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STUDY ON THE APPLICATION OF UNDOPED AND SILVER-DOPED BISMUTH FERRITE SAMPLES APPLIED IN ELECTRONIC DEVICE

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Abstract

In this paper, undoped bismuth ferrite ($BiFeO_3$) and silver-doped bismuth ferrite (Ag-$BiFeO_3$) samples were prepared by the sol-gel method. The resulting powder was characterized by XRD and EDXRF techniques. Comparative studies of the electrical properties of these samples were investigated by using an LCR meter in the frequency range of 20 to 100 MHz at 2 V. In this study, it was found that the AC and CD conductivities, dielectric loss tangent, dielectric constant, and capacitance depend on the frequency. The conductivity values of AC and DC increase with increasing frequency. Dielectric loss tangent, dielectric constant, and capacitance decrease with increasing frequency. These two samples demonstrated semiconducting properties in accordance with their electrical properties. In addition, Ag-$BiFeO_3$ indicates higher conductivity values than the $BiFeO_3$ sample. According to the results, both $BiFeO_3$ and Ag-$BiFeO_3$ samples could be used as touch point electrodes in a touch sensor device for electrical applications.

Keywords: $BiFeO_3$, Ag-$BiFeO_3$, electrical properties, AC and DC conductivities, touch point electrodes

Introduction

Bismuth ferrite ($BiFeO_3$, also commonly referred to as BFO in materials science) is an inorganic chemical compound with an ABO_3-type perovskite structure. In ABO_3, perovskite A is bismuth (Bi) and occupies the corner of the perovskite unit cell. B is iron (Fe), the central atom with an oxygen octahedral arrangement (Sarnatsky *et al*., 2016). Bismuth ferrite is also one of the most extensively investigated multiferroic magneto-electric compounds, in which the 6s lone pair electrons of Bi are believed to be responsible for ferroelectricity while the partially filled d orbital of Fe leads to magnetic ordering (Suastiyanti and Wijaya, 2016). Bismuth ferrite ($BiFeO_3$) has a rhombohedral structure, R3c ($\alpha = \beta = \gamma = 59.4°$, a = b = c = 5.63 Å) at room temperature (Awan and Bhatti, 2009). Bismuth ferrite has several applications in the fields of magnetism, memory devices, spintronics, photovoltaics, etc. (Fu *et al*., 2012). Some excellent reports have reported that $BiFeO_3$ is a very good candidate for visible light-responsive photocatalytic material and semiconductor electrodes in electronic devices (Azmy *et al*., 2017).

Touch sensors are electronic sensors that can detect touch. They operate as switches when touched. These sensors are used in lamps, touch screens on mobile devices, etc. (Catalan and Scott, 2009). Touch sensors offer an intuitive user interface. Touch sensors are also known as tactile sensors. These are simple to design, low-cost and produced on a large scale. These sensors are sensitive to any pressure, force, or touch. The principle of touch is similar to that of a switch. When there is contact or a touch on the surface of the touch sensor, it acts like a closed switch and allows the current to flow through it. When the contact is released, it acts similar to an opened switch, and there is no flow of current. With the advancement of technology, these sensors are rapidly replacing mechanical switches (Dignan *et al*., 2019).

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Materials and Methods

Preparation of $BiFeO_3$ and Ag-$BiFeO_3$ Powder

In a mole ratio of 1:1, bismuth pentahydrate ($Bi(NO_3)_3.5H_2O$) and ferric nanohydrate ($Fe(NO_3)_3.9H_2O$) were dissolved in 2-methoxyethanol. The solution was stirred continuously for an hour at room temperature until it became translucent. As a chelating agent, citric acid ($C_6H_8O_7$) was added, and the mixture was heated and stirred at 80 °C for 2 h. The resulting mixture was then transparent, reddish-black, and clear. Additionally, the solution was placed on a hot plate at 80 °C with constant stirring for 5 h until all the liquid evaporated. Brown vapours were evolving in great quantities. A fluffy brown material (gel) was discovered in the bottom of the beaker near the end of the reaction. The resulting gel was then calcined for 4 h at 550 °C. Then, finely ground $BiFeO_3$ was obtained (Kumar, 2011).

In the chemical reduction process, polyvinyl pyrrolidone (PVP) was employed as a reductant to prepare $BiFeO_3$ powder that was doped with silver. After mixing 1.88 g of PVP with 20 mL of distilled water, the liquid was then heated to 60 °C in the air while being stirred magnetically until the PVP was completely dissolved. In a mole ratio of 5:0.3, silver nitrate ($AgNO_3$) and $BiFeO_3$ powder were dissolved in distilled water, and the PVP solution was then added. The resulting mixture was then heated at 80 °C for 2 h while being stirred continuously. Centrifugation was used to separate the product, which was subsequently cleaned with distilled water and dried in an oven at 100 °C to obtain silver-doped $BiFeO_3$ (Ag-$BiFeO_3$) powder (Lu *et al*., 2015).

Characterization

$BiFeO_3$ and Ag-$BiFeO_3$ samples were confirmed by X-ray diffraction analysis using an X-ray diffractometer (Rigaku, Japan). The average crystallite sizes of these prepared samples were calculated using the Debye-Scherrer equation. The relative abundance of elements in $BiFeO_3$ and Ag-$BiFeO_3$ powder was also determined by an energy dispersive X-ray fluorescence spectrometer (Shimadzu EDX-700, Japan).

Preparation of Pellets

The $BiFeO_3$ and Ag-$BiFeO_3$ samples were pressed into pellets with a diameter of 1.5 cm and a thickness of 0.16 cm using the MAEKAWA Testing Machine.

Determination of the Electrical Properties of $BiFeO_3$ and Ag-$BiFeO_3$

The electrical properties of $BiFeO_3$ and Ag-$BiFeO_3$ pellets were measured by the LCR-8110G meter (Inductance, capacitance, and resistance meter, GwInstek, DC 20-10 MHz). Electrical conductivity measurements were carried out at room temperature.

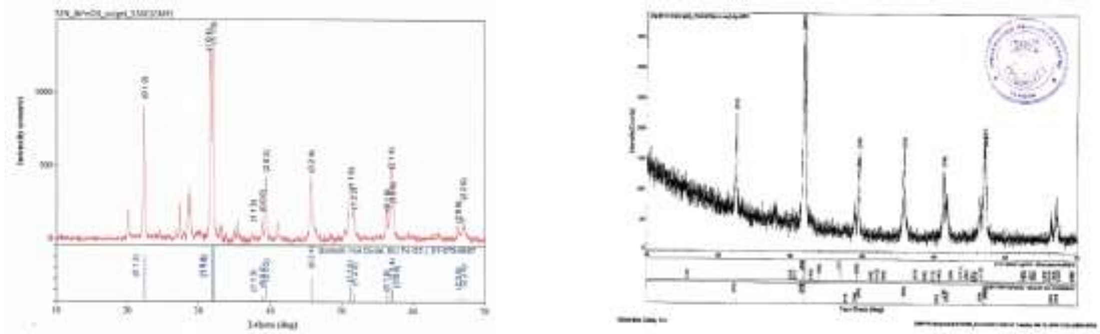
Fabrication of a Touch Sensor Device using $BiFeO_3$ and Ag-$BiFeO_3$ as Electrodes

The simple touch sensor processing was setup as follows: BC 547 transistor was first connected with a resistor 10 kΩ and then connected with a $BiFeO_3$ or Ag-$BiFeO_3$ electrode. The next transistor, BC 547, was connected to the first BC 547. Then, an LED of 5 mm and a resistor of 680 Ω were connected in series. The 1.5 kΩ resistor was connected to the first transistor. The two resistors, 680 Ω and 1.5 kΩ, were joined with the red wire. The first transistor, BC 547, was joined with the black wire.

Results and Discussion

XRD Analysis

Figures 1 (a) and 1(b) show the XRD diffractograms of prepared samples of $BiFeO_3$ and Ag-$BiFeO_3$, respectively. The average crystallite sizes of the $BiFeO_3$ and Ag-$BiFeO_3$ powders were calculated using the Debye-Scherrer equation. From the XRD analysis, the crystallite sizes of these samples were found to be less than 100 nm, i.e., 41.05 nm and 32.10 nm, respectively (Table 1).



(a) **(b)**

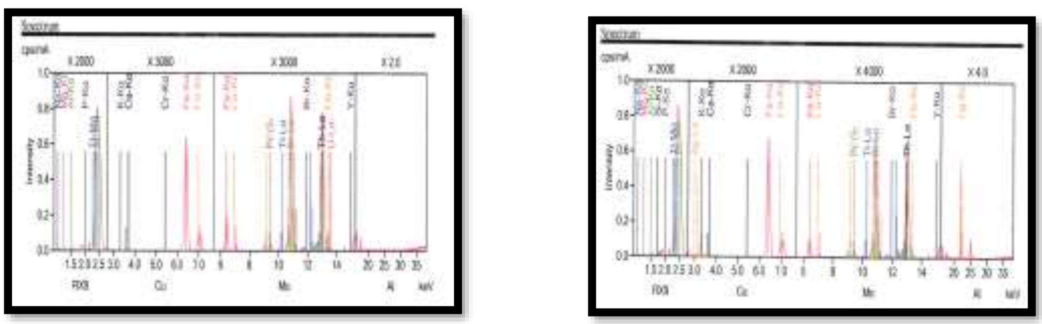
Figure 1. XRD patterns of (a) $BiFeO_3$ (b) Ag-$BiFeO_3$ powder

Table 1. Average Crystallite Sizes of $BiFeO_3$ and Ag-$BiFeO_3$ Powder

Samples	Crystallite sizes (nm)
$BiFeO_3$	41.05
Ag-$BiFeO_3$	32.10

EDXRF

The EDXRF spectra of the prepared samples ($BiFeO_3$ and Ag-$BiFeO_3$) are illustrated in Figures 2 (a) and (b). Bi, Fe, and Ag are the main constituents of the prepared samples. $BiFeO_3$ is composed of 35.6 % Bi and 14.6 % Fe, while Ag-$BiFeO_3$ is composed of 26.9 % Bi, 9.98 % Fe, and 2.74 % Ag, respectively.



(a) **(b)**

Figure 2. EDXRF spectra of (a) $BiFeO_3$, (b) Ag-$BiFeO_3$ powder

Investigation of the Electrical Properties of $BiFeO_3$ and Ag-$BiFeO_3$ Samples

AC and DC Conductivities

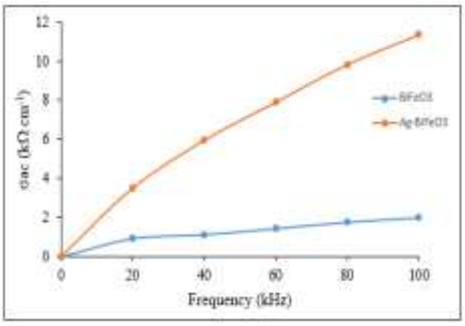
An LCR meter was used to measure the variation of AC and DC conductivities of $BiFeO_3$ and Ag-$BiFeO_3$ samples at 2 V over a frequency range of 20 to 100 kHz. It was found that the AC and DC conductivities of Ag-$BiFeO_3$ were observed to be significantly higher than $BiFeO_3$ (Tables 2 and 3). So, the metal conduction behaviour increases with increasing frequency for both samples, as shown in Figures 3 (a) and (b). In addition, the AC conductivity values gradually increased with the increase in frequency of the applied alternating electric field because the increase in frequency enhanced the migration of electrons (Mubarak *et al*., 2014).

Table 2. **AC Conductivity of $BiFeO_3$ and Ag-$BiFeO_3$ Samples at Different Frequencies**

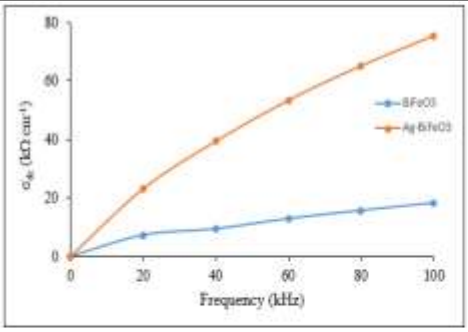
Samples	AC conductivity (kΩ cm^{-1})				
	20 kHz	**40 kHz**	**60 kHz**	**80 kHz**	**100 kHz**
$BiFeO_3$	0.93	1.13	1.44	1.76	1.99
Ag-$BiFeO_3$	3.51	5.95	7.90	9.82	11.35

Table 3. **DC Conductivity of $BiFeO_3$ and Ag-$BiFeO_3$ Samples at Different Frequencies**

Samples	DC conductivity (kΩ cm^{-1})				
	20 kHz	**40 kHz**	**60 kHz**	**80 kHz**	**100 kHz**
$BiFeO_3$	7.24	9.38	12.86	15.65	18.24
Ag-$BiFeO_3$	23.08	39.34	53.34	65.06	75.39



(a)



(b)

Figure 3. Comparison of (a) AC conductivity and (b) DC conductivity of $BiFeO_3$ and Ag-$BiFeO_3$ samples

Dielectric Constant

Table 4 shows the dielectric constant values at different frequencies for the $BiFeO_3$ and Ag-$BiFeO_3$ samples. The values of the dielectric constant decrease with increasing frequency. The reduction of the space charge polarization effect caused a low dielectric constant value. So, the Ag-$BiFeO_3$ sample exhibits the highest value in dielectric constant at the lowest frequency (Figure 4).

Table 4. Dielectric Constant of $BiFeO_3$ and Ag-$BiFeO_3$ Samples at Different Frequencies

Samples	Dielectric constant				
	20 kHz	**40 kHz**	**60 kHz**	**80 kHz**	**100 kHz**
$BiFeO_3$	5.70	4.43	4.42	4.31	4.14
Ag-$BiFeO_3$	9.94	8.47	7.64	7.32	7.11

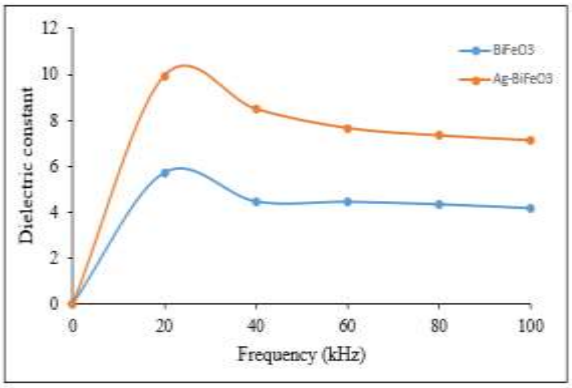


Figure 4. Comparison of dielectric constant of $BiFeO_3$ and Ag-$BiFeO_3$ samples

Dielectric Loss Tangent

The dielectric loss tangent indicates the energy dissipation in the dielectric system. The dielectric loss tangent values of $BiFeO_3$ and Ag-$BiFeO_3$ samples are shown in Table 5. The dielectric loss tangent values of Ag-$BiFeO_3$ are greater than those of $BiFeO_3$ (Figure 5). The dielectric loss tangent peaks shift towards the lower frequency side. It was believed that there was an increase in the crystalline nature of the matrix of materials.

Table 5. Dielectric Loss Tangent of $BiFeO_3$ and Ag-$BiFeO_3$ Samples at Different Frequencies

Samples	Dielectric loss tangent (tan δ)				
	20 kHz	**40 kHz**	**60 kHz**	**80 kHz**	**100 kHz**
$BiFeO_3$	0.14	0.11	0.10	0.09	0.08
Ag-$BiFeO_3$	0.32	0.31	0.30	0.29	0.28

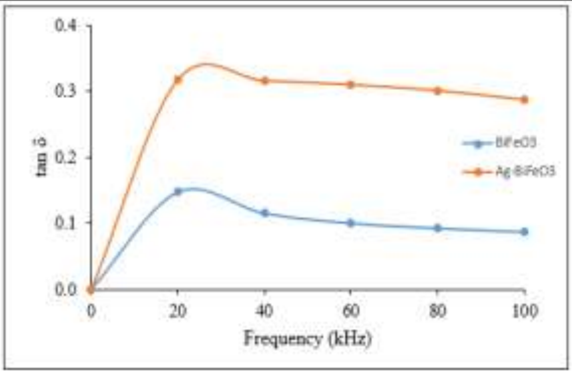


Figure 5. Comparison of dielectric loss tangent of $BiFeO_3$ and Ag-$BiFeO_3$ samples

Capacitance

The frequency-dependent capacitance of $BiFeO_3$ and Ag-$BiFeO_3$ samples is shown in Table 6 and Figure 6. It was also found that the capacitance decreased with an increase in frequency. The maximum value of capacitance was shown at the minimum frequency. This finding indicated that the capacitance decreased as the decrease of dielectric constant. Moreover, the capacitance of both samples was in the picofarad range. This meaning proved that the both samples are enabled to perform charging and recharging power in the form of electrical energy.

Table 6. Capacitance of $BiFeO_3$ and Ag-$BiFeO_3$ Samples at Different Frequencies

Samples	Capacitance (pF)				
	20 kHz	40 kHz	60 kHz	80 kHz	100 kHZ
$BiFeO_3$	4.10	3.19	3.11	3.10	2.98
Ag-$BiFeO_3$	7.17	6.10	5.51	5.28	5.12

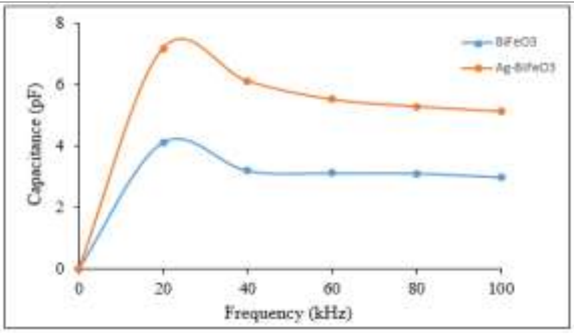
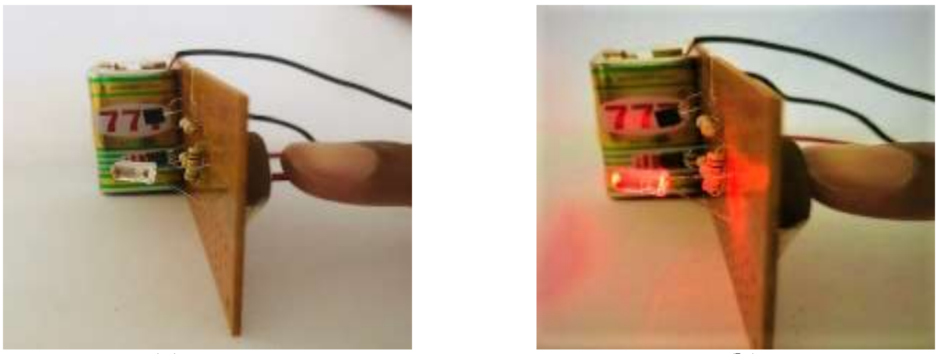


Figure 6. Comparison of capacitance of $BiFeO_3$ and Ag-$BiFeO_3$ samples

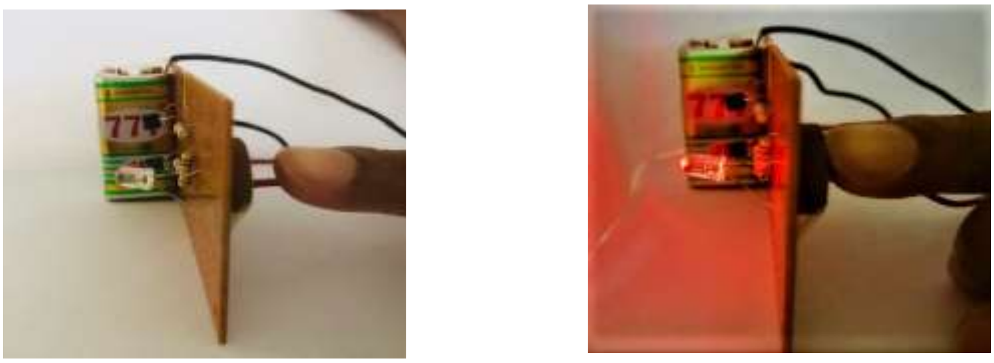
Generating Electricity in a Touch Sensor using $BiFeO_3$ and Ag-$BiFeO_3$ as Electrodes

In the touch sensor, the $BiFeO_3$ and Ag-$BiFeO_3$ samples were used as touch point electrodes (Figures 7 and 8). The black and red wires were connected to the battery. When the finger touched the $BiFeO_3$ or Ag-$BiFeO_3$ electrodes of the touch sensor, the LED lit up brightly. When the finger did not touch the electrode, the LED light faded out. So, these conducting samples could be used as touch point electrodes in touch sensor devices.



(a) (b)

Figure 7. (a) Before touch onto the $BiFeO_3$ electrode **(b)** After touch onto the $BiFeO_3$ electrode



(a) (b)

Figure 8. (a) Before touch onto the Ag-$BiFeO_3$ electrode **(b)** After touch onto the Ag-$BiFeO_3$ electrode

Conclusion

Undoped bismuth ferrite ($BiFeO_3$) and silver-doped bismuth ferrite (Ag-$BiFeO_3$) powder were successfully synthesized by the sol-gel method. The electrical conductivity values of both samples gradually increased with an increase in frequency. The maximum values of AC conductivity for $BiFeO_3$ and Ag-$BiFeO_3$ samples were 1.99 and 11.35 kΩ cm^{-1}, respectively, and and those of DC conductivity were 18.24 and 75.39 kΩ cm^{-1}. These results are evident that the AC and DC conductivity values of the Ag-$BiFeO_3$ sample were higher than those of $BiFeO_3$ sample because silver possesses the highest electrical conductivity among all metals. The semiconducting properties were found out through the investigation of electrical properties. Moreover, these samples have the ability of capacitor to store energy. According to the observations, the prepared materials could be used as touch point electrodes in a touch sensor device.

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