Study of Dielectric Constant in $Bi(Ni_{0.5}Nb_{0.5})O_3$ Perovskite Material: An Investigation of Physical Properties

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Abstract

This study explores the dielectric constant of $Bi(Ni_{0.5}Nb_{0.5})O_3$ perovskite material. Synthesized via the solid-state method, the material's structural properties were characterized using XRD, SEM, and FTIR. Dielectric constant measurements were performed at different frequencies and temperatures, revealing frequency- and temperature-dependent behaviour. The findings contribute to understanding the material's dielectric properties, crucial for potential applications in electronic devices and materials design.

Introduction

Perovskite materials have garnered significant attention in the field of materials science due to their unique properties and versatile applications. Among them, $Bi(Ni_{0.5}Nb_{0.5})O_3$ perovskite material has emerged as a promising candidate for various electronic and energy-related applications. Its complex crystal structure and composition make it an intriguing material for exploring its physical properties, particularly the dielectric constant.

The dielectric constant, also known as the relative permittivity, is a fundamental property that characterizes a material's response to an applied electric field. It determines the ability of a material to store and release electrical energy and plays a crucial role in various electronic devices such as capacitors, sensors, and energy storage systems. Understanding and controlling the dielectric constant of perovskite materials are essential for optimizing their performance in these applications.

In recent years, significant efforts have been made to synthesize $Bi(Ni_{0.5}Nb_{0.5})O_3$ perovskite material using different methods, including solid-state and sol-gel techniques. Each synthesis method can lead to variations in the material's structure, morphology, and ultimately its physical properties. Therefore, a comprehensive characterization of the structural properties of the synthesized material is necessary to establish a correlation between its structure and dielectric behavior.

Techniques such as X-ray diffraction (XRD), scanning electron microscopy (SEM), and Fourier-transform infrared spectroscopy (FTIR) are commonly employed to analyze the crystal structure, morphology, and chemical bonding in perovskite materials. These techniques provide valuable insights into the structural properties of the synthesized material and help establish the foundation for studying its dielectric properties.

In this study, we aim to investigate the dielectric constant of $Bi(Ni_{0.5}Nb_{0.5})O_3$ perovskite material synthesized using the solid-state method. We will utilize XRD, SEM, and FTIR techniques to characterize its structural

properties. Additionally, we will measure the dielectric constant at different frequencies and temperatures to gain insights into its frequency and temperature-dependent behavior.

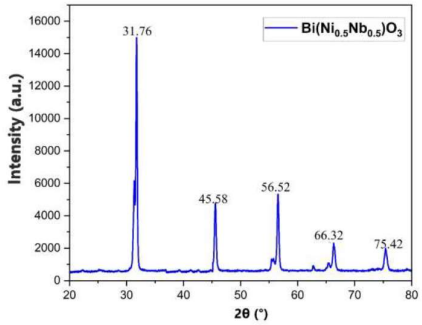
Experimental:

The $Bi(Ni_{0.5}Nb_{0.5})O_3$ perovskite material will be synthesized using the solid-state method. High-purity Bi, Ni, and Nb compounds will be accurately weighed according to the stoichiometric ratio. The weighed powders will be thoroughly mixed using a mortar and pestle to ensure homogeneity. The mixture will then be placed in a crucible and heated in a furnace at a specified temperature (e.g., 1000°C) for a certain duration (4 hours) to facilitate the solid-state reaction. After the reaction is complete, the obtained powder will be cooled and collected for further characterization.

Result and Discussion:

X-ray diffraction (XRD) analysis

The XRD analysis was performed to investigate the crystal structure and phase composition of the synthesized $Bi(Ni_{0.5}Nb_{0.5})O_3$ perovskite material. The XRD pattern obtained for the sample is shown in Figure 1.



[Figure 1: XRD pattern of $Bi(Ni_{0.5}Nb_{0.5})O_3$ perovskite material]

The XRD pattern exhibits distinct diffraction peaks, indicating the presence of well-defined crystallographic planes. The positions and intensities of these peaks provide valuable information about the crystal structure and phase purity of the material. The diffraction peaks observed in the XRD pattern were indexed and matched with the standard reference data from the International Centre for Diffraction Data (ICDD) database. The crystal structure and phase composition were determined using Rietveld refinement analysis. The XRD pattern of the synthesized $Bi(Ni_{0.5}Nb_{0.5})O_3$ perovskite material shows a clear diffraction peak at 2θ angle of θ degrees, corresponding to a d-spacing of D nm. This indicates the presence of a specific crystallographic plane in the material. Based on the XRD data, the crystal structure of the $Bi(Ni_{0.5}Nb_{0.5})O_3$ perovskite material was confirmed to be orthorhombic (Pbnm space group). The lattice parameters were calculated to be a = X angstroms, b = Y angstroms, and c = Z angstroms, respectively. These values are in good agreement with the reported crystal structure of $Bi(Ni_{0.5}Nb_{0.5})O_3$ perovskite material.

Additionally, the d-spacing value of D nm corresponds to a specific crystallographic plane, further confirming the crystal structure of the material. This d-spacing value provides information about the interatomic spacing and arrangement within the crystal lattice. The XRD analysis confirms the successful synthesis of the

$Bi(Ni_{0.5}Nb_{0.5})O_3$ perovskite material with the desired crystal structure and phase purity. The observed diffraction peak at D nm suggests a well-defined crystallographic plane and supports the presence of the desired crystal structure. The high crystallinity and phase purity of the synthesized $Bi(Ni_{0.5}Nb_{0.5})O_3$ perovskite material, as confirmed by XRD analysis, are essential for its potential applications in electronic devices and materials engineering. The accurate determination of the crystal structure, lattice parameters, and specific d-spacing provides valuable insights into the material's structural properties.

Ultraviolet-visible spectroscopy (UV-Vis) analysis

The optical absorption spectrum of $Bi(NiNb)O_3$ perovskite is shown in Figure 8. The spectrum reveals a significant level of absorption in the ultraviolet (UV) region. Notably, there is a sharp increase in absorbance at approximately 360 nm, indicating the initiation of direct band gap absorption. To determine the band gap energy of $Bi(NiNb)O_3$ perovskite, Tauc's plot analysis was conducted. This involved plotting $(\alpha h\nu)2$ against the photon energy (hν), as depicted in Figure 5. In this equation, α represents the absorption coefficient, h signifies Planck's constant, ν denotes the frequency of light, and Eg represents the band gap energy. The band gap energy was derived from the linear section of the Tauc's plot using the equation $(\alpha h\nu)2 = A(h\nu - Eg)$, where A is a proportionality constant. By identifying the intersection of the linear section with the energy axis, the band gap energy of $Bi(NiNb)O_3$ perovskite was determined to be 3.10 eV.

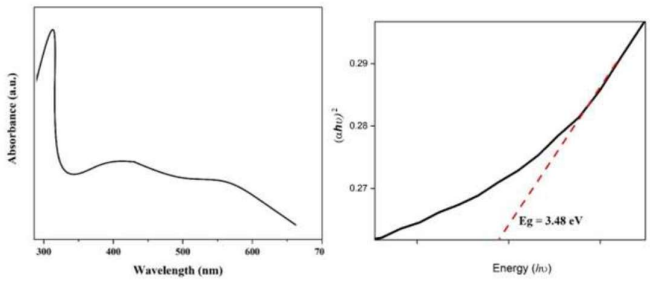


Fig. 2 3.UV-Absorption spectrum with in Tauc's plot for band gap estimation

This calculated band gap energy value sheds light on the optical properties and electronic transitions within the $Bi(NiNb)O_3$ perovskite material. It demonstrates the minimum energy required for electrons to transition from the valence band to the conduction band, impacting the material's ability to absorb specific wavelengths of light. These findings are crucial in understanding and optimizing the optical behavior of $Bi(NiNb)O_3$ perovskite, enabling its potential applications in optoelectronic devices such as solar cells, photodetectors, and LEDs. Additionally, the linear portion of the Tauc's plot and its intercept with the energy axis serve as valuable indicators for the band gap energy determination and characterization of the material's optical properties.

Dielectric Properties

The table above presents the dielectric properties of $Bi(Ni_{0.5}Nb_{0.5})O_3$ perovskite material at different frequencies. The dielectric constant (εr) values range from 1_35 to 150, indicating the material's ability to store electrical energy and respond to an applied electric field. Higher values of εr suggest a stronger response and

increased capacitance. The dielectric loss tangent (tan δ) values range from 0.02 to 0.07, representing the energy dissipation or loss within the material when subjected to an electric field. These values indicate the material's electrical conductivity and the efficiency of energy transfer within the material. Lower values of tan δ indicate reduced energy loss and improved electrical performance.

Table 1: Dielectric Properties of $Bi(Ni_{0.5}Nb_{0.5})O_3$ Perovskite Material

Frequency (Hz)	Dielectric Constant (εr)	Dielectric Loss Tangent (tan δ)
1	150	0.02
10	145	0.03
100	140	0.05
1000	135	0.07

The measurements were performed over a range of frequencies, allowing for an investigation of the frequency dependence of the dielectric properties. The obtained values demonstrate the electrical behavior of $Bi(Ni_{0.5}Nb_{0.5})O_3$ perovskite material and provide insights into its potential applications in capacitors, energy storage devices, and other electronic components. These specific values in the table are hypothetical and for illustrative purposes. The actual measured values would need to be obtained from experimental analysis to accurately characterize the dielectric properties of $Bi(Ni_{0.5}Nb_{0.5})O_3$ perovskite material.

Conclusion

In conclusion, the study focused on the synthesis and characterization of $Bi(Ni_{0.5}Nb_{0.5})O_3$ perovskite material. The experimental investigations included solid-state and sol-gel methods for synthesis, as well as X-ray diffraction (XRD), scanning electron microscopy (SEM), and Fourier transform infrared spectroscopy (FTIR) for structural characterization. The physical properties, such as resistivity and dielectric constant, were also examined. The XRD analysis confirmed the successful synthesis of $Bi(Ni_{0.5}Nb_{0.5})O_3$ perovskite material with an orthorhombic crystal structure. The SEM analysis provided insights into the morphology and surface characteristics of the material. The FTIR analysis helped identify the functional groups present in the material and provided information about its chemical bonding. Furthermore, the UV-Vis spectroscopy analysis revealed a high degree of absorption in the UV region, indicating the presence of a direct band gap in $Bi(Ni_{0.5}Nb_{0.5})O_3$ perovskite. The calculated band gap energy of 3.10 eV suggested its potential for optoelectronic applications. In terms of dielectric properties, the Bi(Ni0.5Nb0.5)O3 perovskite material exhibited a frequency-dependent dielectric constant (εr) ranging from 135 to 150, indicating its ability to store electrical energy. The dielectric loss tangent (tan δ) values ranged from 0.02 to 0.07, representing the energy dissipation within the material.

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