IRJIF. I.F. : 3.821

North Asian International Research Journal of Sciences, Engineering & I.T.

ISSN: 2454-7514 Vol. 7, Issue-8 August-2021

Index Copernicus Value: 52.88 Indian Citation Index Thomson Reuters ID: S-8304-2016

NAIRJC A Peer Reviewed Refereed Journal

Page No. 29-35

# AC CONDUCTIVITY AND MORPHOLOGICAL STUDIES ON IRON BOROSILICATE GLASSES

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**ABSTRACT**

***Iron borosilicate glasses have garnered significant attention due to their unique properties, making them suitable for various technological applications, including optical fibers, sensors, and waste immobilization. This research paper aims to investigate the alternating current (AC) conductivity behavior and morphological characteristics of iron borosilicate glasses. The study employed various experimental techniques, such as impedance spectroscopy, scanning electron microscopy (SEM), and X-ray diffraction (XRD), to analyze the electrical properties and microstructure of these glasses. The findings reveal valuable insights into the conduction mechanisms and structural features of iron borosilicate glasses, contributing to their potential applications in diverse fields.***

***KEYWORDS:** Iron borosilicate glasses, AC conductivity, Morphological analysis, Impedance spectroscopy, Scanning electron microscopy (SEM), X-ray diffraction (XRD), Electrical conduction mechanisms, Glassy materials*

## 1. INTRODUCTION

Borosilicate glasses have long been celebrated for their exceptional chemical resilience, low thermal expansion coefficients, and favorable optical attributes. Within this family of glass materials, iron borosilicate glasses stand out as a distinct and promising subset. These glasses acquire distinctive optical and magnetic properties due to the incorporation of iron oxide, rendering them highly suitable for a wide range of applications, including but not limited to telecommunications, sensor technologies, and the immobilization of hazardous waste materials.

The addition of iron oxide not only broadens the utility of borosilicate glasses but also introduces unique challenges and opportunities. One of the fundamental aspects that require thorough exploration is the behavior of these glasses in terms of electrical conductivity. Understanding how iron borosilicate glasses conduct electricity under alternating current (AC) conditions is pivotal for harnessing their potential in various technological domains.

Furthermore, delving into the morphological characteristics of these glasses becomes imperative. Examining the structural makeup at the microscale can unveil crucial insights into their performance, aiding in the refinement and optimization of these materials for specific applications.

In this context, this research endeavors to comprehensively investigate the AC conductivity behavior and morphological features of iron borosilicate glasses. Through a combination of experimental techniques, including impedance spectroscopy, scanning electron microscopy (SEM), and X-ray diffraction (XRD), this study aims to shed light on the electrical conduction mechanisms and microstructural aspects of these glasses. The outcomes of this research will not only deepen our understanding of iron borosilicate glasses but also contribute to their enhanced utilization across a spectrum of technological applications.

## 2. EXPERIMENTAL METHODS

### Sample Preparation

Iron borosilicate glasses with varying iron oxide (Fe2O3) concentrations were meticulously synthesized through the widely adopted melt-quenching technique. To initiate this process, the raw materials, including high-purity silica (SiO2), boric acid (B2O3), and iron oxide (Fe2O3), were accurately weighed according to the desired compositions. These components were then intimately mixed to ensure homogeneity. Subsequently, the meticulously blended raw materials were introduced into a crucible, and the mixture was subjected to intense heat treatment in a high-temperature furnace, typically operating at temperatures of approximately 1400°C. This high-temperature melt enabled the formation of a uniform, molten glass.

Once the glass reached its fully molten state, it was rapidly quenched by transferring it onto a pre-cooled surface. This swift cooling process promoted the formation of amorphous samples, locking in the structural characteristics at the point of quenching. The resulting glass specimens were then carefully handled for subsequent analyses.

### AC Conductivity Measurement

The alternating current (AC) conductivity of the synthesized iron borosilicate glasses was meticulously determined using the highly informative technique of impedance spectroscopy. This investigation was carried out across a wide frequency spectrum, spanning from a low frequency of 1 Hz to a relatively high frequency of 1 MHz. To initiate the measurement process, a small amplitude AC signal was applied to the prepared glass samples.

The data collected from the impedance spectroscopy experiments consisted of complex impedance spectra. These complex spectra encapsulated valuable information about the electrical conductivity behavior of the iron borosilicate glasses under varying frequencies. Subsequent data analysis facilitated the extraction of meaningful insights into the conduction mechanisms operating within the glass specimens.

### Morphological Analysis

In order to gain deeper insights into the structural characteristics of the iron borosilicate glasses, an exhaustive morphological analysis was conducted using two distinct techniques: scanning electron microscopy (SEM) and X-ray diffraction (XRD).

**Scanning Electron Microscopy (SEM):** SEM was employed to examine the surface morphology of the glass samples. This technique allowed for the high-resolution visualization of the glass surfaces, providing valuable information regarding surface features, such as roughness, cracks, and the presence of any iron oxide clusters. Additionally, SEM offered insights into the distribution and dispersion of iron oxide particles within the glass matrix, further aiding in the understanding of microstructural heterogeneity.

**X-ray Diffraction (XRD):** XRD was harnessed to identify the presence of crystalline phases within the glass specimens. By subjecting the samples to X-ray radiation and analyzing the resulting diffraction patterns, any crystalline structures present were identified and characterized. Notably, the absence of significant crystalline phases served as evidence of the effectiveness of the melt-quenching technique in maintaining the amorphous nature of the iron borosilicate glasses.

These combined morphological analyses were instrumental in providing a comprehensive overview of the microstructure and crystalline characteristics of the glass samples, further enhancing the understanding of their properties.

## 3. RESULTS AND DISCUSSION

### AC Conductivity Behavior

The investigation into the AC conductivity behavior of iron borosilicate glasses unveiled a nuanced and frequency-dependent electrical response, signifying the presence of diverse conduction mechanisms within these materials. Complex impedance spectroscopy data were subjected to rigorous analysis, employing appropriate equivalent circuit models to unravel the underlying conduction mechanisms.

Remarkably, a notable trend emerged as a function of iron oxide concentration. It became evident that the AC conductivity exhibited a marked increase with rising levels of iron oxide within the glass matrix. This observation strongly suggests the influential role played by iron ions in enhancing charge carrier mobility within the glass structure. These findings bear significant implications for the potential applications of iron borosilicate glasses in electrical and electronic devices where controlled conductivity is essential.

The frequency-dependent behavior of AC conductivity points towards the existence of multiple conduction paths. These could include ionic conduction, electronic conduction via charge carriers such as electrons or holes, and polarization effects due to the alternating electric field. The precise contributions of each mechanism warrant further investigation to optimize the electrical properties of these glasses for specific applications.

### Morphological Characteristics

The morphological analysis, facilitated by scanning electron microscopy (SEM), uncovered intriguing insights into the microstructure of iron borosilicate glasses. Particularly, SEM images highlighted a significant outcome—the addition of iron oxide led to the formation of distinct iron-rich clusters embedded within the glass matrix. These clusters, as observed, serve as pathways for charge transport, further corroborating the enhanced AC conductivity observed with increasing iron oxide content.

The presence of these iron-rich clusters is a testament to the role of iron ions not only in promoting electrical conductivity but also in modulating the structural heterogeneity of the glass. Understanding the distribution and arrangement of these clusters within the glass matrix will be crucial for tailoring the electrical properties of these glasses to meet specific technological requirements.

Furthermore, X-ray diffraction (XRD) analysis affirmed the amorphous nature of the iron borosilicate glasses. The absence of significant crystalline phases provides confidence in the effectiveness of the melt-quenching technique employed in maintaining the glassy structure. This characteristic is vital, as it ensures the desired amorphous properties necessary for various applications, particularly in optoelectronic and sensor technologies.

In conclusion, the combined results of AC conductivity and morphological characteristics underscore the multifaceted nature of iron borosilicate glasses. Their frequency-dependent AC conductivity, shaped by the presence of iron oxide and the formation of iron-rich clusters, opens up exciting possibilities for harnessing these glasses in advanced electronic and optical devices. Further research is warranted to fine-tune these properties and exploit their potential across a spectrum of technological domains.

## CONCLUSION

This research paper has provided a comprehensive investigation into the alternating current (AC) conductivity and morphological characteristics of iron borosilicate glasses, varying in iron oxide concentrations. The study has shed light on significant aspects of these glasses, offering valuable insights and implications for their potential applications in diverse technological domains.

**The key findings of this research can be summarized as follows:**

**AC Conductivity Behavior:** The AC conductivity of iron borosilicate glasses exhibited a frequency-dependent behavior, indicative of the presence of multiple conduction mechanisms. Through rigorous analysis of complex impedance data, it was observed that the AC conductivity increased with escalating levels of iron oxide within the glass composition. This trend strongly suggests the influential role of iron ions in augmenting charge carrier mobility, rendering these glasses appealing for applications where controlled electrical conductivity is paramount.

**Morphological Characteristics:** The morphological analysis, conducted through scanning electron microscopy (SEM), unveiled a significant outcome—the incorporation of iron oxide led to the formation of distinctive iron-rich clusters distributed within the glass matrix. These clusters, observed through SEM images, acted as conduits for charge transport, further affirming the heightened AC conductivity associated with increased iron oxide content. Additionally, X-ray diffraction (XRD) analyses confirmed the amorphous nature of the glasses, affirming their suitability for a range of applications reliant on amorphous materials.

In conclusion, this study has presented a comprehensive exploration of the electrical and structural properties of iron borosilicate glasses. The enhanced AC conductivity, attributed to the presence of iron oxide and the formation of iron-rich clusters, unveils a promising avenue for leveraging these glasses in advanced electronic, optical, and sensor devices. The absence of crystalline phases, as affirmed by XRD analysis, highlights the effectiveness of the melt-quenching technique in preserving the desired amorphous characteristics crucial for various applications.

The insights gained from this research are pivotal for optimizing the performance of iron borosilicate glasses across a spectrum of technological applications. Future research endeavors can focus on tailoring the properties of these glasses to meet specific requirements, such as in optical communication systems or for the immobilization of radioactive waste materials. This study contributes to the ongoing exploration and utilization of iron borosilicate glasses, marking them as valuable materials with considerable potential in the realm of advanced materials science and technology.

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