release of H^+ ions during biochemical reactions (Umit, 2010).

Ali et al. (2016), used modified carbon paste electrode (CPE) with zinc oxide (ZnO) nanoparticles for designing a glucose oxidase enzymatic biosensor for investigation of its electrochemical behavior, and determination of glucose concentration. The designed GOD/ZnO/CPE electrochemical biosensor showed high stability and efficiency for glucose sensing. Yuhong et al. (2016) synthesized ZnO nanoparticles via a green biochemical method using Corymbia citriodora leaf extract as a reducing and stabilizing agent. The fabricated electrochemical sensor showed excellent detection performance towards trace amounts of H_2O_2, demonstrating that it could potentially be used in clinical applications.

Muhammad et al. (2019) investigated the biosensing performances of ZnO nanostructures with different dimensions (0-D, 1-D, 2-D and 3-D ZnO). They confirmed that, 0-D ZnO nanostructures had been used widely due to its ease of fabrication before 1-D, 2-D, and 3-D nanostructures were developed. However, the focus turned towards 1-D ZnO because of the issues with low mobility faced in 0-D nanostructures. The vertical and lateral 1-D ZnO-based FET biosensor nanostructures are also proven to enhance the performance of biosensors. As research in the nanotechnology is receiving great attention, the improvement of 0-D ZnO-based electrochemical biosensor nanostructures is reported to be positive form different researchers. Meanwhile, 2-D ZnO nanostructures were also proven to tune the sensing performance of biosensors.

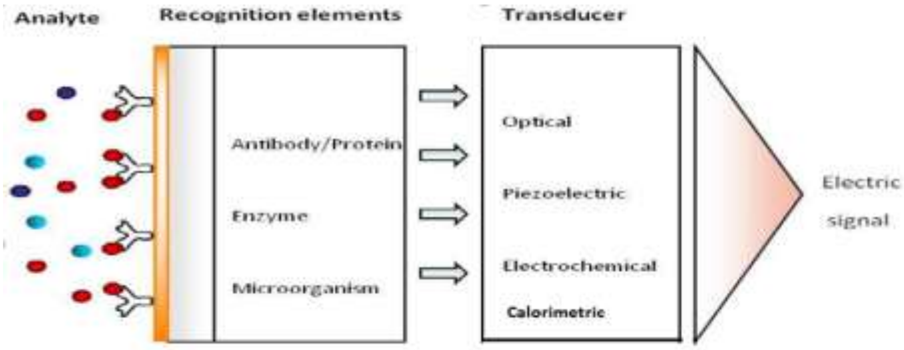

Figure 2. Schematic diagram of a biosensor (Inbasekaran, et al., 2014)

6. BIOMEDICINE

Biomedical nanomaterials have received more concerns because of their prominent biological characteristics and biomedical applications (Jinhuan et al., 2018). Nowadays, microbial infection became an overwhelming issue globally as they are significant in causes of morbidity and mortality because of the development of resistant strains of a virus, bacteria, pathogenic fungi, protozoa and they can survive the clinical treatment with the antibiotic, antifungal, antiviral, antiprotozoal drugs (Yah & Simate, 2015). Sperling et al. (2008) stated that, in present days as an antibacterial agent Nanoparticles are used because they are found to be highly effective and therefore acquire much attention. These nanoparticles satisfy the requirements where antibiotics fail to prevent the development of Multi-Drug Resistant (MDR) mutants.

ZnO NPs have become one of the most popular metal oxide nanoparticles in biological applications due to their excellent biocompatibility, economic and low toxicity. It has emerged a promising potential in biomedicine, especially in anticancer and antibacterial fields (Jinhuan et al., 2018). Sumon and Tamalika (2018) noted that,Silver (Ag) and Zinc Oxide (ZnO) are two metallic nanoparticles that can be synthesized with the help of plant extract and have the antibacterial activities which are exploited to cure several diseases, caused by Multi-Drug Resistant (MDR) bacteria. These two nanoparticles have excessive potential to inhibit MDR bacteria. Mohammad et al. (2010) reported that, application of ZnO nanoparticles in the biological realm requires high quality ZnO nanoparticles in aqueous solution at neutral pH and physiological temperature as biomolecules are very sensitive to changes in the parameters. Omkar (nd) used different sized synthesized zinc oxide nanoparticles to study the antimicrobial activity against Escherichia coli, Bacillus subtilis, Pseudomonas aeruginosa, and Staphylococcus aureus. The result showed that the antimicrobial activity increased with the decrease of the size of the nanoparticles.

7. PIEZOELECTRIC DEVICES

Due to its moderately high (very high for a semiconductor) electromechanical coupling coefficients, ZnO has been successfully used in thin film piezoelectric devices such as bulk acoustic wave and surface acoustic wave (SAW) resonators, filters, sensors and microelectromechanical systems (MEMS). The most common application being the SAW filter, which has been an important component in mass consumer items such as TV filters and wireless communications systems (Umit, 2010).

Zhong and Jinhui (2006) successfully converted nanoscale mechanical energy into electrical energy by means of piezoelectric zinc oxide nanowire (NW) arrays. The efficiency of the NW-based piezoelectric power generator was estimated to be 17 to 30%. Li et al. (2011) stated that under varying applied elastic loads (ZnO deposition on Si substrates with sputtered Pt film), the decrease of transverse electrical conductivity at higher loads is attributed to the depletion zone formation induced by local piezoelectric effect in ZnO proving it an agent of enhancing piezoelectric effect in nanocomposites.

Nour et al. (2014) successfully grown high-quality single crystalline zinc oxide nanowires on silver and gold coated plastic substrates using the aqueous chemical growth method for the fabrication of a sandwich-like nanogenerator. The harvested electrical output under mechanical deformation demonstrated the applicability of this configuration as a nanogenerator. They concluded that more piezoelectric potential can be harvested by using two arrays of ZnO NWs placed face-to-face than by using a single nanowire configuration.

Denishev (2016) emphasized that, the Lead Zirconate Titanate (PZT) and Zinc oxide (ZnO) based thin film devices can be used as piezoelectric stress sensors, energy harvesters and piezoelectric transformers. Depending on the electrodes configuration, piezoelectric sensor structures, using sputtered PZT layers, operate in different ranges of the applied stress. Using of flexible Polyethylenetherephtalate (PET) substrate provides higher elasticity of the piezostructure, which increases the voltage generation, even at lower mechanical loading and makes the energy harvesting devices more sensitive and effective.

8. MICROWAVEABSORBERS

ZnO nanotrees and its paraffin composites have good effect on microwave absorption. The microwave attenuation of ZnO nanotree composite with the volume ratio of 60% is as high as 58 dB at the frequency of 4.2 GHz with a thickness of 4.0 mm as confirmed by Zhuo etal, (2008). Pre-mixed NiZn ferrite/MWNT, according to the weight ratio 1:1, were incorporated into the thermoplastic natural rubber nanocomposite by melt blending process. It was found that both reflection loss (RL) and shielding effectiveness (SE) depend on the filler content. The effect of fillers mixing ratio were investigated too. Results showed samples with higher MWNT content exhibits better shielding effectiveness, while samples with higher NiZn ferrite achieved better reflection loss (Yu, et al. 2012). The essential properties of polymer-based composites can be modified by varying the amount of Zn/Al-NO_3layered double hydroxide (LDH) added to polyvinyl chloride (PVC). The results indicate that these composites show great potential for use as microwave absorbers at low microwave frequencies (Ethar et al., 2014).

Xiaodong etal. (2018) synthesized fe_3O_4/ZnO core–shell nanocomposites through a chemical method of coating the magnetic core (Fe_3O_4) with ZnO by co-precipitation of Fe_3O_4 with zinc acetate in a basic medium of ammonium hydroxide. The electromagnetic parameters of the Fe_3O_4/ZnO core–shell nanocomposites were investigated. It was observed that, Fe_3O_4/ZnO nanocomposites exhibited an enhanced absorption capacity in comparison with the naked Fe_3O_4 nanospheres. It is therefore expected that the Fe_3O_4/ZnO core–shell structured nanocomposites could be a promising candidate as high-performance microwave absorbers.

9. SOLAR CELLS

ZnO is an attractive material for applications in electronics, photonics, acoustics and sensing. In optical emitters, its high binding energy (60 meV) gives it an edge over other semiconductors such as GaN (Umit, 2010). Lai etal. (2011) used ZnO and presents a new structure for nanorod DSSCs. ZnO nanorods and a ZnO film were grown using a one-step chemical-vapor deposition method. The ZnO film functioned as the TCO of the DSSC. The ZnO nanorod/ZnO film structure was sensitized with D149 or N719 dye and assembled into a DSSC. Two notable features in this new DSSC structure are: (1) the junction between the TCO film and the nanorods is completely eliminated; (2) the TCO and the photoelectrode are made of the same material. Testing showed that under AM1.5 illumination, a short current density of 15.7 mA/cm^2 and a power conversion efficiency η of 1.82% was achieved. The η is more than two times higher than the η reported earlier for ZnO-nanorod DSSCs with the same structure. Zinc Oxide thin films are formed by electrodeposition of Zinc Nitrate. Their structural and optical characteristics were confirmed using UV-VIS absorption and emission. Their photoconductive performance was verified which makes them promising candidates for Solar Cells (Sathya et al., 2012).

Yuancheng (2015) has reviewed the research progress in ZnO Nanowires and their application for solar cells. He found that, a number of methods have been employed to achieve ZnO nanostructured arrays and several attempts have been made to use ZnO in solar cells. In his opinion, the quality and stability of the ZnO nanowires need to be further improved and the techniques used in fabricating these solar cells need to be optimized. Once these milestones are achieved, the ZnO nanowire arrays have great potential in improving the performance of solar cells. Vanjaetal**.** **(**2018**)** electrodeposited ZnO thin films to study the effects of different potentials applied during deposition. ZnO photoanodes were synthesized through electrodeposition at the potentials of -1.0 V (film A), -1.2 V (film B) and -1.4 V (film C). DSSCs were assembled and the photovoltaic parameters were obtained through J-V plots. DSSC with 0.031% of efficiency was demonstrated at -1.4 V of deposition potential.

Mati et al. (2019) reported on an efficient dye-sensitized mesoporous photoanode of Ti doped zinc oxide (Ti-ZnO) through a facile hydrothermal method and reported that Ti-ZnO nanoparticles with a high surface area of 131.85 m^2 and a controlled band gap exhibited increased light harvesting efficiency, dye loading capability, and achieved comparable solar cell performance at a typical nanocrystalline ZnO photoanode (figure 3).

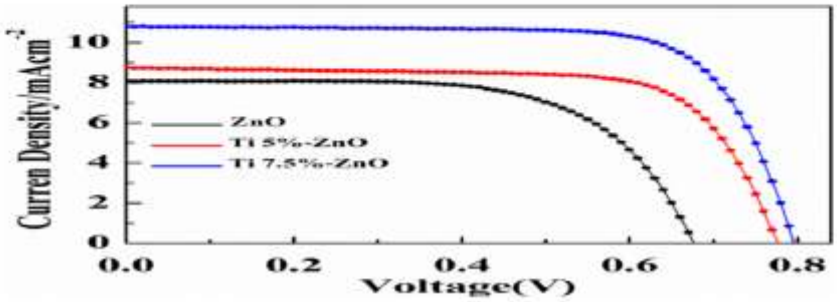

Fig. 3. : I-V curves of ZnO, Ti(5%)-ZnO and Ti(7.5%)-ZnO nanoparticles based DSSCs, in both the active area is 0.25 and under (AM 1.5, 100 mW/cm^{-2}) illumination (Mati et al., 2019).

Babatunde et al. (2019) successfully deposited ZnS thin films on the glass substrate using a chemical bath deposition method. The effect of deposition time on optical and morphological characteristics of the films was investigated. The optical result shows the films have high transmittance, low reflectance in the visible region and also high optical band gap energy from 3.6 eV to 3.8 eV as the time of deposition increases.

10. COSMETICS

ZnO nanoparticles also exhibit tremendous UV-blocking properties. Generally, sunlight consists of three types of UV radiation, i.e., UV-A (320–400 nm), UV-B (290–320 nm), and UV-C (250–290 nm). UV-A radiation is the main concern as it contributes ~95% of the total sunlight radiation. UV-B radiation contributes ~5%, and UV-C radiation has no prominent effect, as it is absorbed by ozone at the surface of the Earth (Fairhurst & Mitchnick, 1997). UV-A radiation is considered more dangerous than UV-B, because it is ~100 times more intense than UV-B and can penetrate deeper into the dermis area of the skin. In the view of the above mentioned UV radiation values, it is important to block such types of harmful radiation, as exposure causes skin cancer in humans. Generally, to protect the skin, materials having UV-blocking properties are added to cosmetic formulations. For the protection of skin from UV-A radiation, ZnO nanoparticles provided an effective UV-blocking material. TiO_2 is also used as a UV-blocking material but reported to be less effective than ZnO because ZnO nanoparticles effectively absorb UV-A radiation rather than scatter it, while TiO_2 usually scatters these wavelengths (Muhammad et al., 2010).

Varsha etal. (2013) reported that the ZnO particles can serve as an excellent material for the removal of Cd(II) from effluents. ZnO nanoparticles used in cosmetic applications also require non-photo catalytic activity, which can be hindered by the uniform surface coating of ZnO nanoparticles by silica or other molecules and toxicity to the human skin is also a main concern. According to Lu et al. (2015) ZnO and TiO_2 NPs can help to prevent skin irritation as well as disruption of the endocrine system typically induced by chemical UV filter. Therapeutic Goods Administration (2016) declared that neither TiO_2 nor ZnO NPs are likely to cause harm when used as ingredients in sunscreens. The current state of knowledge strongly indicates that the minor risks potentially associated with the NPs in sunscreens are vastly outweighed by the benefits that the NP-containing sunscreens afford against skin damage and importantly skin cancer.

11. PAINTS

Paint is a substance that is applied as a liquid or paste and dries into a solid coating that protects or adds colour to a surface to which it has been applied. Nano coatings are polymer-nano composite materials made of resin, solvents, pigments and additives, produced by dispersing nano pigments in resin media at the nano scale to form a denser product, which give a solid film on substrate surface after application (Weichelt etal. 2011). Coatings of wood surface with paint varnish with time and modification with other chemicals improve the durability of wood surface against UV irradiation and weathering factors (Weichelt etal. 2011). The applications of suitable nanoparticles within compatible ratio in paint formulations carry many advantages and opportunities to paint and coating industries. Coating industry is one of the first among all to utilize the potential of nanotechnology (Raymond, 2009).

Dispersed TiO_2 and ZnO particles are excellent UV filters, and are sometimes referred to as mineral or physical filters. Both are commonly used as white pigments (titanium white and zinc white). Ultrafine TiO_2 and ZnO particles lose their capability to scatter visible light, but retain the ability to absorb UV light (Kurapati, 2018). ZnO and TiO_2 are used for improving wood surfaces against UV radiation, water, mildew, fungus growth, stains and grease. ZnO NPs has been used for a long time as a UV stabilizer and preservative component in wood coatings (Vlad-Cristea etal. 2012). Nanoparticles of ZnO have the ability to offer UV protection to coatings so it was low discoloration than from the use of only nano-ZnO (Ahmet & Husseyin, 2014).

12. FERTILIZER

Despite a reasonable number of reports on the endangering nature of some nanoparticles, nanotechnology remains in the frontline as the alternative to revamp the agricultural sector for the better. Its advantages are greater than those of nuclear energy. These advantages are: their manipulative ability that enhances the physicochemical properties; their high carrier system use, bioavailability, and easy processability and engineering; and their low toxicity compared to other compounds (Elias et al., 2019). As food demand is increasing day by day the yield of staple food crops is much low. So there is need to commercialize metal nanoparticles for sustainable agriculture. Zinc oxide nanoparticles (ZnO NPs) also have remarkable optical, physical, and antimicrobial properties and therefore have great potential to enhance agriculture. Zinc (Zn) is considered an essential micronutrient and its deficiency in crops as well as in humans is still an overwhelming issue in the health sector worldwide.ZnO NPs play a significant role in agriculture, where its colloidal solution is used in nanofertilizers as they increase the growth and yield of crops (Sidra et al., 2014). Laware and Shilpa (2014) treated onion plants and concluded that the plants treated with ZnO NPs at the concentration of 20 and 30μg ml^{-1} showed better growth and flowered 12-14 days earlier than the control. This result indicates that ZnO NPs can reduce flowering period in onion by 12-14 days and even produce healthy seeds.

Archana andSatyavikas (2016)conducted a field experiment at M/s. Rashtriya Chemicals and Fertilizers (RCF), Ltd., Mumbai, India, to evaluate the effect of ZnO Nanoparticles (ZnO NP) in combination with N: P: K (15: 15:15) complex fertilizer “Suphala” of the RCF Ltd. on growth attributes of brinjal (SolanummelongenaL) as well as nutrient use efficiency. The experiment was carried out in randomised block design with three replications. The first treatment (T-1), comprised of recommended dose of fertilizer (RDF), N: P: K (50:50:50), applied at the time of transplantation. The second treatment (T-2) was conducted with RDF in combination @ 2kg ZnSO4 (bulk)/ha. The third treatment (T-3) was added, N: P: K (12.5; 12.5; 12.5) in combination to ZnO NP @ 4500mg/ha. The forth treatment (T-C) was without any fertilizer. All treatments were given appropriate quantity of nitrogen per hectare as urea at the 30th day of transplantation.The results of field trials reveal that, there was synergistic effect of ZnO NP @ 4500mg per hectare with N: P: K complex fertilizer on growth attributes of brinjal as well as nutrient use efficiency.

Pankaj (2017) in his PhD thesis, reported that, seed treatment with ZnO NPs at 1000 ppm resulted in significantly maximum seed germination in maize. Healthy and most vigorous seedling with the largest seedling length was observed under the treatment receiving at 1000 ppm of ZnO NPs. However ZnO NPs at higher concentration i.e. 2000 ppm was detrimental to seedling growth in comparison to lower dose. He went further to clarified that, two foliar application of ZnO NPs to maize at 30 and 45 days of sowing was found to be significantly superior in enhancing grain, stover and dry matter yield of maize. Munir et al. (2018) reported that, plant growth, photosynthesis, biomass and Zn concentrations in roots, shoot and grains increased linearly with the seed priming (0, 25, 50, 75, 100 ppm) of ZnO NPs than control. Thus, ZnO NPs could be used as a source of Zn to reduce Zn deficiency in cereals. They emphasized that, their results can help the fertilizer industries to decide the production of nanofertilizers especially ZnO NPs for plant nutrition which will help to reduce the Zn deficiency in plants and finally humans. They concluded that, field studies under different nanostructure sizes, shapes, conditions and plants may further enhance the mechanistic understanding of the applicability of NPs in this field. In another report by Josué et al. (2019), the application of ZnO NPs affects the development of pepper plants. At a concentration of 1000 mg L^{-1}, it promoted plant growth, and increased number and average weight of the fruits, while at 2000 mg L^{-1}, it promoted negative effects on growth and development of the crop. Therefore the ZnO NPs effect depends on the concentration applied. Optimum amount results to positive effects while higher amount signifies overdose and thereby resulting to negative effects.

13. RUBBER INDUSTRY

Natural polymers are polymers with a variety of chemical formula and exhibit unique characteristics. They have received tremendous interest in understanding the transforming mechanism to obtain more useful engineered systems. Metal nanoparticles of different types with ZnO inclusive are subjected to test with a view to enhance the mechanical properties of rubber materials. Neudys et al. (2017) reported that sonication-assisted mechanical mixing of ZnO and TiO_2 nanoparticles inside the non-vulcanized rubber facilitates the dispersion of solids and the proper incorporation of inorganic particles between polymer chains. It also helps in obtaining a stable emulsion and largely avoiding amorphous phase separation after the vulcanization process. The cross-linking density of the vulcanized rubber was slightly improved due to the better filler dispersion, which in turn improve the mechanical and dielectric properties of films. Few defects due to the presence of solid particles inside the polymer matrix and with a better vulcanization process was achieved.

Wang et al. (2017) prepared the samples of 1%, 2%, 3% and 4% Zinc Oxide (ZnO) nano-composite silicone rubber by mechanical method and found that the dielectric constant of the silicone rubber composite increases with the increase of the content of nano-ZnO. They noted that ZnO nano can reduce the hydrophobicity and the breakdown strength of silicone rubber.

II. CONCLUSION

There is a lot of different methods of ZnO nanostructures preparation, like MOVPE, high temperature evaporation, gas spraying, pulsed laser deposition, sputtering, sol-gel, wet chemical and electrochemical methods. ZnO is an attractive material for applications in electronics, photonics, acoustics, and sensing. In general, ZnO NPs are found useful in optical emitters, Lasers, biosensors, gas sensors, solar cells, microwave absorbers, LEDs, piezoelectric devices, cosmetics, biomedicine, paint, coating and rubber industry. The zinc oxide nanoparticle (ZnO NP) is one of the most widely used nanoparticles and is being utilized in the production of pigments, semiconductors, UV protection films, chemical sensors, modern sunscreens and hair care products due to its adsorption ability, large surface area, transparency, UV absorption efficiency and chemical stability.

Conflict of Interest

There was no conflict of interest among authors

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