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Variation of Curie-temperature of Ni-Ti Ferrite by Using Different Techniques

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ABSTRACT

The present research work, reports the synthesis and structural properties of a $Ni_{1+x}Ti_xFe_{2-2x}O_4$ spinel ferrite system prepared by a prevalent solid-state reaction technique. To confirm the crystal structure acquired by the prepared samples, we examined these samples using an X-ray diffraction pictograph taken at room temperature with a slow scanning rate. The Curie temperature (T_c) of Ni-Ti ferrites is a critical property that dictates their magnetic behavior, which can be influenced by various factors such as composition, synthesis techniques, and structural modifications. This study investigates the variation of the Curie temperature of Ni-Ti ferrites by employing different techniques, including AC susceptibility, DC resistivity and Loria techniques. Each method leads to distinct microstructural and phase characteristics that significantly influence the magnetic properties of the ferrites. In contrast, samples prepared by solid-state reactions show lower Curie temperatures due to greater disorder and grain boundary effects. The findings contribute to optimizing the fabrication techniques for high-performance Ni-Ti ferrites in technological applications such as magnetic sensors, transformers, and inductors.

Keywords: Ni-Ti ferrite, Curie temperature, X-ray diffraction, solid-state reaction, AC susceptibility, D.C. resistivity, Loria techniques.

1. Introduction

Among the many electrical and electromagnetic uses for ferrites are those using nickel-titanium (Ni-Ti) ferrites, which are magnetic materials characterised by a high resistivity, excellent thermal stability, and adjustable magnetic characteristics. For ferrite-based devices, the range of operation and efficiency are highly dependent on the Curie temperature (Tc), which is the point at which the material changes from ferromagnetic to paramagnetic. Magnetic ceramics known as ferrites play a significant role in the manufacturing of many components, including electronics. Their versatility allows them to find use in anything from simple electrical gadgets to large permanent magnets. Among the many fascinating uses are in a variety of electrical and microwave devices, permanent magnets, telecommunications equipment, computer peripherals, and more [1].

The many desirable properties of nickel ferrite—including its high Curie temperature, mild saturation magnetisation, low electrical resistivity, and exceptional chemical stability—make it a highly sought-after magnetic material in many fields of science and technology. The octahedral B site is occupied by Ni ions in nickel ferrite, an inverse spinel ferrite, whereas the tetrahedral (A) and octahedral [B] sites are equally distributed with Fe^{3+} ions. Numerous researchers have focused on nickel-ferrite and replaced nickel ferrite [2-5]. The electrical and magnetic characteristics of nickel ferrite are affected by the addition of tetravalent ions. Various scholars have investigated Ti^{4+} substituted nickel ferrite in an effort to comprehend its magnetic, electrical, and structural characteristics. Research on $Ni_{1+x}Ti_xFe_{2-2x}O_4$ has shown a lack of investigation into cation distribution, dielectric characteristics, and infrared spectroscopy (IR Studies). Spinel ferrite's magnetic characteristics may be better understood via cation distribution research. How the cations are distributed across the tetrahedral A and octahedral B sites determines the magnetic characteristics. A wide variety of high-frequency electronic devices may benefit from ferrite's strong electrical resistivity, little eddy current, and low dielectric losses. Therefore, for potential microwave applications using spinel ferrite, it is crucial to examine its dielectric characteristics. Taking all of this into account, we've settled on investigating how the synthesis process, particle size and dispersion, and ferrite composition affect the Curie temperature. It has been shown that ferrites may be synthesised using a variety of approaches, including solid-state reactions, sol-gel procedures, and hydrothermal synthesis. These methods impart distinct structural features to the ferrites, which influence their magnetic properties and Tc. The purpose of this research is to better understand the effects of these procedures on Ni-Ti ferrites' Curie temperatures and to provide suggestions for improving the material's performance during production.

2. Experimental

The polycrystalline samples of $Ni_{1+x}Ti_xFe_{2-2x}O_4$ were prepared by using a ceramic technique [6]. A stoichiometric percentage of A.R. grade oxides (SD fine) of the appropriate ions (NiO, TiO2, and Fe_2O_3) is mixed. Each sample underwent four hours of grinding with agate mortar. After being heated to 9000C for 12 hours in a muffle furnace, the samples were pre-sintered. Afterwards, a 6-ton hydraulic press was used to reground the powder and compress it into pellet form. I sintered the pellets in air at 12,000 degrees Celsius for one day. Samples were cooled to room temperature using a furnace. At room temperature, X-ray diffraction patterns were recorded to validate the presence of a single-phase cubic spinel structure. Using AC susceptibility, D.C. resistivity, and Loria methods, the samples were also characterised for Curie temperature. [7]. Each method have their own identification. The Curie temperature recorded by these techniques used to study of phase transition of the ions in the prepared samples.

3. Results And Discussion

The X-ray powder diffraction (XRD) patterns are sharp and intense of $Ni_{1+x}Ti_xFe_{2-2x}O_4$; where $x = 0.0 \leq x \leq 0.7$ are shown in **Fig 1** for typical samples x= 0.0. XRD analysis reveals the following reflections: (220), (311), (222), (400), (422), (511), (440), and (533). There is a cubic spinel structure present, as these reflections show. The presence of a cubic spinel type and crystalline phase diffraction line clearly indicates that $Ni_{1+x}Ti_xFe_{2-2x}O_4$ spinel ferrite was formed in a single phase. The sample was formed according to the crystal structure of mixed ferrite materials, as evidenced by the X-ray powder diffraction patterns.

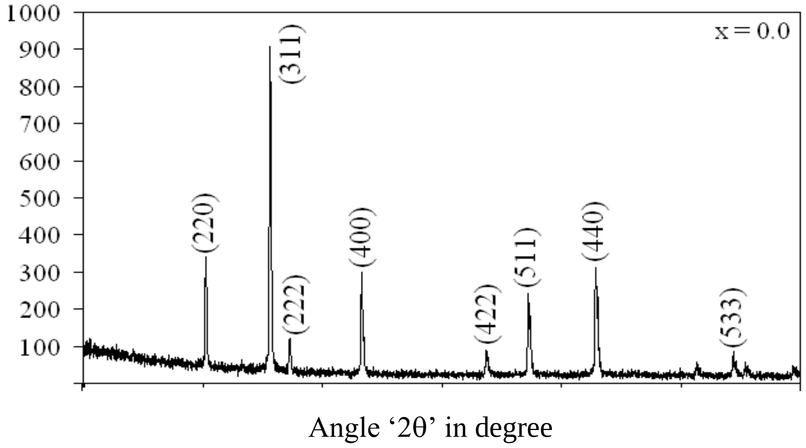

Fig 1: The X-ray powder diffraction (XRD) patterns for x=0.0 of $Ni_{1+x}Ti_xFe_{2-2x}O_4$ system.

The prepared materials ate used to study of phase change using Curie temperature study by using different methods. The Curie temperature variation can be attributed to differences in the microstructure, crystallinity, and the nature of the grain boundaries, all of which impact the magnetic interactions between the particles.

3.1. Curie temperature

3.1.1. Measurement of Curie temperature by A. C. Susceptibility

A.C. susceptibility (χ_{ac}) is defined as the ratio of the induced magnetic moment to the applied oscillating magnetic field. When a material undergoes a magnetic phase transition, such as the Curie transition, the A.C. susceptibility exhibits a characteristic peak at the Curie temperature. Below Tc, the material is ferromagnetic, and its susceptibility increases as the temperature approaches Tc, above Tc, the material becomes paramagnetic, and the susceptibility decreases. Mathematically, the temperature dependence of the susceptibility near the Curie temperature can be described by the Curie-Weiss law:

$$\chi(T) = \frac{C}{T - Tc}$$

Where, $\chi(T)$ is the susceptibility at temperature T, C is the Curie constant, and Tc is the Curie temperature. The experimental setup for a.c. susceptibility is as shown in **Fig. 2.**

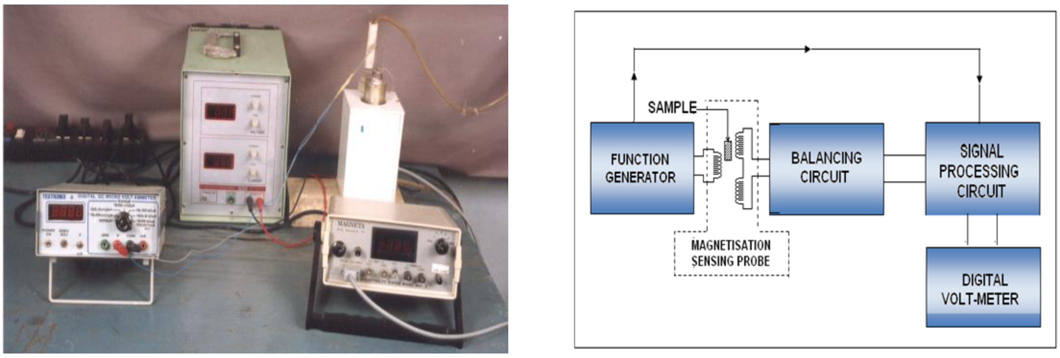

Fig. 2: Experimental setup for a. c. susceptibility

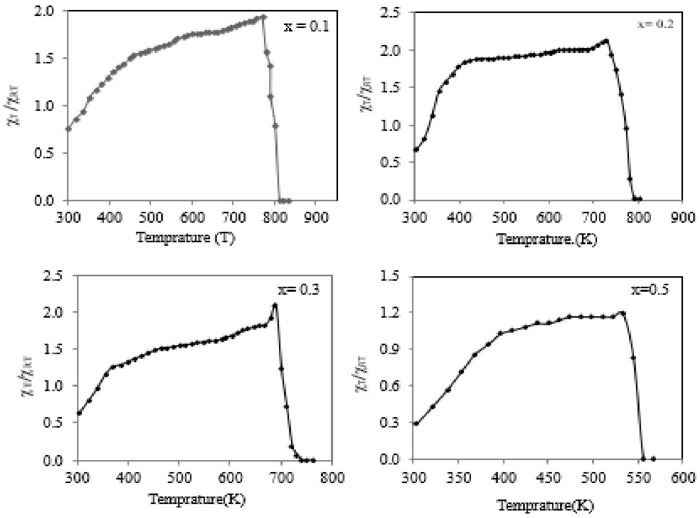

Fig.3: AC susceptibility plots

The values of Curie temperature are determined from susceptibility plots (**Fig.3.**) and are given in **table 1.**

3.1.2. Measurement of Curie temperature by D.C. Resistivity

In ferromagnetic materials, the electrical resistivity is strongly influenced by the material's magnetic state. Below the Curie temperature (Tc) [8], the material is in a ferromagnetic state, and the resistivity is relatively low. This is because electron scattering due to spin disorder is minimized in the ferromagnetic state. As the temperature increases towards Tc, the spin alignment begins to break down, and the resistivity increases due to enhanced electron scattering.

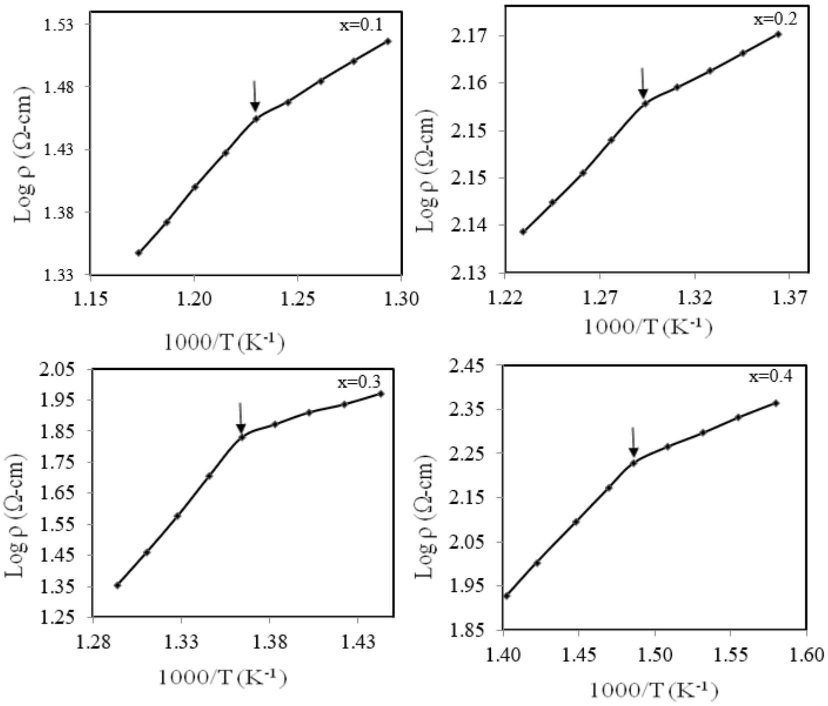

Fig.4: Measurement of Curie temperature dc resistivity

D.C. resistivity is an effective and reliable method for determining the Curie temperature of ferromagnetic materials, including ferrites. The resistivity measurement provides a clear, reproducible indication of the magnetic phase transition and offers a non-invasive, cost-effective alternative to traditional methods. The results demonstrate (**Fig.4**) that the Curie temperature can be accurately determined from the sharp change in resistivity, which corresponds to the transition from ferromagnetic to paramagnetic behavior [9].

3.1.3. Measurement of Curie temperature by using Loria techniques

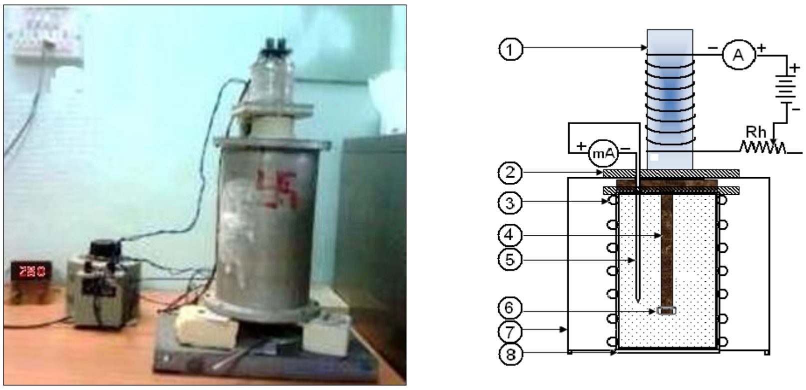

Fig.5: Experimental set up for Loria method

The Loria technique is a lesser-known but effective method for determining the Curie temperature of magnetic materials by measuring the resistance as a function of temperature in the presence of a magnetic field. The Loria technique relies on the fact that the magnetic phase transition alters the material's electrical resistance, making it possible to detect the Curie temperature through resistance changes. The Loria technique is the most simple and versatile technique to measure Curie temperature of magnetic materials. A schematic diagram of the experimental setup is shown in **Fig.5.**

In **Fig.5**, 1-Electromagnet**,** 2-Procelain sheet**,** 3-Heating coil**,** 4-Soft iron piece, 5-Thermocouple, 6-Pellet**,** 7-Furnace**,** and 8-Metal lead. The Loria technique is based on the observation that the electrical resistance of ferromagnetic materials varies with temperature due to changes in their magnetic ordering. As the temperature increases and approaches the Curie temperature, the material transitions from a ferromagnetic state (where magnetic moments are aligned) to a paramagnetic state (where magnetic moments are random). This transition leads to changes in the electron scattering mechanisms, thereby affecting the material’s resistance

The Loria technique offers an effective and reliable method for determining the Curie temperature of ferromagnetic materials. By measuring the temperature-dependent resistance, the Loria technique provides clear and precise information about the magnetic phase transition from ferromagnetic to paramagnetic states. The results from Ni-Ti ferrites show that the Loria technique can be used to accurately identify the Curie temperature, with results that are consistent with those obtained from traditional methods like magnetization measurements and D.C. resistivity [9-10]. The main advantages of the Loria technique include its high sensitivity, simplicity, and non-invasive nature. It is a valuable tool for the study of magnetic materials, especially in cases where traditional techniques may be challenging or time-consuming. Additionally, the method’s applicability to a wide range of materials, including thin films and bulk samples, makes it a versatile technique for material characterization.

Table 1: Curie temperature ‘Tc’ (K) by A.C. Susceptibility, D.C. Resistivity and Loria technique of $Ni_{1+x}Ti_xFe_{2-2x}O_4$; where $x = 0.0 \le x \le 0.7$ ($x=0.0 \le x \le 0.7$) system

Ti content x	**Curie temperature** ‘T_c’(K)		
	A.C. Susceptibility	D.C. Resistivity	Loria technique
0.0	854	853	859
0.1	813	813	811
0.2	782	773	793
0.3	741	733	729
0.4	665	673	690
0.5	556	563	560
0.6	530	543	532
0.7	471	483	455

Normal ferrimagnetic behaviour, which declines with Ti substitution, is shown by all the susceptibility maps. The presence of a multi-domain structure is suggested by the susceptibility behaviour. The relationship between Ti substitution and Curie temperature is shown in Table 1 as a reduction in Curie temperature. Figure 6 shows the change in Curie temperature. As the magnetic connections between the tetrahedral (A) and octahedral (B) sites weaken, the Curie temperature drops. The replacement of nonmagnetic titanium ions reduces magnetic connections, leading to a drop in the Curie temperature.

[12].

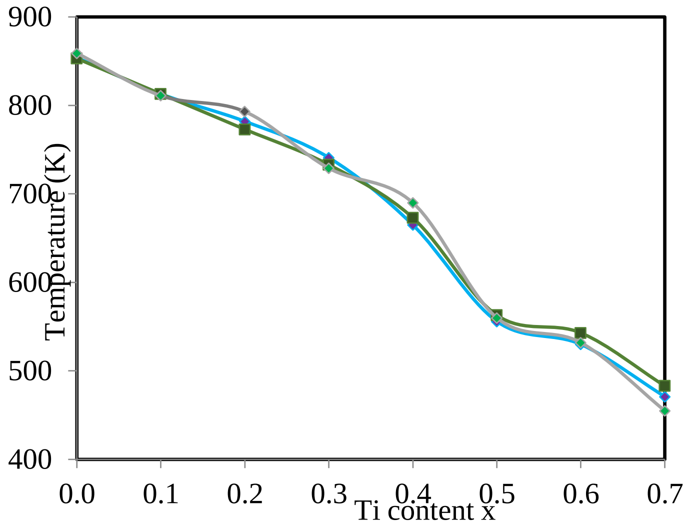

Fig.6: Variation of curie temperature T(K) utilising different method versus Ti content x for the system $Ni_{1+x}Ti_xFe_{2-2x}O_4$ with x=0.0 to 0.7

4. Conclusion

In the system $Ni_{1+x}Ti_xFe_{2-2x}O_4$, where x=0.0 to 0.7, the variations of the curie temperature T(K) as a function of Ti content x show intersecting behaviour when analysed using various techniques. As the concentration of Ti drops, so does the value of the Curie temperature. As the magnetic connections between the tetrahedral (A) and octahedral (B) sites weaken, the Curie temperature drops. The magnetic connections are diminished and the Curie temperature drops with titanium substitution because nonmagnetic titanium ions are substituted.

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