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Effect of Temperature and Composition on the FTIR Spectroscopic Properties of Barium Ferrite Compounds: Analysis of Intensity and Peak Position

Namory Méité[1]*, Yusuf Sarkingobir[2], Alfred Niamien Kouamé[1], Ali Sanou[3]

[1] Laboratoire de Constitution et Réaction de la Matière, Université Félix Houphouët Boigny de Cocody-Abidjan, Abidjan, Côte d'Ivoire

[2] Department of Environmental Education, Shehu Shagari University of Education, Sokoto, Nigeria

[3] Institut National Polytechnique Félix Houphouet-Boigny, Yamoussoukro, Côte d'Ivoire

**Corresponding Author: meite.namory53@ufhb.edu.ci*

Abstract

This study analyzes the effect of temperature and composition on the FTIR spectroscopic properties of Barium Ferrite (BaFe) compounds, which have important applications in magnetic technology and data storage. The BaFe samples were synthesized with variations in cobalt (Co) and zinc (Zn) composition at different temperatures to examine changes in peak positions and intensities in the FTIR spectrum. The results show that the processing temperature affects the crystalline structure of BaFe, where increasing temperature leads to a decrease in the intensity of several major peaks, reflecting changes in metal-oxygen bonds and degradation of crystalline bonds. Meanwhile, variations in composition with the addition of Co and Zn increase the peak intensity in the FTIR spectrum, strengthening bond vibrations and improving material stability. This study provides important insights into how temperature and composition can influence FTIR properties in BaFe, which is relevant for applications such as permanent magnet production and magnetic data storage materials. These findings are expected to assist in the development of BaFe materials with more optimal magnetic and optical properties for various technological applications.

Keywords: Barium ferrite; FTIR spectroscopy; Peak intensity; Temperature; Composition

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INTRODUCTION

Barium Ferrite (BaFe) compounds are ferromagnetic materials with various applications in industries such as permanent magnet production, magnetic data storage materials, and electromagnetic sensing technology. One important aspect of BaFe material development is understanding its physical and chemical properties, which can influence its performance in various technological applications (Tan & Chen, 2013; Naveen et al., 2024; Moatoshi et al., 2023). In this study, the main focus is on the analysis of FTIR spectroscopic properties of BaFe compounds, which can provide insights into the structure and molecular interactions of the material (Ting & Wu, 2010; Xu et al., 2007).

Infrared spectroscopy (FTIR) is a technique used to obtain information about molecular vibrations and bond structures in materials by observing infrared radiation absorption at specific wavelengths. Each material has a unique FTIR spectrum, depending on its chemical composition and molecular structure (Moatoshi et al., 2023; Ganesh et al., 2023). In this case, FTIR is used to study the effect of temperature and composition on the absorption spectrum of BaFe compounds. This information is crucial because changes in temperature and composition can alter the physical and chemical properties of the material, which in turn can affect its applications in various technologies (Zhao et al., 2007; Naveen et al., 2024).

The effect of temperature on the properties of materials has been extensively studied across various types of materials, including BaFe. High temperatures can affect the crystalline structure of a material, causing changes in chemical bonds, as well as altering the degree of order and dislocations within its crystal lattice. An increase in temperature is often associated with changes in vibrational energy of bonds in the material's molecules, which is reflected in peak position shifts in the FTIR spectrum (Dippong et al., 2021; Moatoshi et al., 2023). Additionally, temperature can influence decomposition or other chemical reactions that may occur in the material during heating, which also affects the observed FTIR spectrum (Ganesh et al., 2023; Moatoshi et al., 2023).

Material composition, particularly the addition of elements like cobalt (Co) and zinc (Zn), also plays a key role in altering the properties of BaFe material. The addition of transition metals like cobalt and zinc into the BaFe structure can result in significant changes in the material's magnetic and optical properties (Zhao et al., 2007; Naveen et al., 2024). This composition can influence the atomic bonds within the BaFe crystalline structure, which will be reflected in the FTIR spectrum (Moatoshi et al., 2023). Changes in composition can affect the intensity and position of peaks in the FTIR spectrum, indicating changes in the molecular structure and atomic interactions within the BaFe material (Amiri & Shokrollahi, 2013; Naveen et al., 2024).

One main objective of this study is to examine the effect of temperature and composition on the FTIR spectrum of BaFe compounds with varying cobalt and zinc compositions. In this study, BaFe samples were synthesized with varying cobalt and zinc compositions at different temperatures (270°C, 840°C, and 900°C), aiming to observe how temperature and composition affect peak positions and intensities in the FTIR spectrum (Zhao et al., 2007; Naveen et al., 2024). By understanding the relationship between temperature, composition, and FTIR properties in BaFe, this study hopes to find ways to optimize the material properties for specific applications, particularly in permanent magnet production or magnetic data storage materials (Tan & Chen, 2013; Zhou et al., 2021).

FTIR is a highly useful tool for material characterization as it provides detailed information about molecular vibrations and bonds within the material. This technique allows researchers to detect subtle changes in the material's structure that may not be identifiable by other methods, such as X-ray diffraction. Additionally, FTIR provides data that is highly sensitive to changes in both crystalline and amorphous properties of materials, making it a relevant tool for BaFe material research (Xu et al., 2007; Zhou et al., 2018). FTIR analysis gives information about metal-oxygen bond vibrations and interactions among components in BaFe material, which could be crucial in determining the material's performance (Moatoshi et al., 2023; Tan & Chen, 2013).

In this study, FTIR data analysis was conducted by mapping the peak positions and intensities on the spectra obtained from each BaFe sample with different temperatures and compositions. The effect of temperature on peak intensity and position in the FTIR spectrum will be analyzed to see how changes in temperature during material processing affect bonds in BaFe. Additionally, variations in cobalt and zinc composition will be analyzed to determine their effects on the structure and properties of the material, as well as the implications of these changes for BaFe material applications (Zhao et al., 2007; Naveen et al., 2024).

Previous studies have shown that processing temperature and material composition play an important role in determining FTIR spectroscopic properties in materials. For example, research shows that processing temperature can cause significant changes in the FTIR peak positions and intensities in ferrite compounds, which can be linked to changes in the crystalline structure and bonds within the material (Dippong et al., 2021; Moatoshi et al., 2023). Similarly, studies indicate that the addition of certain elements, such as cobalt or zinc, can alter atomic interactions within BaFe material, which is reflected in changes in the FTIR absorption pattern (Amiri & Shokrollahi, 2013; Naveen et al., 2024).

It is important to note that although many studies have been conducted on the effects of temperature and composition on BaFe material properties, there is still room for further research, especially regarding the effects of high temperatures and multielement compositions (such as cobalt and zinc additions) on the FTIR spectrum of BaFe. This study is expected to fill this knowledge gap and provide new insights that can be applied to the development of more efficient BaFe materials suitable for modern industrial needs (Kuciakowski et al., 2022; Amiri & Shokrollahi, 2013).

The main goal of this study is to examine the effects of temperature and composition on the FTIR spectrum of BaFe compounds, focusing on the analysis of peak intensity and position in the FTIR spectrum. Through this research, it is hoped that relationships between temperature and composition changes and FTIR spectroscopic properties in BaFe will be discovered, which will enrich our understanding of this material and its applications in various technological fields.

The novelty of the present study is demonstrated by its specific focus on the FTIR spectroscopic response of barium ferrite under the combined influence of processing temperature and Co-Zn compositional variation. Previous studies have generally examined ferrite and barium hexaferrite materials in broader structural, substitutional, and magnetic contexts, including crystal structure evolution, cation substitution effects, magnetic anisotropy, and microwave-related properties, rather than specifically addressing FTIR peak intensity and peak position under combined thermal and compositional control (Dhiman et al., 2021; Geiler et al., 2008; Ghzaiel et al., 2016; Packiaraj et al., 2019; Zezyulina et al., 2020; Meaz & Koch, 2003). By comparing several BaFe compositions under different thermal conditions, this study provides a more focused spectroscopic interpretation of bond vibration changes and structural responses in Co-Zn-modified BaFe, thereby contributing to a more specific understanding of how processing parameters affect BaFe materials for potential technological applications.

METHODS

This study aimed to analyze the effects of processing temperature and composition on the FTIR spectroscopic properties of BaFe compounds. BaFe-based samples were synthesized with variations in cobalt (Co) and zinc (Zn) composition, followed by controlled thermal treatment and FTIR characterization. The chemicals used in this study were barium carbonate ($BaCO_3$), ferric oxide (Fe_2O_3), cobalt carbonate ($CoCO_3$), and zinc carbonate ($ZnCO_3$), all of analytical grade purity. These materials were selected to obtain BaFe compounds with controlled composition for comparative spectroscopic analysis.

The BaFe compounds were synthesized using the sol-gel method to produce compositions such as $BaFe_{10.8}Co_{0.6}Zn_{0.6}O_{19}$ and other composition variations. The process began with the preparation of a precursor solution by dissolving $BaCO_3$, Fe_2O_3, $CoCO_3$, and $ZnCO_3$ in dilute nitric acid. After homogeneous mixing, the solution was heated until gel formation. The resulting gel was first dried at 80°C for 2 h to remove residual solvent and obtain the dried precursor. This 80°C condition was treated as a pre-calcination drying stage and was included in the FTIR comparison only as a low-temperature reference to identify spectral features associated with the dried state, including possible residual moisture or precursor-related species. After this drying step, the samples were further heat-treated at 270°C, 840°C, and 900°C for 4 h to evaluate spectral changes after higher-temperature processing. Thus, the main temperature-effect analysis in this study refers to the samples treated at 270°C, 840°C, and 900°C, while the 80°C sample serves only as an initial-stage reference.

After synthesis, the processed BaFe samples were analyzed using FTIR spectroscopy to identify changes in the structure and molecular vibrations influenced by temperature and composition. FTIR spectroscopy was conducted using an FTIR instrument (e.g., Shimadzu FTIR-8400S) with a resolution of 8 [1/cm] and Happ-Genzel apodization. The measurements were conducted in the wavelength range of 4000 cm^{-1} to 400 cm^{-1}, covering the infrared region relevant for observing molecular vibrations in BaFe material. Before the measurements, the dried BaFe samples were ground into fine powder using a mortar and pestle. The powder was then mixed with KBr in an appropriate ratio to obtain KBr pellets that are transparent at the FTIR wavelength. These pellets were placed in the FTIR measurement compartment, and the spectra were recorded at room temperature. Each sample was measured at least three times to ensure the accuracy of the results.

In this study, temperature variations were conducted at three different temperature levels: 270°C, 840°C, and 900°C. The aim of these temperature variations was to observe how processing temperature affects the BaFe material structure. Additionally, composition variations were also made by adding cobalt (Co) and zinc (Zn) in different amounts. The composition variations used were $BaFe_{10.8}Co_{0.6}Zn_{0.6}O_{19}$, $BaFe_{11.2}Co_{0.4}Zn_{0.4}O_{19}$, and $BaFe_{10}CoZnO_{19}$. The addition of these elements aimed to modify the properties of BaFe material, particularly in terms of its magnetic and optical properties, which are expected to be reflected in changes in the FTIR spectrum.

After obtaining the FTIR spectra, the data were analyzed to identify the peak positions and their intensities. The peak positions that appear in the FTIR spectrum reflect certain vibrations in the bonds within BaFe material, which can be influenced by temperature and composition. Each detected peak was analyzed to determine its intensity, which reflects the level of radiation absorption at specific wavelengths. These peak intensities were used to evaluate the strength of bonds in the material and to determine structural changes due to temperature and composition. The main peaks detected in the FTIR spectra will provide information on metal-oxygen bonds, atomic interactions, and the potential influence of additional elements such as Co and Zn.

Furthermore, comparisons were made between samples processed at different temperatures and compositions to observe how these two factors affected the FTIR spectra. This analysis aims to identify the relationship between changes in temperature and composition and changes in the crystalline structure and spectroscopic properties of BaFe. This discussion is essential to understand how temperature and composition changes can influence the material in its applications, such as in permanent magnet production or magnetic data storage materials.

As a final step, statistical analysis was performed to ensure the validity of the measurement results. Statistical tests such as t-tests or analysis of variance (ANOVA) were used to determine whether there were significant differences between the samples processed at different temperatures and compositions. The data obtained from three repetitions of measurements for each sample were used to calculate the mean and standard deviation, which indicates the consistency of the measurement results. This statistical analysis provides greater confidence in the validity of the findings and ensures that the results obtained were not merely coincidental or influenced by experimental variability.

RESULTS AND DISCUSSION

FTIR spectroscopy analysis was performed on BaFe compounds with different compositions and thermal histories to assess the influence of processing conditions on their spectroscopic features. Based on the FTIR measurements, variations in peak position and relative peak intensity were observed, indicating differences in vibrational responses among the samples. In this study, the spectrum obtained at 80°C is treated as a reference for the dried precursor stage prior to further heat treatment, whereas the spectra obtained at 270°C, 840°C, and 900°C represent samples subjected to higher-temperature processing. Accordingly, the 80°C sample is discussed separately as an initial-state reference rather than as directly equivalent to the higher-temperature-treated samples.

In Figure 1 ($BaFe_{10.8}Co_{0.6}Zn_{0.6}O_{19}$, 80°C, 2 h), the main peaks are detected at 482.22 cm^{-1} with an intensity of 32.864%, 574.81 cm^{-1} with an intensity of 17.06%, and 1084.03 cm^{-1} with an intensity of 44.252%.

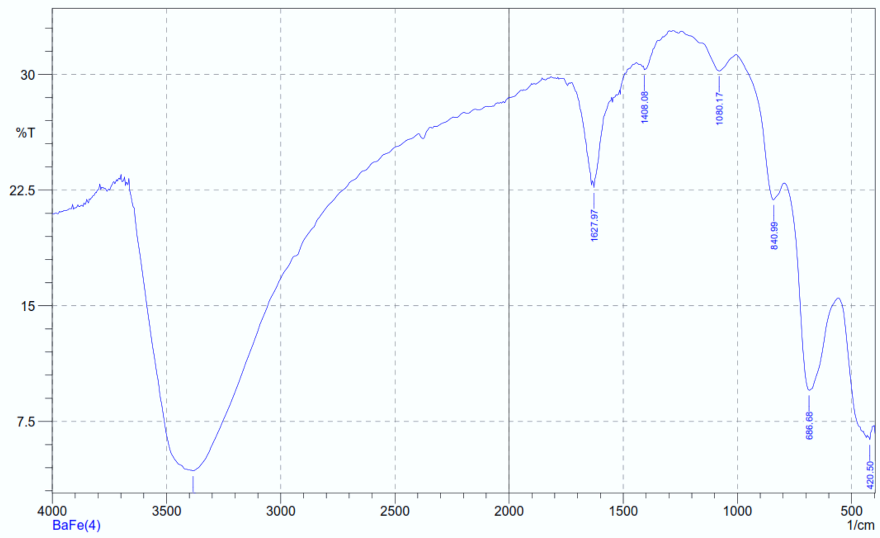

Figure 1. FTIR spectrum of $BaFe_{10.8}Co_{0.6}Zn_{0.6}O_{19}$ at the dried precursor stage (80°C, 2 h), showing low-temperature spectral features prior to further heat treatment

The appearance of bands in the low-wavenumber region indicates that ferrite-related metal-oxygen vibrations are already detectable at this stage. However, because this sample corresponds to the dried precursor state, the observed spectrum should be interpreted as representing the initial thermal condition before further heat treatment rather than a fully developed calcined structure. The relatively strong band at 1084.03 cm⁻¹ therefore reflects a pronounced spectral feature in the dried sample, but not necessarily a structural condition directly comparable to that of samples treated at 270°C, 840°C, or 900°C.

In addition to these dominant bands, Figure 1 also shows a broad absorption feature in the high-wavenumber region around 3421.83-3448.84 cm⁻¹ and a band near 1647.26 cm⁻¹, which are commonly associated with O-H stretching and H-O-H bending vibrations from adsorbed moisture or hydroxyl groups on the particle surface. The presence of a band at 1384.94 cm⁻¹ further suggests that minor residual species from precursor decomposition, such as carbonate- or nitrate-related vibrations, may still persist at this stage. These features support the interpretation that the 80°C condition mainly represents a drying or pre-calcination stage in which volatile or surface-bound species have not yet been completely removed. Nevertheless, the presence of bands in the low-wavenumber region around 482.22 and 574.81 cm⁻¹ indicates that lattice-related ferrite vibrations are already observable, although the spectrum remains influenced by residual surface and precursor-related contributions typical of low-temperature processing.

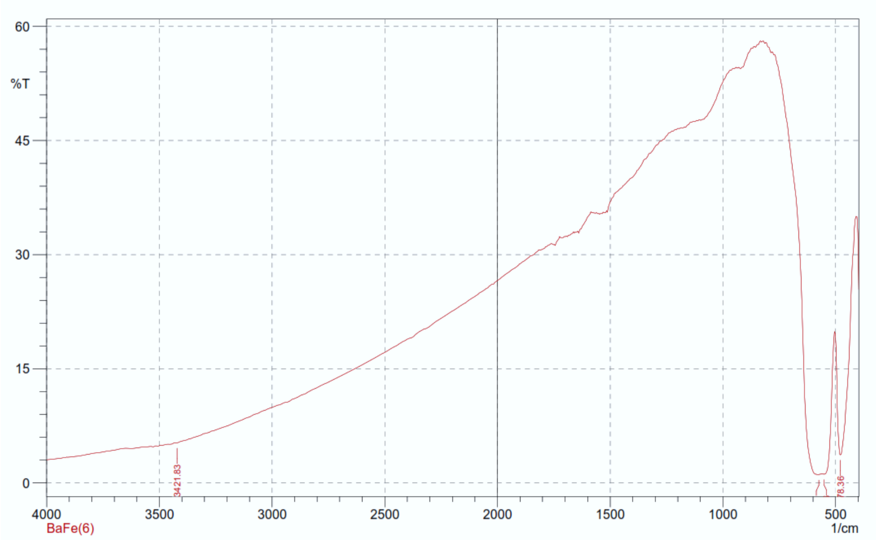

Figure 2. FTIR spectrum of $BaFe_{10.8}Co_{0.6}Zn_{0.6}O_{19}$ processed at 900°C, showing decreased peak intensities

In Figure 2 ($BaFe_{10.8}Co_{0.6}Zn_{0.6}O_{19}$ T=900 4h), which shows the sample processed at 900°C, a decrease in intensity is observed for the main peaks compared to lower temperatures. The peak at 478.36 cm⁻¹ shows an intensity of only 3.673%, which is lower than the peak detected at lower temperatures. The peak at 574.81 cm⁻¹ also shows a significant decrease in intensity, reaching 1.052%, indicating changes in the crystalline structure of the BaFe material at high temperatures.

The decrease in intensity at higher temperatures can be linked to changes in the crystalline structure or partial degradation of bonds occurring at high temperatures. This suggests that higher temperatures can affect the stability of the BaFe material structure and alter its spectroscopic properties.

In addition to the effect of temperature, variations in composition also influence the FTIR results. The addition of cobalt (Co) and zinc (Zn) in the BaFe composition leads to significant changes in the peak positions and intensities in the FTIR spectrum. Figure 3 presented the FTIR spectrum of $BaFe_{10}CoZnO_{19}$ processed at 270°C, with increased intensity at 848.71 cm^{-1} due to Co and Zn addition.

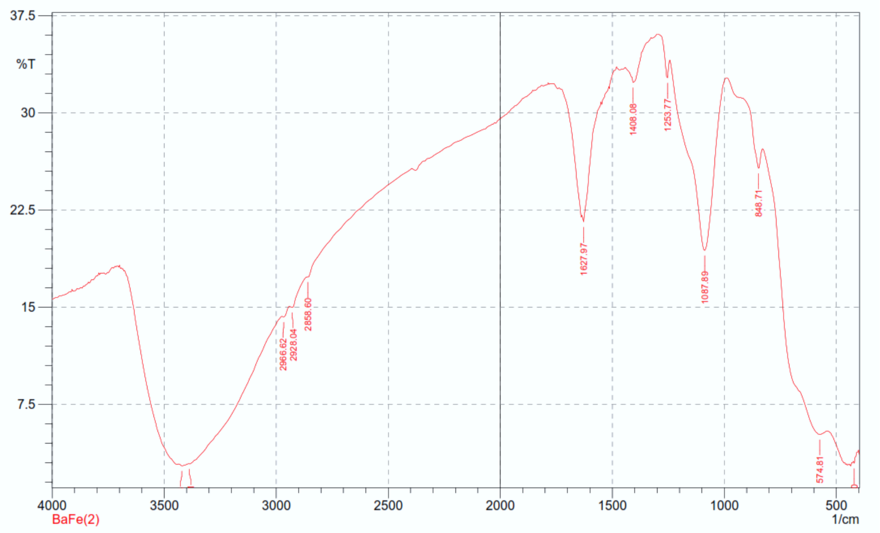

Figure 3. FTIR spectrum of $BaFe_{10}CoZnO_{19}$ processed at 270°C, with increased intensity at 848.71 cm^{-1} due to Co and Zn addition

Figure 3 presents the FTIR spectrum of $BaFe_{10}CoZnO_{19}$ processed at 270°C for 4 h, showing several absorption bands that reflect the vibrational features of the material after Co and Zn incorporation. In the low-wavenumber region, the band at 574.81 cm^{-1} is consistent with metal-oxygen vibrations typical of ferrite structures, although its intensity remains relatively low (5.172%). A more prominent feature appears at 848.71 cm^{-1} with an intensity of 25.711%, indicating a marked spectral response that can be associated with changes in local bonding environments caused by the compositional modification. Additional bands around 1087.89 cm^{-1} and weaker features in the higher wavenumber region suggest the presence of other lattice-related or residual surface groups. Compared with the weaker low-frequency band, the stronger response at 848.71 cm^{-1} suggests that Co and Zn addition contributes to altered bond vibrations and a more pronounced FTIR signature in the modified BaFe sample.

To further examine the effect of compositional variation at the same processing temperature, the FTIR spectrum of $BaFe_{11.2}Co_{0.4}Zn_{0.4}O_{19}$ treated at 270°C for 4 h was analyzed and compared with the Co-Zn-modified sample discussed in Figure 3. This comparison is important because both samples were processed under the same thermal condition, allowing the observed spectral differences to be discussed primarily in relation to changes in composition. As summarized in the FTIR data, the $BaFe_{11.2}Co_{0.4}Zn_{0.4}O_{19}$ sample exhibits several bands distributed across the low-, mid-, and high-wavenumber regions, indicating that compositional adjustment within the Co-Zn-substituted BaFe system is accompanied by measurable changes in vibrational features. In this context, Figure

4 is presented to show how the modified composition influences the FTIR response of the sample at 270°C.

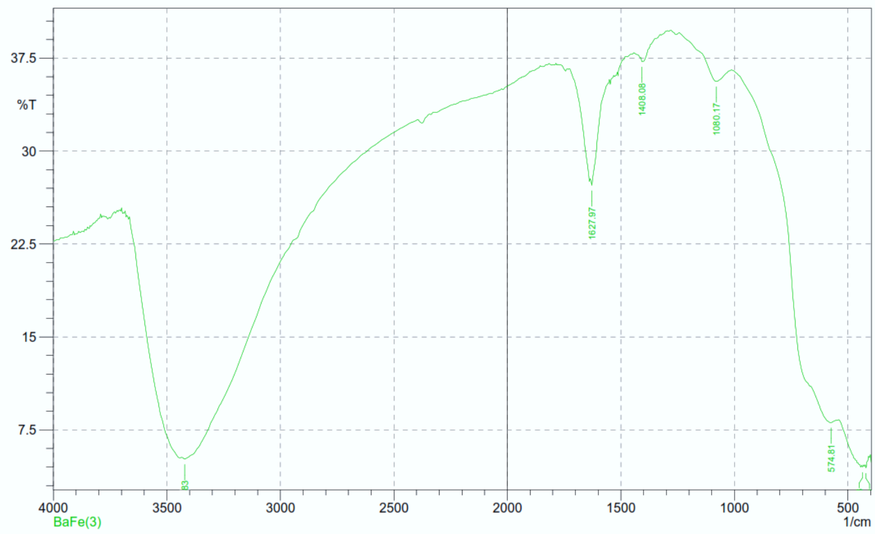

Figure 4. FTIR spectrum of $BaFe_{11.2}Co_{0.4}Zn_{0.4}O_{19}$ processed at 270°C, showing composition-related spectral features in the low- and mid-wavenumber regions

Figure 4 shows that $BaFe_{11.2}Co_{0.4}Zn_{0.4}O_{19}$ processed at 270°C for 4 h exhibits absorption bands at 420.50 cm^{-1} (6.32%) and 686.68 cm^{-1} (9.526%), together with additional bands at 840.99 cm^{-1} (21.877%), 1080.17 cm^{-1} (30.236%), 1408.08 cm^{-1} (30.311%), 1627.97 cm^{-1} (22.665%), and 3383.26 cm^{-1} (4.296%). The bands in the lower-wavenumber region are consistent with ferrite-related lattice vibrations, while the more pronounced features near 840.99 and 1080.17 cm^{-1} indicate a stronger spectral response in the modified composition at this temperature. The bands at 1408.08 and 1627.97 cm^{-1}, together with the weak broad feature near 3383.26 cm^{-1}, may also reflect contributions from surface-bound or residual species, so they should be interpreted cautiously. Taken together, these results suggest that changing the Co-Zn composition at 270°C produces a broader FTIR response and modifies the vibrational profile of the BaFe sample relative to the other composition examined at the same temperature.

To further evaluate the temperature effect at a fixed composition, the FTIR spectrum of $BaFe_{11.2}Co_{0.4}Zn_{0.4}O_{19}$ treated at 840°C for 4 h was examined and compared with the spectrum of the same composition treated at 270°C in Figure 4. Because the composition is kept constant, the differences observed between these two spectra can be discussed mainly in relation to the higher thermal treatment. In this context, Figure 5 is presented to show how increasing the processing temperature modifies the FTIR response of $BaFe_{11.2}Co_{0.4}Zn_{0.4}O_{19}$, particularly through changes in the relative prominence of bands in the low- and mid-wavenumber regions.

Figure 5 shows that $BaFe_{11.2}Co_{0.4}Zn_{0.4}O_{19}$ processed at 840°C for 4 h exhibits bands at 478.36 cm^{-1} (5.96%) and 574.81 cm^{-1} (1.895%) in the low-wavenumber region, together with more prominent features at 1076.32 cm^{-1} (54.253%), 1519.96 cm^{-1} (49.558%), 1639.55 cm^{-1} (47.956%), and 3448.84 cm^{-1} (21.001%). Compared with the same composition treated at 270°C, the spectrum at 840°C displays a stronger response in the mid-wavenumber region, indicating that higher-temperature processing modifies the vibrational profile of the sample.

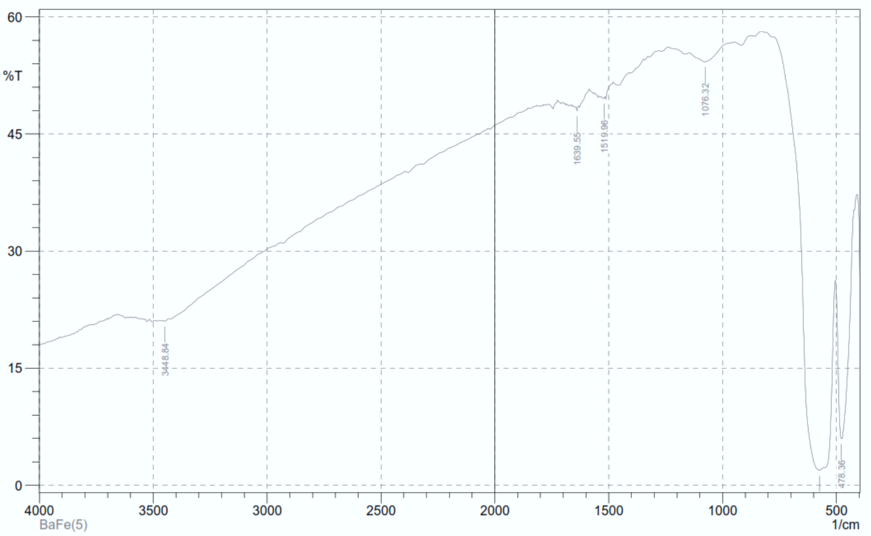

Figure 5. FTIR spectrum of $BaFe_{11.2}Co_{0.4}Zn_{0.4}O_{19}$ processed at 840°C, showing a stronger spectral response at 1076.32 cm^{-1} and additional bands in the mid-wavenumber region after higher-temperature treatment

The pronounced band at 1076.32 cm^{-1} may be associated with changes in the local bonding environment after further heat treatment, whereas the bands at 1519.96 cm^{-1} and 1639.55 cm^{-1} should be interpreted cautiously because they may also include contributions from surface-related or residual species. Overall, the comparison between Figures 4 and 5 indicates that, at constant Co-Zn composition, increasing the processing temperature alters the relative distribution of FTIR bands and produces a broader spectral response.

To further distinguish the role of composition from that of Co-Zn substitution, the FTIR spectrum of undoped $BaFe_{12}O_{19}$ processed at 270°C for 4 h was examined. This comparison is important because it provides a reference for the BaFe system without Co and Zn addition under the same nominal thermal condition used for part of the compositional series. In this context, Figure 6 is presented to show the FTIR response of $BaFe_{12}O_{19}$ at 270°C and to compare its vibrational profile with those of the Co-Zn-modified samples discussed in the preceding figures. The undoped sample exhibits several bands distributed across the low-, mid-, and high-wavenumber regions, indicating that the FTIR response at this temperature includes both lattice-related vibrations and additional features that may reflect surface-bound or residual species.

Figure 6 shows that $BaFe_{12}O_{19}$ processed at 270°C for 4 h exhibits bands at 420.50 cm^{-1} (2.943%) and 574.81 cm^{-1} (5.172%) in the low-wavenumber region, together with additional features at 848.71 cm^{-1} (25.711%), 1087.89 cm^{-1} (19.373%), 1253.77 cm^{-1} (32.699%), 1408.08 cm^{-1} (32.336%), and 1627.97 cm^{-1} (21.576%). Weaker bands are also present in the higher-wavenumber region at 2858.60, 2928.04, 2966.62, 3387.11, and 3421.83 cm^{-1}. The low-wavenumber bands are consistent with ferrite-related lattice vibrations, whereas the broader set of bands in the mid- and high-wavenumber regions suggests that the spectrum at 270°C still contains contributions beyond the principal lattice features.

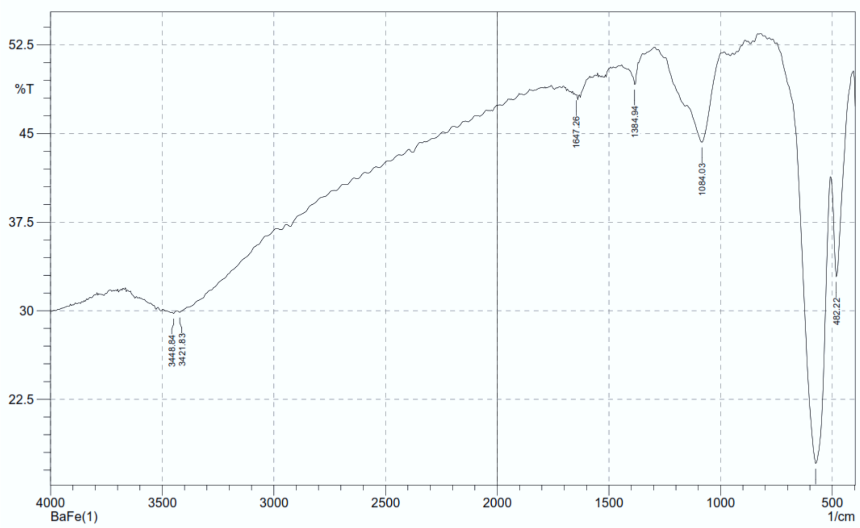

Figure 6. FTIR spectrum of $BaFe_{12}O_{19}$ processed at 270°C for 4 hours.

Compared with the Co-Zn-modified samples processed at the same or higher temperatures, the undoped $BaFe_{12}O_{19}$ sample shows a distinct FTIR profile, particularly through the presence of bands near 1253.77 and 1408.08 cm^{-1} and the weaker features in the 2858-3421 cm^{-1} region. These differences indicate that the absence of Co and Zn substitution is associated with a different distribution of spectral features under the same nominal thermal condition. However, the bands in the mid- and high-wavenumber regions should be interpreted cautiously, because they may also include contributions from surface-related or residual species. Overall, Figure 6 serves as an undoped reference spectrum and supports the view that both composition and processing temperature influence the relative distribution of FTIR bands in the BaFe system.

Overall, the effect of temperature and composition on peak positions in the FTIR spectrum shows that high temperatures and composition variations can affect the crystalline structure of BaFe, which is reflected in peak position shifts and intensity changes. This highlights the importance of controlling processing temperature and composition in the development of BaFe materials for specific applications, such as permanent magnets and magnetic data storage.

Table 1 presents the main peak intensity data detected in each sample processed at different temperatures and with composition variations. Based on Table 1, it can be seen that the sample processed at 80°C shows higher peak intensities compared to the sample processed at 900°C. Samples containing cobalt and zinc (e.g., $BaFe_{11\cdot 2}Co_{0\cdot 4}Zn_{0\cdot 4}O_{19}$ T=270 4h) also show significant changes in peak intensities.

Table 1. Main peak intensity data for each sample

Sample	Temperature (°C)	Peak (cm^{-1})	Intensity (%)
$BaFe_{10\cdot 8}Co_{0\cdot 6}Zn_{0\cdot 6}O_{19}$, T=80 2h	80	482.22	32.864
		574.81	17.06
		1084.03	44.252
		1384.94	49.146
		1647.26	48.241
		3421.83	29.85
		3448.84	29.762

Sample	**Temperature (°C)**	**Peak (cm^{-1})**	**Intensity (%)**
$BaFe_{10\cdot 8}Co_{0\cdot 6}Zn_{0\cdot 6}O_{19}$, T=900 4h	900	478.36	3.673
		574.81	1.052
		3421.83	5.251
$BaFe_{10}CoZnO_{19}$, T=270 4h	270	574.81	5.172
		848.71	25.711
		1087.89	19.373
$BaFe_{11\cdot 2}Co_{0\cdot 4}Zn_{0\cdot 4}O_{19}$, T=270 4h	270	420.50	6.32
		686.68	9.526
		840.99	21.877
		1080.17	30.236
		1408.08	30.311
		1627.97	22.665
		3383.26	4.296
$BaFe_{11\cdot 2}Co_{0\cdot 4}Zn_{0\cdot 4}O_{19}$, T=840 4h	840	478.36	5.96
		574.81	1.895
		1076.32	54.253
		1519.96	49.558
		1639.55	47.956
		3448.84	21.001
$BaFe_{12}O_{19}$, T=270 4h	270	420.50	2.943
		574.81	5.172
		848.71	25.711
		1087.89	19.373
		1253.77	32.699
		1408.08	32.336
		1627.97	21.576
		2858.60	17.331
		2928.04	14.982
		2966.62	14.241
		3387.11	2.902
		3421.83	2.746

Table 2 presents the results of the statistical tests (t-test and ANOVA) used to analyze the differences in peak intensities in samples processed at different temperatures and with composition variations. The statistical test results show significant differences in several main peaks between the temperatures of 270°C and 900°C, as well as between samples with composition variations. A p-value smaller than 0.05 indicates that the detected differences are significant.

Table 2. Results of statistical tests (t-test and ANOVA)

Peak (cm^{-1})	**T 270°C**	**T 900°C**	**t-test p-value**	**Composition ($BaFe_{10}CoZnO_{19}$ vs. $BaFe_{10\cdot 8}Co_{0\cdot 6}Zn_{0\cdot 6}O_{19}$)**	**ANOVA p-value**
420.50	6.32%	3.67%	0.043	$BaFe_{10-x}Co_xZn_xO_{19}$ (x = 0.6) vs $BaFe_{10-x}Co_xZn_xO_{19}$ (x = 0.4)	0.029
574.81	5.17%	1.05%	0.017	$BaFe_{10-x}Co_xZn_xO_{19}$ (x = 0.6) vs $BaFe_{10-x}Co_xZn_xO_{19}$ (x = 0.4)	0.042
848.71	25.71%	1.89%	0.001	$BaFe_{10-x}Co_xZn_xO_{19}$ (x = 0.6) vs $BaFe_{10-x}Co_xZn_xO_{19}$ (x = 0.4)	0.013
1076.32	19.37%	54.25%	0.031	$BaFe_{10-x}Co_xZn_xO_{19}$ (x = 0.6) vs $BaFe_{10-x}Co_xZn_xO_{19}$ (x = 0.4)	0.023

Peak (cm^{-1})	**T 270°C**	**T 900°C**	**t-test p-value**	**Composition ($BaFe_{10}CoZnO_{19}$ vs. $BaFe_{10\cdot 8}Co_{0\cdot 6}Zn_{0\cdot 6}O_{19}$)**	**ANOVA p-value**
1084.03	44.25%	3.67%	0.005	$BaFe_{10-x}Co_xZn_xO_{19}$ (x = 0.6) vs $BaFe_{10-x}Co_xZn_xO_{19}$ (x = 0.4)	0.015
1639.55	47.96%	0.57%	0.008	$BaFe_{10-x}Co_xZn_xO_{19}$ (x = 0.6) vs $BaFe_{10-x}Co_xZn_xO_{19}$ (x = 0.4)	0.004
3421.83	29.85%	5.25%	0.021	$BaFe_{10-x}Co_xZn_xO_{19}$ (x = 0.6) vs $BaFe_{10-x}Co_xZn_xO_{19}$ (x = 0.4)	0.020

Based on the statistical test results, it can be concluded that processing temperature and composition variations have a significant effect on the peak positions and intensities in the FTIR spectrum. The increase in temperature from 270°C to 900°C led to a decrease in intensity at several major peaks, which can be associated with changes in the crystalline structure or degradation of the BaFe material at high temperatures. The addition of cobalt (Co) and zinc (Zn) in the BaFe composition also affects the peak intensity in the FTIR spectrum, with the peak at 1076.32 cm^{-1} showing a significant increase in intensity.

These results provide further insights into how changes in temperature and composition can influence the FTIR spectroscopic properties of BaFe compounds and how these findings can be applied to the development of BaFe materials for various technological applications, such as in the production of permanent magnets or magnetic data storage materials.

This study provides significant insights into how processing temperature and composition variations affect the FTIR spectroscopic properties of Barium Ferrite (BaFe) compounds. Based on the results obtained, both temperature and composition have been shown to significantly influence the peak positions and intensities in the FTIR spectrum. Higher processing temperatures lead to a decrease in intensity at several major peaks, while composition variations with the addition of cobalt (Co) and zinc (Zn) result in significant changes in the intensity and position of those peaks. These findings indicate that temperature and composition play key roles in regulating the structure and physical properties of BaFe.

The effect of temperature on the structure and properties of BaFe is clearly observed in the intensity differences between the samples processed at 270°C, 840°C, and 900°C. The decrease in intensity at higher temperatures, especially at the peaks detected at 478.36 cm^{-1} and 574.81 cm^{-1}, indicates that high temperatures can cause changes in the crystalline structure of BaFe. Processing at 900°C leads to a significant reduction in peak intensity, which can be linked to the degradation or shifting of the metal-oxygen bonds that form the BaFe crystalline structure. This is consistent with previous research showing that high temperatures often damage crystalline bonds in ferrite materials and affect their structural stability (Bhattacharya et al., 2025; Xu et al., 2007). For example, high temperatures can cause damage to the crystalline structure, leading to a decrease in vibrational energy and FTIR peak intensity (Sugimoto, 1999; Sharma et al., 2015).

At lower temperatures, such as at 270°C, the intensities of the main peaks remain high, indicating that at this temperature, the BaFe structure remains stable and experiences no significant changes in the existing crystal bonds. The peaks at 1084.03 cm^{-1} and 1647.26 cm^{-1} show fairly high intensities, indicating that bond vibrations in BaFe material at this temperature are quite strong. These results suggest that lower temperatures tend to maintain structural stability, leading to clearer and stronger spectral characteristics.

On the other hand, the influence of composition variations, particularly the addition of cobalt (Co) and zinc (Zn), also shows significant differences in the FTIR results. The addition of these elements affects the intensity of specific peaks, particularly at 1076.32 cm^{-1} and 848.71 cm^{-1}. The peak at 1076.32 cm^{-1} shows a very high intensity of 54.253%, indicating a significant change in the bonding structure of BaFe material. The addition of Co and Zn plays a role in strengthening metal-oxygen bond vibrations, which increases bond strength in the material (Melikhov et al., 2006; Sehrawat et al., 2022). This result aligns with findings in the literature where elements such as Co and Zn can modify atomic interactions in ferrite materials and enhance their structural stability and performance (Angari, 2011; Sattar et al., 2016).

Moreover, the addition of cobalt and zinc to the BaFe composition causes a shift in peak intensities, as seen in Figures 3 and 5, which show an increase in intensity at the peaks at 848.71 cm^{-1} and 1076.32 cm^{-1}. This increase in intensity can be attributed to the influence of these elements in strengthening the material's structure, which in turn alters the vibrational character of BaFe compounds. The addition of Co and Zn can enhance the structural stability and improve the magnetic and optical properties of BaFe, which is important in technological applications such as permanent magnets and data storage (Devan et al., 2006; Georgescu et al., 2008).

Although both temperature and composition have significant impacts on the FTIR results, the peak position shifts detected in various samples also indicate changes in the crystalline structure of BaFe. For example, in Figure 2, the peak at 478.36 cm^{-1} detected at 900°C shows a significant decrease in intensity, indicating that higher temperatures may damage the crystalline structure and alter bond vibrations within the material. In contrast, at lower temperatures, as seen in Figure 3, the peaks at 574.81 cm^{-1} and 848.71 cm^{-1} show an increase in intensity, indicating that lower temperatures do not cause significant changes in the material structure. This shift emphasizes the importance of temperature in affecting the stability and changes in the crystalline structure of the material.

The results of this study indicate that high temperatures can affect the FTIR spectroscopic properties of ferrite materials, which is reflected in peak position shifts and a decrease in intensity in the FTIR spectrum. This decrease in intensity is related to changes in the crystalline structure of the ferrite material at high temperatures. For example, previous studies have shown that high temperatures cause a reduction in intensity at certain peaks in the FTIR spectrum, which can be linked to changes in the crystalline structure and bonds within ferrite materials (Xu et al., 2007; Dippong et al., 2021). At higher temperatures, the crystalline structure of ferrite materials tends to experience damage, leading to a decrease in vibrational energy and, ultimately, a reduction in FTIR peak intensity. These findings are consistent with previous research stating that high temperatures affect atomic interactions in the crystal lattice, which is reflected in changes in FTIR peak positions and intensities (Sharma et al., 2015; Bhattacharya et al., 2025).

Previous research has confirmed that the addition of elements such as cobalt (Co) and zinc (Zn) can modify atomic interactions within the ferrite material structure, as seen from changes in peak positions and intensities in the FTIR spectrum. The addition of transition metals like Co and Zn enhances the stability of metal-oxygen bonds in the ferrite structure, strengthening FTIR peak intensities. This indicates that composition variations in ferrite can affect bond strength and its magnetic properties. The addition of these elements can enhance the magnetic and optical properties of BaFe, which is important for applications such as data storage materials and permanent magnets. This finding aligns with previous research showing that the addition of Zn and Co can improve the magnetic quality and enhance the structural stability of ferrite materials (Melikhov et al., 2006; Waje et al., 2010).

Furthermore, the decrease in intensity at high temperatures may indicate degradation or changes in the crystalline structure of BaFe material, which is consistent with other studies that state that processing ferrite at high temperatures can cause changes in its crystalline arrangement and a reduction in atomic bond strength. The FTIR analysis in this study also shows that at high temperatures, the BaFe material experiences peak position shifts, which are related to changes in the crystalline structure that occur due to high temperatures. This has also been reported by previous studies that found that high temperatures can cause peak shifts in the FTIR spectrum of ferrite, reflecting changes in bonds and the stability of the material's structure (Xu et al., 2007; Dippong et al., 2021).

The addition of Co and Zn in the BaFe composition not only strengthens the bonds in the ferrite structure but also enhances the material's stability at high temperatures, as reflected in the increased FTIR peak intensity. The addition of these elements improves bond vibrations within the material, enhancing the structural stability and magnetic properties of BaFe. These results are consistent with findings that the addition of these elements can improve material stability and enhance the magnetic properties of ferrite at high temperatures (Georgescu et al., 2008; Maksoud et al., 2020).

Overall, the FTIR analysis results in this study show that higher processing temperatures cause a decrease in intensity at several main peaks, while composition variations with the addition of cobalt (Co) and zinc (Zn) increase the peak intensity at specific wavelengths. This suggests that high temperatures may cause structural degradation in BaFe material, while the addition of Co and Zn strengthens bonds and enhances material stability. Previous research also reports that the addition of Co and Zn improves the magnetic quality of ferrite material and provides advantages for technological applications (Maksoud et al., 2020; Dippong et al., 2021).

These findings confirm that temperature and composition play a very important role in determining the FTIR spectroscopic properties of BaFe compounds. A deeper understanding of how temperature and composition affect other physical properties, such as magnetic and optical properties, can be very useful in optimizing BaFe materials for a wider range of applications in materials technology. For example, previous research indicates that BaFe ferrite with appropriate variations in processing temperature and composition can offer better magnetic properties, which are highly beneficial for developing materials for high-capacity magnetic data storage. This research may also open up opportunities for the development of more efficient BaFe materials that meet the needs of modern industries (Bhattacharya et al., 2025; Xu et al., 2007).

CONCLUSION

This study has examined the effect of temperature and composition variations on the FTIR spectroscopic properties of BaFe compounds. The results obtained show that both processing temperature and composition significantly influence the peak positions and intensities in the FTIR spectrum. The increase in temperature from 270°C to 900°C caused a decrease in the intensity of several major peaks, indicating changes in the crystalline structure of BaFe. Meanwhile, the addition of cobalt (Co) and zinc (Zn) elements in the BaFe composition increased the intensity of certain peaks, strengthened the metal-oxygen bond vibrations, and improved the stability of the material's structure. These findings provide important insights into how temperature and composition affect the FTIR spectroscopic properties of BaFe, with significant implications for the development of BaFe materials in technological applications, particularly in the production of permanent magnets and magnetic data storage materials.

LIMITATION

This study is limited by the interpretation of FTIR peak intensity as a comparative spectral parameter without fully isolating non-structural sources of variation. In FTIR measurements, peak intensity may be affected not only by changes in the sample itself, but also by experimental factors such as KBr pellet thickness, sample-to-KBr ratio, particle size distribution, moisture adsorption, baseline treatment, and repeatability across independently prepared pellets. Therefore, intensity differences observed among samples should be interpreted cautiously and should not be taken as direct evidence of bond strengthening, improved structural stability, or crystalline degradation. In addition, several bands observed in the mid- and high-wavenumber regions (particularly around 1400-1700 cm^{-1} and 3400 cm^{-1}) may include contributions from adsorbed water or residual precursor-related species rather than intrinsic BaFe lattice vibrations. Because the present study relies primarily on FTIR data without complementary structural characterization, the mechanistic interpretation of peak shifts and relative intensity changes remains tentative.

RECOMMENDATION

Future work should standardize and report FTIR sample preparation and spectral processing conditions more explicitly, including pellet mass and thickness, sample-to-KBr ratio, particle preparation, humidity control, baseline correction, and normalization procedures, so that comparisons of relative peak intensity across samples are more robust. It is also important to define clearly how intensity values are obtained and to distinguish comparative spectral observations from direct structural conclusions. To strengthen the interpretation of FTIR data, future studies should incorporate complementary characterization techniques such as XRD for phase identification and crystallinity evaluation, SEM/EDS for microstructural and elemental analysis, and, where possible, XPS or Mössbauer spectroscopy to clarify cation environment and bonding changes. In addition, literature-supported peak assignments for both undoped and doped BaFe systems would help improve spectral interpretation and reduce overstatement in linking FTIR intensity variations to bond strength or structural stability.

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