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Review

Ferrite nanoparticles: Synthesis, characterisation and applications in electronic device

Kebede K. Kefeni *, Titus A.M. Msagati, Bhekie B. Mamba

University of South Africa, College of Science, Engineering and Technology, Nanotechnology and Water Sustainability Research Unit, Florida Science Campus 1710, P.O. Box. 392, South Africa

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ABSTRACT

Ferrite nanoparticles (FNPs) have attracted a great interest due to their wide applications in several areas such as biomedical, wastewater treatment, catalyst and electronic device. This review focuses on the synthesis, characterisation and application of FNPs in electronic device with more emphasis on the recently published works. The most commonly used synthesis techniques along with their advantages and limitations are discussed. The available characterisation techniques and their application in electronic materials such as sensors and biosensors, energy storage, microwave device, electromagnetic interference shielding and high-density recording media are briefly reviewed.

Contents

* Corresponding author.
E-mail address: kkefeni@gmail.com (K.K. Kefeni).

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1. Introduction

Ferrite nanoparticles (FNPs) belong to a broad group of magnetic nanoparticles (MNPs) and have received a considerable amount of attention due to their wide applications in various fields, which ranges from biomedical to industrial. FNPs are metal oxides with spinel structure of general formula AB_2O_4, where A and B are metallic cations positioned at two different crystallographic sites, tetrahedral (A site) and octahedral (B site). The cations of both positions are tetrahedrally and octahedrally coordinated to oxygen atoms, respectively (Fig. 1). For the chemicals to be named ferrite, at least, there must be iron (III) in the chemical formula. The common examples for ferrites are MFe_2O_4 (where M = Mn, Fe, Co, Ni, Cu and Zn), and most of them show superparamagnetic (SPM) properties at the size below or about 20 nm in diameter. In one unit cell of ferrite, there are 64 tetrahedral and 32 octahedral positions are available for cations, out of which only 8 tetrahedral and 24 octahedral are occupied by cations [1,2]. The distributions of each metal cations over both sites are dependent on their affinity for both positions. Which depends upon the stabilisation energy, ionic radii of the specification, size of the interstices, the types of synthesis and conditions employed during the synthesis time [3–6]. The type and distribution of cations at tetrahedral and octahedral sites have a significant implication on the physical and chemical properties of FNPs [3,7–9]. For example, the magnetic properties of FNPs are directly proportional to the type and distribution of the cations at octahedral and tetrahedral sites of the spinel structure. Because, the electron spin of the magnet is ordered parallel within each lattice site while anti-parallel between the two sublattice sites and the net magnetic moment of FNPs is the difference between the two sites [10,11]. Therefore, FNPs with almost the same size and composition may have different saturation magnetisation (M_s) values due to the differences in cation distribution over both sites. Based on the types of cation distribution at both sites, three types of spinel structures are known, namely normal, inverse and mixed spinel types. Representing ferrite with general formula as $(M^{2+}_{1-x})(Fe^{3+}_{x})[M^{2+}_{x}(Fe^{3+}_{2-x})]O_4$, where x represent the degree of inversion, ions inside the square bracket occupy the B sites while ions outside the square brackets occupy the A sites. In the above formula, the ferrite has normal spinel structure when x = 0, inverse spinel structure when x = 1, and mixed spinel structure when $0 < x < 1$ [12]. $ZnFe_2O_4$ is an example of normal spinel ferrite while Fe_3O_4 and $NiFe_2O_4$ are common examples for inverse spinel. An example for a mixed ferrite is $MnFe_2O_4$ ($Mn_{0.8}Fe_{0.2}[Mn_{0.2}Fe_{1.8}]O_4$). Generally, irrespective of their type of spinel structure, ferrites have wide applications in biomedical, wastewater treatment, catalyst and electronic device. Each area of applications requires FNPs to have different properties. For example, for biomedical use, the FNPs should be in the SPM state at room temperature [13]. For the rapid removal of pollutants from water and wastewater, ferrites must have excellent chemical reactivity, high adsorption capacity and reasonable M_s value for easy of removal by external magnetic field [14]. The summary of major application areas of FNPs is given in Fig. 2.

In order to obtain the utmost advantage of FNPs, one has to be aware of advanced technologies for synthesis and characterisation of FNPs. Therefore, this review includes the recent advances in the synthesis, characterisation and their applications in electronic materials.

2. Synthesis methods of FNPs

Synthesis of FNPs is becoming one of the interesting research areas due to their technological importance [15], and fascinating

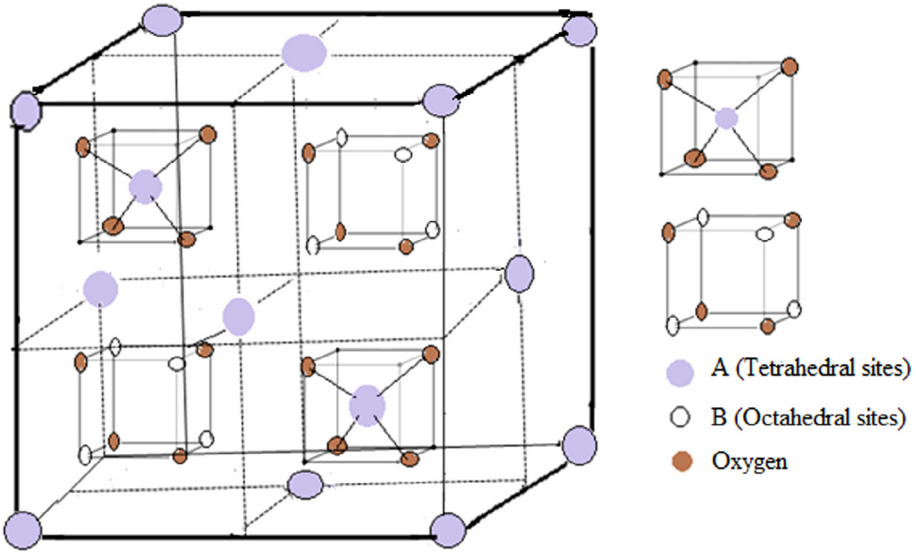

Fig. 1. Spinel ferrite structure showing tetrahedral and octahedral sites.