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Nature of Ferromagnetic and Its Behaviour: An Overview

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INTRODUCTION

This article starts off by giving a brief induction to the fundamentals of ferromagnetism, which includes a discussion of issues such as the beginnings of magnetism and anisotropy, domains and domain barriers, as well as the mechanisms that allow magnetization to reverse in magnetic materials. In addition to this, it is discussed how the microstructural qualities of hard magnets correspond with their magnetic properties, which is a correlation that is well known and well accepted.

Ferromagnetism in addition to the characteristics associated with magnetism the phenomena that are known as magnetism is characterized by the fact that some materials exert a compelling attractive or repulsive force or effect on other materials. This fact distinguishes magnetism from other types of forces and effects. Although it has been known for thousands of years, critical understanding about it did not begin to emerge until relatively recent years. In this section, we shall have a brief explanation not only of the various macroscopic magnetic features, but also of the mechanics that lie at the foundation of magnetism.

When the moment cancellation is taken into account, the magnetic moment of a single atom is computed as the sum of that atom's orbital moment and its spin moment. This calculation is done before the moment cancellation is taken into account. When it comes to classification, magnetism may be broken down into a total of thirteen distinct groups. Among these classifications are diamagnetism, paramagnetism, and ferromagnetism. Additionally, antiferromagnetism and ferrimagnetism are regarded to be subclasses of ferromagnetism. Each of these classes is included in at least one of the things that make up every material. When a magnetic field is applied to diamagnetic materials, it causes a shift in the orbital motion of the electrons, which, in turn, creates a magnetic response that is insignificantly weak in the direction that is perpendicular to the direction in which the field is applied. It is believed to be nonpermanent, and its status as such will only be maintained for the duration that an external magnetic field is present. It is important that you keep in mind that diamagnetism may be found in a wide variety of various types of materials. On the other hand, due to the fact that it possesses such a low magnetic strength, it can only be observed in conditions in which all other types of magnetism are absolutely nonexistent. On the other hand, each atom already possesses a permanent dipole moment when it is present in paramagnetic materials. This dipole moment shows up in the world as an unsatisfactory cancellation of the magnetic moments associated with the orbital spin of the electron or the electron spin itself.

The magnetic moments will not align themselves in the direction of the field if there is not an external magnetic field present to organize them; instead, they will continue to be unorganized. On the other hand, the magnetic moments do not interact with one another in any way between adjoining dipoles since they are completely isolated from one another. Because they only exhibit magnetization when they are in the presence of a magnetic field, diamagnetism and paramagnetism are both categorized as nonmagnetic behaviors (Fig.). In contrast to this, ferromagnetic materials always have a magnetic moment, regardless of whether or not there is a magnetic field present in the material itself. In this particular instance, the alignment of the net spin magnetic moments with one another is brought about as a result of the coupling that occurs between surrounding atoms. On the other hand, antiferromagnetism is distinguished by the alignment of the spin moments of neighboring atoms or ions in orientations that are diametrically opposing to one another. These orientations are called antiparallel. It is possible to witness antiferromagnetism in MnO, and a simplified illustration of this phenomenon is presented in Figure (b). It is evident that magnetic moments that behave in a manner that is antagonistic to one another cancel each other out, which results in their being no magnetic moment overall. Certain ceramic materials have ferrimagnetic behavior, which is similar to ferromagnetism but with unique sources of 14 net magnetic moments. This behavior is akin to ferromagnetism. It is possible for certain ceramic materials to exhibit ferrimagnetism. One such illustration may be seen in this article in the form of Fe3O4 in its schematic representation.

Nature of Ferromagnetism

It is not quite clear where the property of ferromagnetism in non-magnetic semiconducting materials originates from; the topic is currently up for discussion. On the other hand, structural faults and magnetic impurities are often evoked in order to explain magnetic ordering. In binary or ternary metal oxides, the magnetic behavior and the origin of ferromagnetism that are generated by dopant may be linked to the production of a secondary phase or clusters.

According to the results of this research the phenomena of ferromagnetism may be traced back to defects such as oxygen vacancy, Zn interstitial, and Sn interstitial. The spin polarization of the carriers that defects create is caused by the interaction of these free carriers with the localized d electrons of cobalt ions. Defects have a tendency to function as generators of free carriers, and this interaction is what produces the spin polarization. After then, it is anticipated that the free spin polarized carriers will engage in some form of interaction with the element cobalt's nearest localized electrons. According to Simoll et al. (2012), the origin of observed ferromagnetism in Co-doped ZTO might be due to s–d exchange interactions of spin moments generated by defects such as oxygen, Zn, and Sn interstitials. These interactions are thought to be the cause of ferromagnetism in the material. Because of this, certain residencies of Co ions, in conjunction with the presence of defects, preserve ferromagnetic ordering in nanostructures of cobalt-doped zinc stannate. This is because of the fact that cobalt is a valence electron.

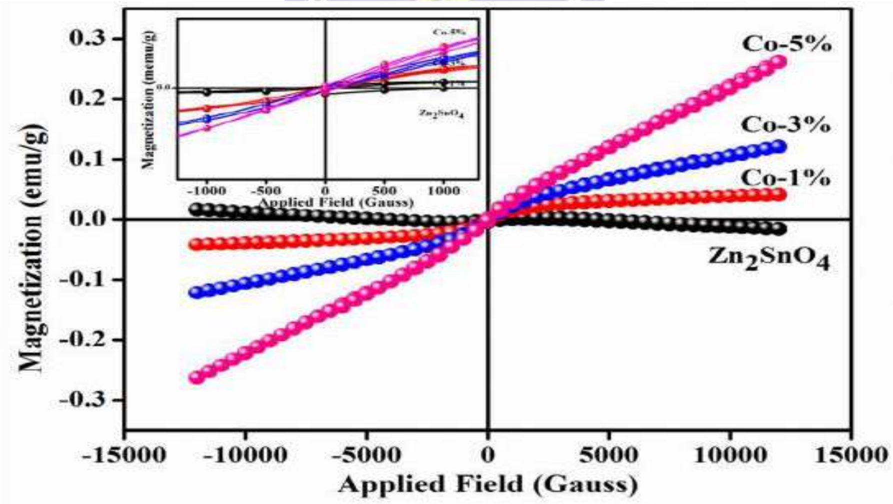

Figure: Magnetization behaviour of pure and Co doped Zn2SnO4 compounds

Table: Magnetization values of pure and Co doped Zn2SnO4 compounds

Sample	Coercivity (He) (Gauss)	Saturation magnetization (Ms)(memu/g)	Remanent magnetization (MR)(memu/g)	Squareness ratio (MR/Ms)
Zn2SnO4	-	-	-	-
Co 1%	129	41.7	1.269	0.0304
Co 3%	91	121.7	1.270	0.0104
Co 5%	121	265.7	2.326	0.0087

SYNTHESIS AND CHARACTERIZATION ON STRUCTURAL, OPTICAL AND MAGNETIC PROPERTIES OF PURE AND Fe DOPED Zn2SnO4 COMPOUNDS Zinc stannate, also known as Zn2SnO4, is a component of the ZnO-SnO2 system that belongs to the type M2SnO4 (where M is a divalent metal cation). Zinc stannate is both an important and fascinating compound. This system has been the subject of research due to the diverse array of applications that it may fulfill. Some of these applications include chemical sensors, photoelectric devices, transparent conducting electrodes, anode materials in Li-ion batteries, functional coatings, and photocatalysts. It is well known for being transparent in the visual spectrum and having a high electrical conductivity, both of which have gained widespread recognition. Zn2SnO4, most commonly referred to as ZTO, is a semiconducting oxide that is n-type and transparent. It has an electron mobility in the range of 10–15 cm2 V-1s-1 and a bandgap of 3.6 eV. Crystallization of zinc stannate often results in the formation of an inverted 2–4 cubic spinel that has the space group fd-3m. Zn2+ (B) ions may be found randomly occupying octahedral spaces, whereas Sn4+ (A) ions can be found randomly occupying tetrahedral voids within this structure. Zn2+ (B) ions can be found filling tetrahedral voids.

Even though it is a candidate with enormous potential to serve as good spintronic materials, there are only a few articles accessible on the magnetic properties of the TM doped ZTO system. This is despite the fact that there are only a few studies available. Despite this, spintronic materials are already being used in a wide variety of applications. First-principle calculations were utilized by Deng et al. (2013) in order to provide evidence that ferromagnetism may be found in Mn-doped zinc stannate systems. They did some experimental research on the phenomena as well, producing ZTO nanowires by the use of chemical vapour transfer.

Only iron, out of all the TM ions, has the ability to keep ferromagnetism in DMS materials, even when there are multiple other ions. Because iron may offer a powerful relation to the distribution of oxygen vacancy and the abundant occurrence of iron-oxygen-iron groups, both of which can modify the magnetic properties of the host material, this is the case. Iron may also offer a powerful relation to the distribution of iron-oxygen-iron groups. There are a number of studies that can be found on the literature for binary semiconducting oxides that are doped with iron and demonstrate significant ferromagnetic ordering at room temperature. These oxides can be located by searching "binary semiconducting oxides doped with iron." Zinc oxide and tin dioxide are two examples of oxides that fall within this category.

In this context, the methods of synthesis play an important part in the alteration of the crystal structure and stability of the nanoparticles, which in turn impacts the features of spinel oxides. It is believed that the circumstances of the synthesis as well as the thermal treatment have a direct influence on the distribution of cations in spinels. The hydrothermal synthesis of nanoparticles has a number of advantages over the other procedures that may be used to create nanoparticles. These benefits are a direct result of the high level of control that can be exerted during the hydrothermal synthesis of nanoparticles over the processes of hydrolysis, nucleation, and development of nanoparticles. This control is attained by carefully regulating both the pressure and the temperature of the reaction.

Because of this, the structural, optical, and magnetic properties of pure and Fe-doped zinc stannate nanostructures were investigated in this chapter. These nanostructures were created using the hydrothermal technique.

Birth of Ferromagnetism

It has been found that the birth of ferromagnetism in non-magnetic oxides is contingent on having the suitable degree of dopant concentration as well as cluster formation on the surface of compounds. This is because both of these factors are necessary for the genesis of ferromagnetism. Structural defects and magnetic impurities are commonly given as possible explanations in attempt to make sense of magnetic ordering in materials that are not themselves magnetic.

SYNTHESIS AND CHARACTERIZATION ON STRUCTURAL, OPTICAL AND MAGNETIC PROPERTIES OF PURE AND Co DOPED

CaSnO3 COMPOUNDS

Because of their exceptional ferromagnetic properties and high Curie temperatures, dilute magnetic semiconductors, also known as DMSs, have attracted a significant amount of interest due to the potential technical implications that they might have in the field of second-generation spintronics devices. This interest is due to the fact that dilute magnetic semiconductors could potentially have these implications. Since it was found that Mn-doped ZnO exhibited ferromagnetism at room temperature, a large amount of effort has been spent into the search for alternative materials that exhibited the same feature. As a direct consequence of this fact, a wide range of transition metal (TM) doped wide-bandgap oxide semiconductors, such as ZnO, TiO2, SnO2, and HfO2, have been examined to see whether or not they display any signs of RT ferromagnetism. Aside from these binary oxides, researchers have also focused on achieving RT in ternary perovskite structured materials like as MTiO3 and MSnO3 that have been doped with magnetic impurities. These materials have been used as examples. The formula for these compounds looks like this: M = Sr, Ba, or Ca.

In this context, the broad applications of alkaline earth stannates as photocatalysts, ceramic dielectric bodies, lithium ion batteries, and gas sensors have resulted in an increase in the amount of attention that has been paid to these materials. Dopants such as Co, La, Sb, Nb, and Er, amongst others, have been selected for doping with the MSnO3 system in order to examine the magnetic and dielectric properties of the dopants that have been selected for doping. Doping nanocrystalline BaSnO3 with iron and manganese led to the discovery by Balamurugan et al. (2009) that the material exhibited ferromagnetism even when it was kept at room temperature. When Sr and Pb were added to BaSnO3, it was discovered that both the luminescence efficiency as well as the photocatalytic activity were greatly increased. In addition to this, it has been shown that La and Sb doped MSnO3 compounds demonstrate extraordinarily high levels of conductivity and transmittance in their properties.

Perovskite type alkaline earth stannates, such as the compound CaSnO3, have captured the interest of the scientific community as a result of their remarkable optical and semiconducting properties, in addition to their interesting dielectric characteristics (Moseley et al. 1988; Shimizu 1989). Perovskite-type alkaline earth stannates, such as CaSnO3, are referred to as stannates. CaSnO3 is particularly well-known for the high up conversion efficiency it demonstrates, which is mostly a direct result of the low phonon energy it possesses. According to research carried out by Mizoguchi et al. (2004), CaSnO3 is a promising contender for the role of host material in up conversion luminescence. Because of the nature of this luminescence, it is feasible to create almost any needed visible emission by making use of light that is low in energy and near infrared. In addition, CaSnO3 has a wide bandgap and a high melting point, both of which qualify it for a variety of applications. These applications include display matrices, thermally stable capacitors in electronic industries, ceramic materials for lithium ion batteries, photo catalytic utilization, and gas sensor hosts (Shang et al. 2014; Li et al. 2014). CaSnO3 has also been used in photocatalytic utilization (Shang et al. Due to these properties, CaSnO3 is an excellent candidate for use in various applications. Phosphors are known to benefit greatly from the incorporation of trivalent rare earth elements into CaSnO3, since this results in the production of a good raw material. This is because it is thought that SnO44- anions are optically-inert and have the ability to function as a suitable host (Chen et al. 2004; Kim et al. 2002). The reason for this is because SnO44- anions have the capacity to operate as a good host. Even though this stannate is incredibly important to the development of technology, it has not yet been examined for its prospective use as a dilute magnetic oxide. This is despite the fact that it plays an extremely vital role in the development of technology. There are no studies that we are aware of so far that discuss the magnetic behavior of calcium stannate nanoparticles that have been doped with transition metal (TM) cations. This is something that we are very interested in learning more about. According to the best of our knowledge, this is the case.

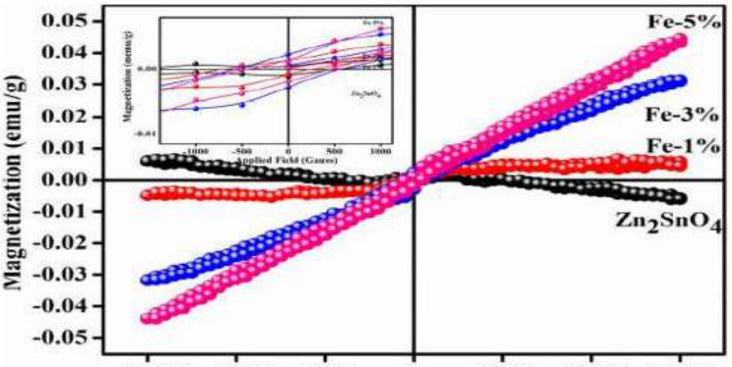

Figure: Magnetization behaviour of pure and Fe doped Zn2SnO4 compounds

The results of this study indicate that an exchange interaction between the locally spin-polarized electrons of Fe3+ and the conduction band electrons may be responsible for the birth of magnetism in Fe-doped ZTO samples. The spin polarization of the conducting electrons is the result of this interaction with the other particles. Because of this, nearly all of the Fe3+ ions exhibit the same spin orientation as a result of a number of long-range exchange contacts; the observation of ferromagnetism is a direct result of this phenomenon.

Table: Magnetization values of pure and Fe doped Zn2SnO4 compounds

Sample	Coercivity (HC) (Gauss)	Saturation magnetization (memu/g)	Remanent magnetization (MR)(memu/g)	Squareness ratio (MR/MS)
Zn2SnO4	258	-----	-----	-----
Fe-1%	360	5.5	1.180	0.1967
Fe-3%	420	31.5	1.399	0.0447
Fe-5%	647	44.2	3.067	0.0693

When there is a larger concentration of iron, the average distance between the ions in the substance grows shorter. This is because iron is an electronegative element. It's possible that this is what causes the magnetic to shift when there are different concentrations of iron present. When there is a low concentration of Fe, the distance between the Fe ions is higher, which results in a weaker ferromagnetic link. When there is a high concentration of Fe, the distance between the Fe ions is smaller. However, when there is a higher concentration of iron, the interactions that occur between the iron ions become more robust, which in turn results in an increase in the ferromagnetism.

As a result, the sp-d exchange interactions of spin moments may be responsible for the observed ferromagnetism in Fe ZTO systems. These interactions may have been brought on by flaws in the host lattice, such as the 2p and 3d states of oxygen, for example. Both doping with iron ions and the presence of defects in zinc stannate nanostructures that have been doped with iron encourage the formation of ferromagnetic ordering.

MAGNETIZATION STUDIES

It is possible to generate ferromagnetic ordering in non-magnetic oxides in one of two ways: either by the influence of doping or by the development of secondary phase or cluster formation of magnetic dopants in the host lattice. Both of these methods require the presence of magnetic dopants in the host lattice. Both of these approaches will each be broken down into even more specific steps below. Both of these strategies are going to be dissected in the following paragraphs. According to one proposal, the ferromagnetism that may be seen in DMS has been connected to a mechanism that is assumed to be carrier-mediated. This hypothesis was developed based on observations of the material. In this particular setting, the idea of oxygen vacancies has been investigated as a potentially significant step forward in the quest to explain the magnetic genesis of oxide-based DMS materials. Vacancies are spaces in an oxygen atom that are empty. This would be a huge advance in the sense that it would be a step that would greatly shift the needle in the direction that we want it to go. The scientific literature now contains a number of research that provide the appearance that oxygen vacancies may produce remarkable variations in the band structure of the host, which would eventually result in a major contribution to the ferromagnetism. These studies offer the impression that oxygen vacancies might generate extraordinary alterations in the band structure of the host. The production of bound magnetic polarons, also known as BMPs, is an additional crucial idea for defining the development of RTFM in materials that are composed of insulating oxide. This process takes place when electrons become locally trapped in oxygen vacancies, and these bound electrons occupy an orbital that overlaps with the d shells of TM cations in the surrounding region. In other words, the d shells of TM cations are filled with overlapping electrons. BMPs are formed whenever electrons find themselves locally stuck in oxygen vacancies. This phenomenon is what leads to the production of BMPs. It is probable that not all of the processes that induce magnetism in binary oxides are the same as those that create magnetism in ternary oxides. This is because binary oxides and ternary oxides have two different types of electrons. In addition, there are not a lot of studies in the scientific literature that investigate ferromagnetism in ternary oxides that have TM doping. On the other hand, the mechanisms of magnetism in binary oxides have already been thoroughly discussed in the portion of this article that came before it.

Figure illustrates the M-H curves for nanoparticles that are pure CaSnO3 as well as those that have been doped with iron. Also included in this figure are the nanoparticles that have been doped with iron. These curves were measured with the temperature kept constant at room temperature. Table contains a listing of the values for saturation magnetization (MS), remanent magnetization (MR), and coercivity (HCi) for each of the samples. Pure CaSnO3 exhibited unsaturated ferromagnetism on the magnetization plot, but samples containing 1 and 3% Fe dopant demonstrated obvious indications of hysteretic activity. This phenomenon may be observed if one so chooses. When the materials were doped with 5% iron, not only did the ferromagnetic ordering of the materials improve, but the materials also demonstrated greater levels of saturation magnetization and coercivity. The M-H loops, as a direct result of this, unequivocally demonstrate that there is dopant-induced ferromagnetic ordering present in the samples that have been produced.

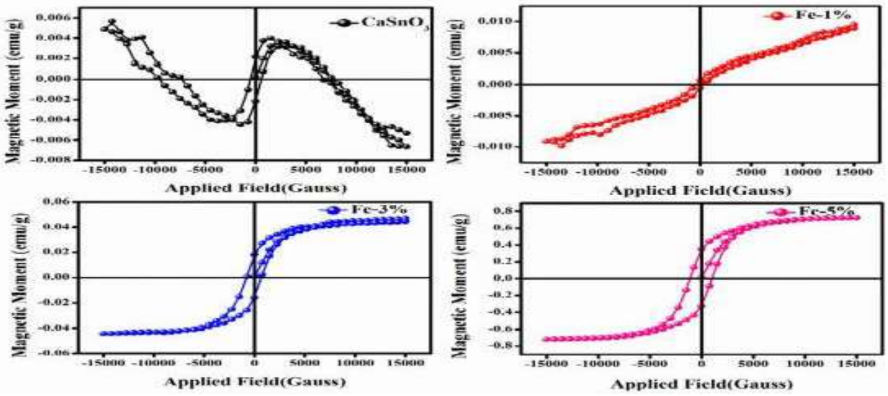

Figure: Magnetization behaviour of pure and Fe doped CaSnO3 compounds

Table: Magnetization values of pure and Fe doped CaSnO3 compounds

Sample	Coercivity (HC) (Gauss)	Saturation magnetization (memu/g)	Remanent magnetization (MR)(memu/g)	Squareness ratio (MR/MS)
CaSnO3	------	-----	-----	-----
Fe-1%	493	9.7	0.875	0.0902

Fe-3%	720	46.7	1.572	0.0336
Fe-5%	1100	714.1	3.243	0.0453

The research that was conducted in 2009 by Balamurugan and colleagues found that the ferromagnetism that was observed in samples of Fe-doped CaSnO3 was equivalent to that which was observed in Fe- and Mn-doped BaSnO3, in addition to that which was observed in other perovskite oxides. There is a possibility that the F-centre exchange (FCE) mechanism might provide an explanation for the observed ferromagnetism in the Fe-doped CaSnO3. This theory was proposed by, and according to it, the direct ferromagnetic coupling of metal ions takes place as a result of an oxygen vacancy (Vo). When an electron that is confined and unable to move is grabbed by an oxygen vacancy, this results in the formation of an F-center. The spin of each Fe2+ and Fe3+ ion has an antiferromagnetic interaction with the spin of this attached electron, which results in an antiferromagnetic interaction. As a result, there is a chance that the RT-FM in the samples was brought on by the FCE of (Fe3+/ Fe2+)-V0-(Fe3+/ Fe2+). An increase in the concentration of iron may cause an increase in the amount of oxygen vacancies and Fe3+/Fe2+ ions inside the structure. This may promote an increase in the number of interactions between iron ions and volatile oxygen species. Because of this, magnetic moments will also increase, which will ultimately result in a discernible increase in ferromagnetism in the Fe-doped samples.

CONCLUSION

In recent years, magnetoelectronics has emerged as one of the scientific topics that is receiving the most attention as being one of the most interesting and rapidly evolving. Two fundamental criteria, such as the size of the particles and the spin injection of foreign atoms into the host lattice, are responsible for determining the one-of-a-kind and intriguing properties of DMS materials. These properties are defined by the DMS materials. As a consequence of this, the synthesis and characterization of cobalt and iron doped stannate-based compounds is going to be the major focus of this thesis. The purpose of these compounds is to endow materials that are planned for use in magneto-optical applications with ferromagnetic characteristics even when the materials are kept at ambient temperature.

The adoption of a straightforward co-precipitation procedure is capable of facilitating the synthesis of polycrystalline Zn2SnO4 compounds that are both pure and co-doped. The XRD patterns of the compounds that have been synthesized allow one to see that a cubic inverse spinel structure was formed during the synthesis of these compounds. An FTIR analysis may be able to determine the presence of functional groups in addition to the vibrations of metal oxides (such as Zn, Sn, O, and Co). The findings of the SEM investigation indicate that the morphology consists of both plates and rods in equal measure. The presence of some elements may be inferred from an EDAX spectrum. These elements include zinc, tin, oxygen, and cobalt. The optical absorption characteristics of pure and Co-doped Zn2SnO4 have been analyzed, and the results show that the highest absorption occurs at a wavelength of 280 nm. Doping a material induces a shift toward longer wavelengths, which in turn results in a narrowing of the optical bandgap. The findings of the photoluminescence tests indicate that each of the newly developed compounds produce light in a variety of hues. In the instance of pure Zn2SnO4, a low-key form of ferromagnetism was found, and one possible explanation for this behavior is that it is caused by faults that are built into the system. The linear increase in ferromagnetism that takes place when the concentration of cobalt rises, which can be attributed to free spin polarized carriers if they are present.

It is explored how the incorporation of Fe alters the surface form of the cubic spinel Zn2SnO4, in addition to its optical and magnetic characteristics. Both the pure Zn2SnO4 compounds and the compounds that contain Fe can be produced by the hydrothermal process. The results of the XRD analysis offer evidence that phase formation has taken place in the samples that were produced. In the Zn-Sn-O lattice, evidence of the effect that Fe has on the microstructure may be seen in the form of insignificant variations in crystallite size and micro strain across the lattice. Both Fourier transform infrared spectroscopy and Raman spectroscopy are utilized in order to locate and interpret metal oxide vibrations (Zn, Sn, O, and Fe) as well as to determine whether or not compounds include Raman modes. This demonstrates that the molecules are unadulterated in both their structural and chemical aspects. The Field Emission Scanning Electron Microscopy (FESEM) reveals the existence of agglomerated poly dispersed particles of compounds that are both pure and doped with iron. It was observed that adding Fe to a material causes the particles to get bigger, which in turn enhances the red shift in the optical absorption spectrum. The optical energy bandgap of pure Zn2SnO4 has been measured to be 3.51 eV, and it has been seen to dip to 3.14 eV. The high emission of blue and blue-green light in the PL spectrum may be used to verify the presence of oxygen vacancies and interstitial defects in a material. The resonant EPR signal that is observed in compounds containing Fe-doped Zn2SnO4 is brought on by electrons that become trapped in oxygen vacancies. According to the findings of the magnetic analysis, the pure Zn2SnO4 compound does not exhibit any signs that are characteristic of ferromagnetic ordering. However, all of the Fe-doped compounds display strong magnetic ordering because of the oxygen vacancies in the lattice. This, in conjunction with charge carriers, causes the change from diamagnetism to ferromagnetism in the compounds.

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