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Research Article

Investigation of the Thermal and Dielectric Properties of $MnFe_2O_4$ Nanoparticles

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Abstract

This work investigates the thermal characteristics and dielectric response of manganese ferrite ($MnFe_2O_4$) nanoparticles under varying temperatures and γ-irradiation conditions. Commercial nanopowder with a nominal particle size of 60 nanometers and a stated purity of 98.5% was used. Differential scanning calorimetry (DSC) was employed to characterize the thermal response of the material within the temperature interval from −100 to 550 °C. In addition, temperature-dependent capacitance measurements were performed on pressed specimens to assess their dielectric response. The results obtained from untreated samples were subsequently evaluated against those recorded for specimens exposed to γ-radiation for different periods. The analysis considered the combined influence of temperature and irradiation exposure on the measured dielectric response. The observed variations may be associated with temperature-dependent polarization processes and changes in charge-carrier transport, while irradiation-related effects may influence localized electrical states within the material. The results contribute to the understanding of the thermal and dielectric characteristics of $MnFe_2O_4$ and may support further evaluation of its suitability for electronic components operating in environments involving temperature fluctuations and radiation exposure.

Keywords: $MnFe_2O_4$; manganese ferrite; nanoparticles; dielectric properties; electrical capacitance; differential scanning calorimetry (DSC); γ-irradiation

1. Introduction

$MnFe_2O_4$ is a ferrimagnetic material belonging to the spinel ferrite family whose thermal and electrical characteristics make it relevant to the study of functional materials. Its response to external conditions depends on several factors, including chemical composition, particle size, temperature, and exposure to ionizing radiation. Understanding these dependencies is important when evaluating the potential use of ferrite-based materials in electronic and dielectric components.

The electrical response of $MnFe_2O_4$ is related to charge transport and polarization processes within the material. Temperature variations can influence these processes by changing the mobility of charge carriers and the contribution of different polarization mechanisms. Consequently, measurable electrical parameters, including capacitance, may change with temperature. Investigating these variations can help clarify the dielectric response of manganese ferrite under different operating conditions.

Temperature-dependent dielectric measurements are particularly useful for assessing the suitability of materials for electronic applications. Measurements performed over a range of temperatures provide information that cannot be obtained from room-temperature data alone. Depending on the material and measurement conditions, thermal activation may influence charge transport, electrical conductivity, and polarization behavior. These effects should be considered when interpreting changes in the dielectric characteristics of ferrite-based systems [1], [2], [3].

Another factor that may affect the electrical response of ferrites is exposure to gamma radiation. The interaction of ionizing radiation with a solid can produce electronic excitations and, under appropriate conditions, radiation-induced defects or changes in localized charge states. Such processes may influence the electrical response of a material. However, the magnitude and direction of these changes depend on the composition of the sample, its initial condition, the absorbed radiation dose, and the irradiation conditions. Experimental comparison of irradiated and unirradiated specimens is therefore necessary to establish whether irradiation is associated with measurable changes in electrical capacitance.

Thermal analysis and electrical measurements provide complementary information about material behavior. Differential scanning calorimetry (DSC) makes it possible to examine heat-flow changes over a defined temperature interval, whereas capacitance measurements reveal variations in the electrical response under specified measurement conditions. Although these techniques investigate different physical characteristics, their combined use can provide a broader assessment of $MnFe_2O_4$. It is important, however, to distinguish the thermal behavior measured in nanopowder from the dielectric response of compacted specimens, because sample form and measurement method may influence the observed results.

In the present study, the thermal characteristics of commercial $MnFe_2O_4$ nanopowder were investigated by DSC over the temperature interval of −100 to 550 °C. Separately, the temperature dependence of electrical capacitance was examined using pressed $MnFe_2O_4$ specimens in their unirradiated state and after different periods of gamma irradiation. The study aims to characterize the thermal response of the nanopowder, compare the capacitance behavior of irradiated and unirradiated specimens, and evaluate the changes associated with temperature and irradiation duration. The results are intended to improve the understanding of the thermal and dielectric behavior of manganese ferrite under the investigated experimental conditions.

For this purpose, DSC analysis of the nanoparticles was performed, and the temperature dependence of electrical capacitance was comparatively investigated for unirradiated, 1 h γ-irradiated, and 10 h γ-irradiated samples [4], [5], [6], [7].

2. Experimental Procedure

Commercial manganese ferrite ($MnFe_2O_4$) nanopowder was used in this study. According to the manufacturer's specifications, the material had a nominal particle size of 60 nm and a purity of 98.5%. The powder was used directly for thermal analysis, while compact specimens were prepared for electrical capacitance measurements.

To obtain the specimens for dielectric measurements, the $MnFe_2O_4$ powder was placed in a specially designed mold and compressed to form pellets. The prepared specimens were subsequently used to investigate the temperature dependence of electrical capacitance and to compare the electrical response of unirradiated and γ-irradiated samples. The resulting pressed specimens were subsequently used for the temperature-dependent dielectric measurements. The resulting samples had dimensions of approximately 4 × 15 × 5 mm. Specimen compaction was performed with the aid of a hydraulic pressing system. The prepared samples were subsequently used for electrical measurements.

The thermal behavior of the nanoparticles was investigated using a DSC 204 F1 Phoenix differential scanning calorimeter. Measurements were performed over the temperature range of −100 to 550 °C. During DSC analysis, the response of the sample to temperature variation and the corresponding thermal effects were recorded. This method allows the characterization of thermal processes occurring in the material as a function of temperature.

To investigate the dielectric properties, the electrical capacitance of pressed $MnFe_2O_4$ samples was monitored at different temperatures. Three groups of samples were considered for comparison: an unirradiated sample, a sample irradiated with γ-rays for 1 h, and a sample a specimen exposed to γ-radiation for 1 h and another subjected to the same radiation for 10 h. The irradiation process was used to evaluate possible changes in the electrical parameters induced by γ-radiation.

3. Results and Discussion

3.1. Thermal Behavior of $MnFe_2O_4$ Nanoparticles

The DSC analysis of $MnFe_2O_4$ nanoparticles enabled the thermal behavior of the material to be evaluated over a wide temperature range. The selected temperature interval of −100 to 550 °C allowed thermal effects that may occur both in the low-temperature region and at higher temperatures to be observed.

In analyzing the DSC curve, changes in heat flow as a function of temperature were considered. Local variations observed in the curve may be associated with thermal processes occurring within the material. Changes observed in the low-temperature region may be related to the behavior of adsorbed components or weakly bound species under thermal influence. As the temperature rises, the measured response may additionally reflect variations in the material's energy states and physical transformations taking place within the solid.

The relatively high specific surface area of nanoparticles can increase the contribution of surface-related processes to their thermal behavior. As particle size decreases, the ratio of surface atoms and ions to the total number of atoms increases. Therefore, surface-related thermal processes in nanomaterials may have a different character compared with those in bulk materials.

Another important aspect of the DSC results is the evaluation of the thermal stability of $MnFe_2O_4$ nanoparticles. During practical applications, maintaining the physical properties of a material within a specific temperature range is an important requirement. The observed thermal behavior over the investigated temperature interval should therefore also be considered when interpreting the results of subsequent electrical measurements [4], [7], [8], [9].

It should be noted that it is not appropriate to associate every thermal effect observed in DSC measurements with a single process. The thermal behavior of nanomaterials may be determined by the combined effects of surface phenomena, adsorbed components, defects, and localized changes in the solid phase. Therefore, a more reliable interpretation can be obtained when DSC results are evaluated together with other physical measurements.

3.2. Temperature Dependence of Electrical Capacitance

The variation in capacitance with temperature provides important information about the dielectric characteristics of the investigated material. Measurements were performed for unirradiated and γ-irradiated samples to evaluate the effects of temperature and irradiation.

The thermal variation in capacitance in the unirradiated $MnFe_2O_4$ sample reflects changes in its dielectric response under different thermal conditions. With increasing temperature, charge carriers activated by thermal energy transport and the response of localized charge centers may affect the material's dielectric polarization characteristics. The extent and direction of the capacitance change depend on the relative contributions of these processes and the measurement conditions.

In manganese ferrite, the electrical response may also be associated with charge transfer between localized electronic states and the displacement or redistribution of charges under an applied electric field. Temperature-dependent changes in these processes can affect the effective dielectric properties of the sample. Similar mechanisms have been discussed in studies of ferrite materials. Nevertheless, the specific mechanism responsible for the observed capacitance variation should be established by considering the experimental data and, where available, complementary electrical measurements.

3.3. γ-Radiation-Induced Changes in the Electrical Capacitance

The influence of γ-irradiation on the electrical response of $MnFe_2O_4$ was examined by comparing the capacitance–temperature characteristics of unirradiated specimens with those irradiated for 1 h and 10 h. This comparison makes it possible to assess differences in capacitance associated with irradiation exposure under the investigated conditions.

Gamma radiation can interact with a ferrite material through energy transfer to its electronic system and may influence defect-related states and the distribution of localized charges. Depending on the absorbed dose and the initial condition of the specimen, these effects may modify charge transport and polarization processes,

thereby contributing to changes in electrical capacitance. However, the presence and relative importance of individual mechanisms cannot be established from capacitance measurements alone.

The comparison between the 1 h and 10 h irradiated specimens is particularly relevant for examining the relationship between irradiation duration and dielectric response. A longer exposure does not necessarily produce a proportional change in capacitance, because the response may depend on the absorbed dose, radiation-induced changes, and the characteristics of the material before irradiation. Therefore, the experimental capacitance values should be considered alongside the irradiation conditions when interpreting the observed differences.

The capacitance–temperature curves also provide information about how the electrical response of the specimens varies under thermal conditions following irradiation. Temperature may affect charge transport and polarization, while irradiation may modify the conditions under which these processes occur. Consequently, differences between the curves of unirradiated and irradiated samples should be interpreted in terms of their combined dependence on temperature and irradiation history [7].

Measurements over a range of temperatures offer a broader basis for comparing the dielectric response than measurements performed at a single temperature. In the present study, this approach was used to examine the electrical capacitance of $MnFe_2O_4$ specimens subjected to different irradiation durations. The results may help clarify the sensitivity of the material's electrical response to external influences and provide a basis for further investigation of its potential use in electronic components exposed to varying thermal and radiation conditions.

3.4. Correlation Between Thermal and Dielectric Results

DSC and electrical capacitance measurements provide complementary information about $MnFe_2O_4$, as they characterize different aspects of its physical behavior. DSC records heat-flow changes during temperature variation, whereas capacitance measurements describe the electrical response of the specimens under the applied measurement conditions. Considering these results together allows the thermal characteristics of the nanopowder to be discussed alongside the dielectric behavior of the compacted samples.

Temperature may influence several processes in ferrite materials, including thermally activated charge transport and polarization. However, the relationship between the DSC response and the measured capacitance should be interpreted cautiously, since the two techniques examine different physical quantities and the measurements were performed on samples in different physical forms.

Gamma irradiation provides an additional factor for evaluating the electrical response of $MnFe_2O_4$. Differences between unirradiated and irradiated specimens may reflect changes associated with radiation exposure, although capacitance data alone cannot identify the specific microscopic mechanisms responsible. Examining the temperature-dependent electrical response after different irradiation periods therefore provides a basis for assessing the sensitivity of the material to its thermal conditions and irradiation history.

Overall, the combined investigation of thermal and dielectric characteristics contributes to a more comprehensive assessment of $MnFe_2O_4$ under the experimental conditions considered. Additional investigations combining electrical measurements with complementary analytical techniques could clarify the underlying mechanisms of the physical processes contributing to the recorded effects and help establish potential technological uses of the investigated substance [8], [9].

4. **Conclusion**

The thermal and dielectric characteristics of $MnFe_2O_4$ were examined using differential scanning calorimetry and temperature-dependent electrical capacitance measurements. DSC analysis was performed across the investigated interval extending from −100 to 550 °C, while the electrical response of compacted specimens was evaluated for unirradiated samples and samples exposed to γ-radiation for 1 h and 10 h.

The capacitance measurements revealed a temperature-dependent electrical response, indicating that the dielectric behavior of $MnFe_2O_4$ varies under different thermal conditions. Differences between the unirradiated and irradiated specimens further demonstrated the sensitivity of electrical capacitance to irradiation history. These variations may be related to changes in charge transport and polarization, although further measurements are required to establish the underlying mechanisms.

The results provide experimental information on the thermal behavior of $MnFe_2O_4$ nanopowder and the dielectric response of compacted specimens. This information may serve as a basis for further investigations of manganese ferrite for applications involving variable temperatures and radiation exposure.

Author Contributions

All authors reviewed, edited, and approved the manuscript.

Conflict of Interest

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