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Ammonia sensor and antibacterial activities of green zinc oxide nanoparticles

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ABSTRACT

Zinc oxide nanoparticles was synthesized by alginate (A) through a rapid and a facile step in the aqueous solution condition at room temperature. Fabrication of zinc oxide nanoparticles was characterized by ATR-FTIR, TEM and XRD. ATR-FTIR analysis confirmed that the A/ZnO NPs were encapsulated by the polymerized alginate. Their shape, structure and composition were assessed by SEM. TEM and XRD analysis indicated that the A/ZnO NPs give evidence of the crystalline nature of ZnO and hybrid NPs structure, which is suitable for ammonia gas sensor development. The controlled size of the A/ZnO NPs obtained using this innovative synthesis strategy minimizes the response time of 2–3 s to sense the ammonia gas significantly with a detection limit of 1 ppm were found at room temperature. The antibacterial tests revealed that the A/ZnO NPs exhibits a potent activity against gram positive and gram negative bacteria.

1. Introduction

In the fields of nanotechnology metal oxides nanostructures stand out as being among the most versatile nanomaterials because of their excellent high surface area to volume ratio, low toxicity, are environment-friendly, have chemical stability and biocompatibility. Among metal Zinc oxide nanoparticles (ZnO NPs) are of the most promising metal oxides due to their attractive physical and chemical properties. Recently, fabrication of nanosized semiconductors rapidly increasing in regards to their novel optical, chemical, photoelectrochemical and electronic properties which are different from that of bulk [1]. Among various semiconductor materials, zinc oxide nanomaterials have attracted huge attention in sensing areas due to its relatively large surface area to volume ratio, larger band gap (3.37 eV at room temperature), high exciton binding energy (60 meV) which makes excitons in ZnO stable up to 350 K, high transparency, its high ionicity and biocompatibility [2]. ZnO NPs are the forefront of research due to their unique properties such as semiconductor properties, antibacterial, antifungal, wound healing, UV filtering, high catalytic and photochemical activity and also has potential advantages in detecting volatile gas [3].

Currently, so much effort has been devoted to study ZnO NPs as a very promising gas sensing due to its high activity, low cost and environmentally friendly feature and semiconductor properties. It is well known that gas sensors is strongly depends on the large surface-to volume ratio it provided that can greatly facilitate gas diffusion and mass transport in sensor material, thus improving sensor performance [4]. On the other hand, the metal oxide nanoparticles have well anti bacterial activities and antimicrobial formulations comprising nanoparticles, which can be used as an effective bactericidal agent [5]. ZnO nanoparticles are synthesized by different methods: direct precipitation, homogeneous precipitation, solvothermal method, sonochemical method, reverse micelles, sol gel method, hydrothermal, thermal decomposition, and microwave irradiation [6].

Recently, researchers have discovered the possibilities of developing nanomaterials using a green approach in an aqueous medium with the help of stabilizing, capping or hydrolytic agents importance due to its simplicity, inexpensive and eco-friendly [7]. Several polysaccharides, including starch, pectin, cellulose, chitin, and chitosan, have found potential uses in the pharmaceutical and biomedical fields [8]. Polysaccharides of chitosan, starch and alginate are particularly interesting as a matrix polymer since their chains possess large numbers of hydroxyl groups that complex well with metal ions and make them a good environment for the growth of metal and semiconductor nanoparticles [9]. Among polysaccharides, the most abundant cellulose and chitosan are not soluble in water and challenging to dissolve in most organic solvents. Alginate has also been shown to be bio and mucoadhesive, biocompatible and nonirritant, thus finding commercial applications which are useful in biomedical applications such as drug delivery, bionanoreactors, nanofiltration, biosensors and antimicrobial activities [10].

Alginate is a readily water-soluble polysaccharide and a desirable candidate for aqueous processing. Alginate was used as a controlled environment for the growth of ZnO NPs [11]. From this point of view, an effort has been made to develop a simple green route to synthesize ZnO nanocubes using alginate in order to achieve controlled synthesis

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of A/ZnO NPs and investigate their structural, optical, thermal, antimicrobial properties and examine the NH_3 sensing performance of such a device at room temperature.

2. 2. Experiments

2.1. Materials

Alginate from brown algae with M_r~48,000–186,000 (Biochemica) Fluka was used in the present study. Zinc acetate and sodium hydroxide were purchased from Merck and used as received. All reagents used were of analytical grade and were used without further purification.

2.2. Fabrication of alginate–nO nanoparticles

Green synthesis of alginate–zinc oxide nanoparticles was successfully fabricated by a simple and cost-effective procedure. In a typical synthetic procedure for the preparation of alginate–ZnO NPs (A/ZnO NPs), 0.2 g Sodium alginate, 1.2 g $Zn(NO_3)_2$.$6H_2O$, and 40 mL distilled water were added into a 100 mL beaker. After full dissolution, 40 mL of 0.125 M NaOH solution was added dropwise under constant stirring. The reaction was allowed to proceed at room temperature for 24 h. Then, the obtained white precipitate was centrifuged at 10,000 rpm for 10 min and collected and washed with deionised water several times to remove the byproducts. After drying in vacuum at 40 °C for 4 h, the final product was obtained as a white powder.

2.3. UV–Visible (UV–Vis) spectroscopy

UV–vis absorption spectra of a water solution of the A/ZnO NPs and a water dispersion of the ZnO micropowder were performed using a commercial Perkin Elmer Lambda 5 spectrophotometer at room temperature with 1 cm optical path length.

2.4. Attenuated total reflectance-Fourier transform infrared (ATR-FTIR) spectroscopy

The chemical structure of the prepared A/ZnO NPs was characterized using an attenuated total reflectance Fourier transform (ATR-FTIR) spectrophotometer (Shimadzu IR affinity —1S). Each spectrum was acquired in transmittance mode on a Quest ATR ZnSe crystal cell by accumulation of 250 scans with a resolution of 4 $cm^{-1}$and a wavenumber range of 4000–400 cm^{-1}.

2.5. Thermo gravimetric analysis (TGA)

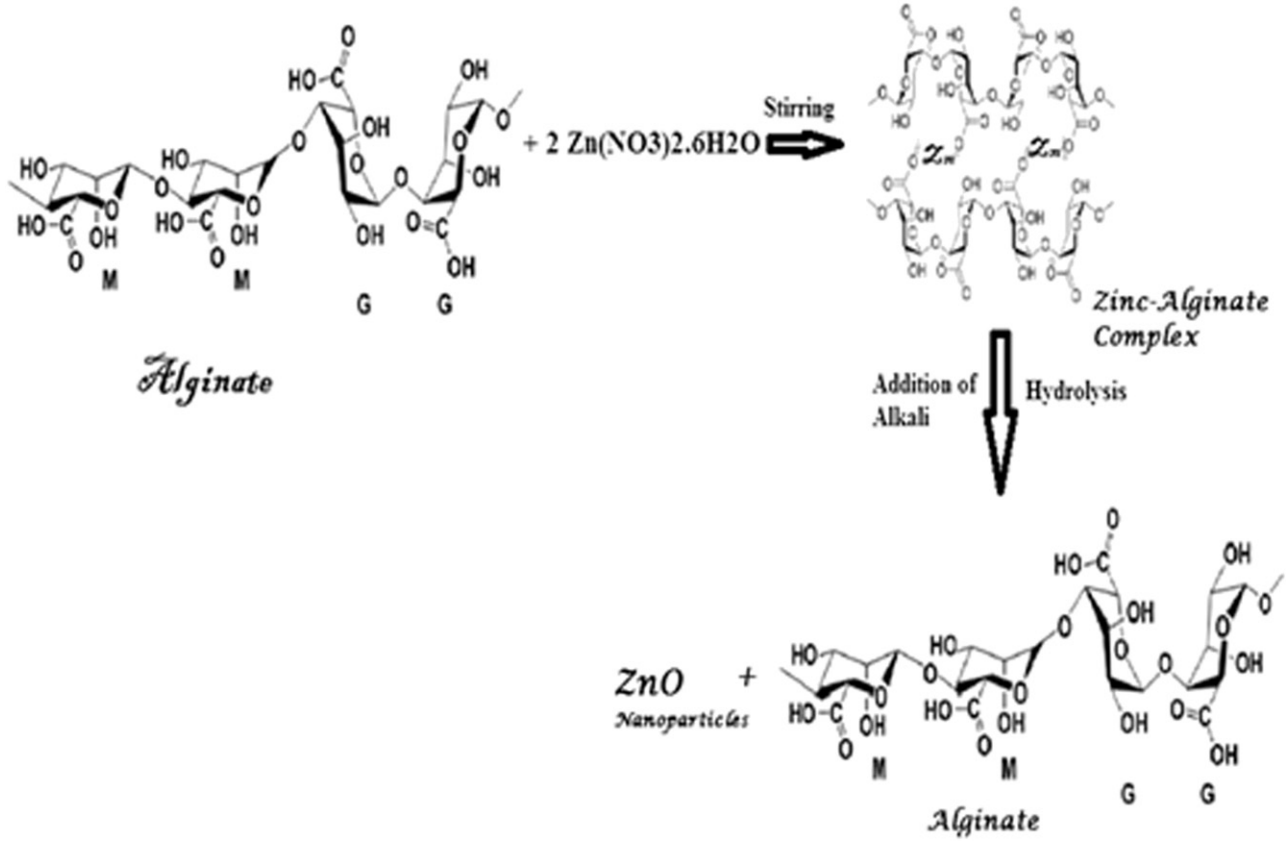
Thermo gravimetric analysis of the A/ZnO NPs was carried out using a TGA (Perkin Elmer STA 6000) analyzer. Experiments were carried out under a nitrogen atmosphere and the temperature range 30–800 °C at the heating rate of 10 °C/min in N_2 atmosphere.

2.6. XRD analysis

X-ray diffraction patterns of A/ZnO NPs were recorded with an X-ray diffractometer (XRD; Bruker AXS D8 Advance). The voltage and current used were 40 kV, and a current of 40 mA using Cu K α radiation (k = 0.154178 nm).

2.7. Scanning electron microscope (SEM)

The A/ZnO NPs were mounted on carbon stubs and the images were studied using scanning electron microscope (SEM- JEOL model JJM-6390LV).



Scheme 1. Possible mechanism of A/ZnO NPs formation.