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Effect of Zinc Additive and Annealing on Dielectric Characteristics of the PSCCO Compound

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Abstract

The ceramic PSCCO ($PbSr_2Ca_2Cu_3O$) and ($PbSr_2Ca_2Cu_{2.4}Zn_{0.6}O$) compounds were prepared using high-purity oxides (x=0 and0.6%) via solid reaction. The samples were then pressed into tablets with 1.5 cm diameter, at 5.4MPa for two minutes and sintered at 850°C for 24 hours. AFM was used to study the surface structure. It showed a stable improvement in the crystallization of the model surfaces. As a result of the chemical reaction between the raw materials, the granules united with each other, increasing their size. At a frequency range of 50-10^6 Hz, regarding the dielectric properties, including the dielectric constant, and dielectric loss factor, at room temperature, it measured electrical conductivity and electrical resistance as a function of frequency in the range from 50 to10^6 Hz, Measurements of the ceramic composite model PSCCO ($PbSr_2Ca_2Cu_3O$) plus ($PbSr_2Ca_2Cu_{2.4}Zn_{0.6}O$) showed dielectric constant (11.23 and 10.30), while also measuring the loss angle shadow and alternating conductivity. The following parameters were measured for two models at a frequency range of 50-10^6 Hz: dielectric loss factor (7.76 and 9.45), tangent loss tangent (tanδ) (0.69 and 0.91), and alternating electrical conductivity ($\sigma_{a.c}$). The dielectric constant values for both models were 11.23 and 12.43. The insulating properties showed good stability with temperature within the range of room temperature to 200°C.and 13.71 for the base compound $PbSr_2Ca_2Cu_3O$, at different temperatures, the dielectric constant of compound $PbSr_2Ca_2Cu_{2.4}Zn_{0.6}O$ was measured to be 10.3, 11.15, and 12.06, indicating its potential use at high temperatures.

Keywords: alternating electrical conductivity, composite, superconductivity, Ceramic, dielectric properties, Electric Capacitance.

1. Introduction

The discovery of superconductivity in the La-Ba-Cu-O system by Bednorz and Muller in 1986 initiated the study of copper oxide-based high-temperature superconductors referred to as high-temperature transition superconductors (HTS). Since then, scientists have synthesized several hundred chemically distinct copper superconductors (1).

Due to significant advancements in science and increasing demand for electronics in various aspects of life, creating innovative superconductors with high-temperature superconductivity has become crucial. As a result, there have been considerable efforts to develop superconducting conductors with high-temperature capabilities, as evidenced by numerous studies (2-5).

When the material reaches the superconducting state, it shows several amazing macroscopic properties, such as the absence of a magnetic field and zero DC resistance. Most investigations in the superconductor area are focused on increasing the critical temperature to almost the surrounding temperature. As a result. researchers try to adjust the preparation parameters or switch out specific elements of medication for others. Discover the effects of charged particle fields and electromagnetic fields on superconductivity (6-8).

Superconducting applications are widely used in engineering and medicine. The non-conducting materials' dielectric characteristics may be used to describe how the materials interact with electric fields. Important characteristics include the capture of electric potential energy and its storage as polarization inside the dielectric material, as well as the partial dissipation of energy upon removal of the dielectric field (9-10). Because these applications are used in laser devices that need particular operation, magnetic resonance imaging, and radiometric testing, it is important to determine the dielectric characteristics and electrical conductivity of these materials businesses(10).

$$[\varepsilon = d * C / A * \varepsilon] \quad (1)$$

$$\tan\delta = \varepsilon'' / \acute{\varepsilon} \quad (2)$$

$$\sigma = 2\pi f * \varepsilon_{\circ} * \ddot{\varepsilon} \quad (3)$$

.in this research the dielectric properties of $PbSr_2Ca_2Cu_3O$ basic compound and $PbSr_2Ca_2Cu_{2.4}Zn_{0.6}O$ in the frequency range from (50 Hz - 1 MHz) and the wide temperature range 25 and 200 degrees Celsius. Then the frequency and temperature dependence of all measurements are discussed.

2. Materials and Methods

The $PbSr_2Ca_2Cu_3O$ basic compound and $PbSr_2Ca_2Cu_{2.4}Zn_{0.6}O$ were produced by the solid-state reaction technique(6,12) using high-purity oxides (lead oxide, copper oxide, calcium oxide, strontium oxide, and zinc oxide), Depending on their molecular weights(14,15). When they were created, the samples were 0.63 cm in thickness and 1.5 cm in diameter, and they were sintered for 24 hours at 850 degrees Celsius.

2.1. The Tests

2.1.1. Electrical Property Measurement

Using the FLUKE RCL Meter program electrode type LCR Meter PM6303, produced in Japan, the amplitude Cp and shadow loss tanδ of all samples are evaluated at various frequencies ranging from (50 Hz - 1 MHz) at room temperature (25 degrees Celsius). The gadget was calibrated and verified using standard capacitance before taking any readings. The values of the oscillating electrical conductivity, dielectric loss factor, and dielectric constant may be obtained (15-18).

2.1.2. The Capacitance

The capacitance Cp and the loss shadow tanδ are measured as a function of temperature. This system consists of an electrically powered oven model (Griffin Incubator, made in England), where the cell containing the sample is placed. The temperature of the sample is measured by connecting the cell to a thermocouple using a connecting wire, and the LCR measuring device communicates with the cell using the same connecting wire. At 50 Hz and 1 MHz, measurements were made between ambient temperature and 200 degrees Celsius. The dielectric constant, dielectric loss factor, and oscillating electrical conductivity are computed.

3. Results and Discussion

The LCR Meter was used, which measures Cp and dissipation factor (D) as a function of applied frequency in the 50–10^6 Hz range at room temperature. It can be seen significant improvements in every characteristic where the samples displayed similar behavior while measuring a voltage difference and current at various frequencies, and It will go into further detail about them. **Figure 1.** shows that the dielectric constant values at 10^6 Hz dropped. **Figure 1.** shows the shift in the dielectric constant values from one base sample to the next, the reduction in the dielectric constant with rising frequencies, and the variation in dielectric constant values from one the rise in the proportion of zinc exchange is the cause of this, both within one frequency and between frequencies(19,20). Conversely, a rise in the proportion of zinc causes an increase in the concentration of charges and gaps inside the sample, as we see in the dielectric constant values at two-half frequencies.

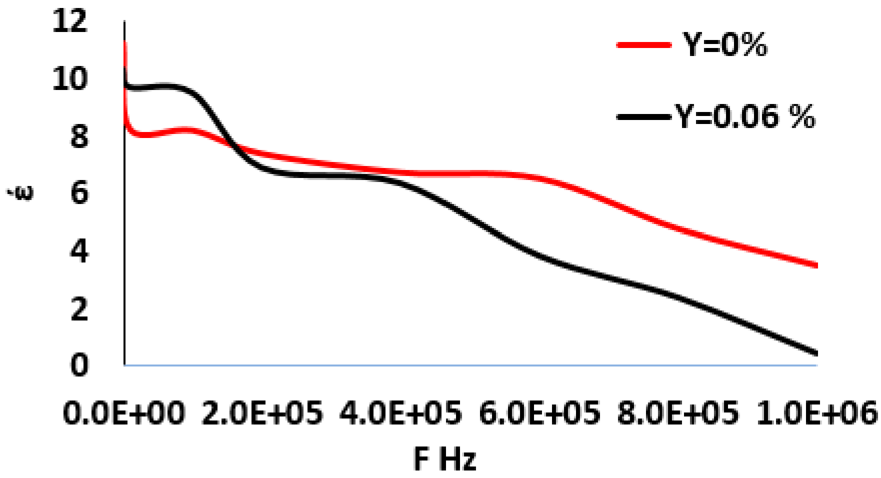

Figure 1. The dielectric constant for the $PbSr_2Ca_2Cu_3O$ and $PbSr_2Ca_2Cu_{2.4}$ ZN0.6O compounds.

The relationship between electrical capacitance and frequency is depicted in **Figure 2.**, where It can be observed observe a notable increase and decrease in capacitance, respectively, upon adding zinc. This decrease in dielectric constant will result in a corresponding decrease in capacitance, as the two quantities are directly proportional, as stated in the equation(1) (22).

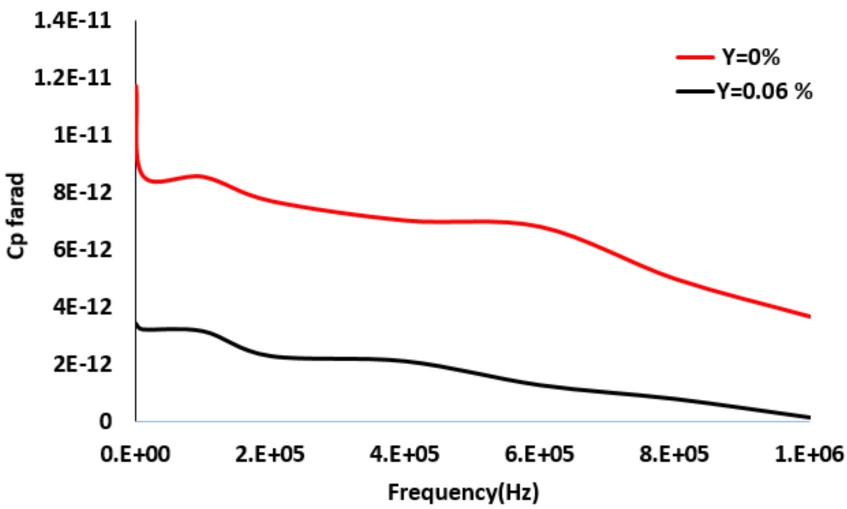

Figure 2. Capacitance of the $PbSr_2Ca_2Cu_3O$ and $PbSr_2Ca_2Cu_{2.4}$ ZN0.6O compounds.

By increasing the zinc concentration throughout the range of 50 to 106 Hz, **Figures 3.** and **4.** show variations in the imaginary dielectric constant and the dielectric loss factor. This is because, in addition to the influence of granular boundaries on the multiphase crystal structure of the samples, the replacement ratio of zinc can defector the crystal structure and form secondary phases and impurities. The loss of energy under the influence of an alternating electric field is referred to as isolated loss. It is important to remember that insulating materials can cause insulating loss through a combination of internal friction caused by the absorption of electrical energy (from the dipoles' internal friction) and surface or volume leakage current, This is created by raising the electric field frequency; here, It can be seen that the insulating loss factor increases as the frequency increases. The power loss is explained by the energy needed to keep the rotation going, and inversely, as the frequency rises, the surface and volumetric leakage current rises, fluctuations in the capacitance can also be directly related to the imaginary dielectric constant. These variations in loss values from sample to sample can be caused by the presence of fluid and impurities as a result of the change in the replacement ratio due to the possibility of different heat distribution on the sample inside the furnace during the sintering process for one sample as well as between samples. As per the eq(2) (23,24).

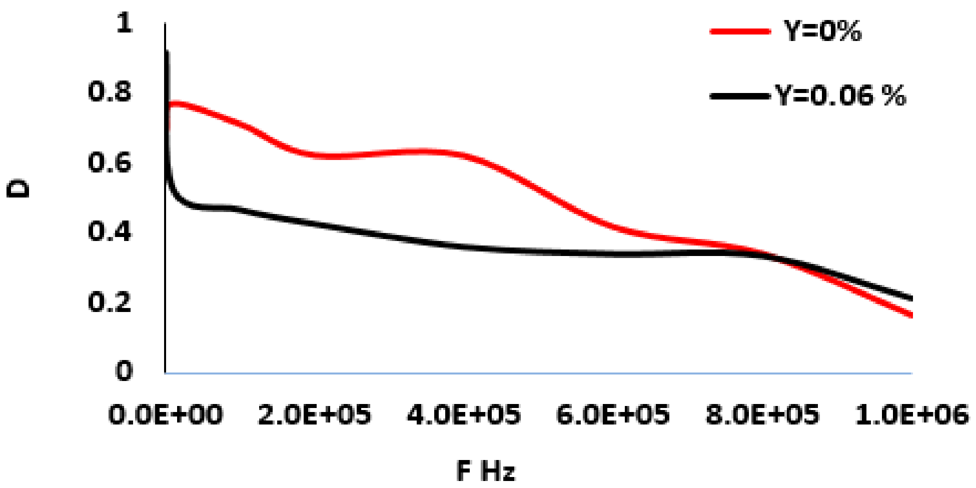

Figure 3. Variations in the dielectric constant as a function of frequency for the $PbSr_2Ca_2Cu_3O$ and $pbSr_2Ca_2Cu_{2.4}Zn0.6O$ compounds

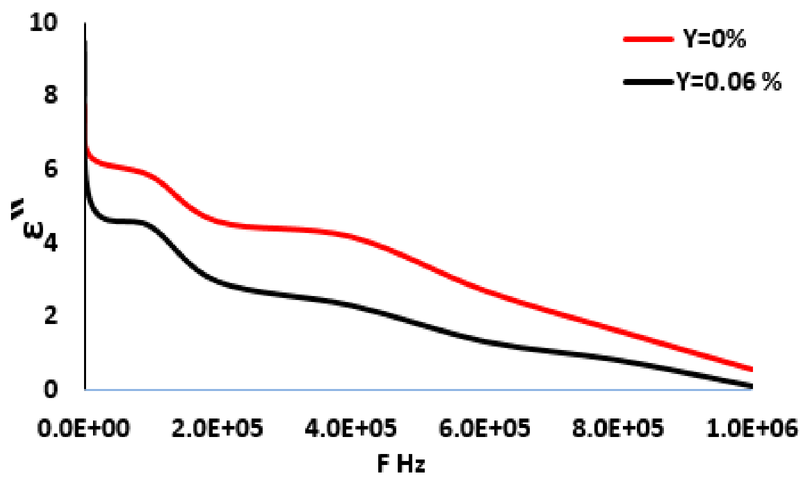

Figure 4. Variations in the imaginary dielectric constant as a function of frequency for the $PbSr_2Ca_2Cu_3O$ and $pbSr_2Ca_2Cu_{2.4}Zn0.6O$ compounds

Accordingly, a portion of the energy will be absorbed by the electric field, and the alternating conductivity indicates how much insulation is lost as a result of the dipoles' movement when the dielectric material faces up to the alternating field's impact, as represented by the equation(3) (23,24)It is important to note that the electrical conductivity in insulators originates from where It can be observed through this relationship the direct dependence of alternating conductivity on both the frequency of the pointed out electric field and its dependence on the imaginary part of the dielectric constant, which represents the absorption of energy and its dispersion in the insulating material under the influence of an alternating electric field(23).

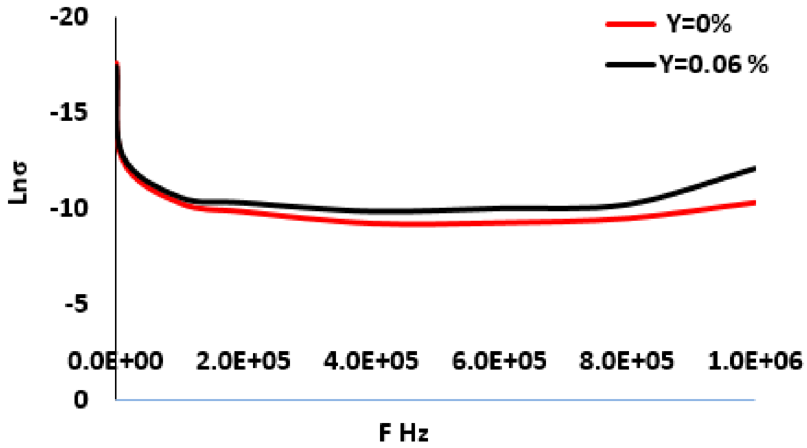

Figure 5. Electrical Conductivity as a function of frequency for the $PbSr_2Ca_2Cu_3O$ and $pbSr_2Ca_2Cu_{2.4}Zn0.6O$ compounds

Different substances have different dielectric characteristics, which are influenced by extrinsic variables such as humidity, temperature, crystal structure, frequency of the applied field, and others. Additionally, the answer may be nonlinear or linear.

The effects of temperatures between 25 and 200 degrees Celsius and frequencies between (10^2 - 10^6) Hz on the dielectric constant and dielectric loss factor are included in electrical experiments, Electrical conductivity in alternate mode and tangent loss tanδ the dielectric constant values of the base compound rise from 11.23 to 12.34 and 13.72 at a frequency of 50 Hz, however when zinc is substituted for copper, the values shift from 10.31 to 11.15 and 12.06 at a temperature increase of (25-200) degrees Celsius, respectively ,Since these semiconductors struggle to spin at extremely low temperatures and become easier to rotate as the temperature rises, the degree of dipole alignment in insulating materials is temperature-dependent Thus, as **Figures 6.** and **7.** demonstrate, the dielectric constant value rises with temperature. For the remaining frequencies, the values fluctuate with temperature but stay constant up to 200 degrees Celsius. The following describes the nature of the dielectric constant's temperature dependency, The dipole polarization will change as the temperature rises, causing the atoms to vibrate more quickly and be able to follow the applied field at higher frequencies. Thus, the dipoles are pointing in the direction of utility, and the dielectric constant values are rising (24).

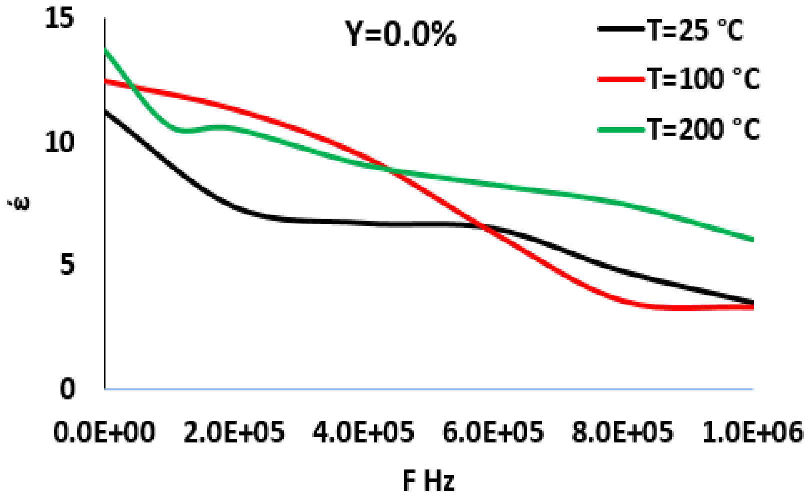

Figure 6. Real Dielectric Constant as a function of frequency for the PbSr2Ca2Cu3O base compound as a function of temperature

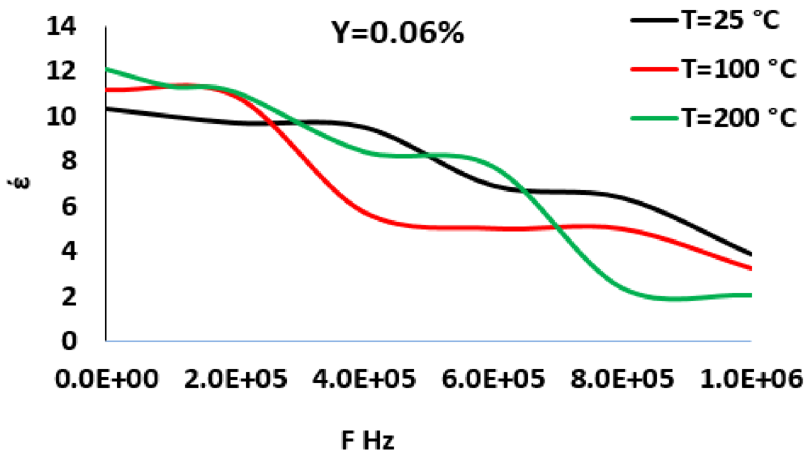

Figure 7. Real Dielectric Constant as a function of frequency for the $PbSr2Ca_2Cu_{2.4}$ ZN0.6O compound as a function of temperature

Figures 9. and **8.** show the change in the dielectric loss factor as a function of temperature for both the base compound and the compound, measured between 25 and 200 degrees Celsius $PbSr_2Ca_2Cu_{2.4}$ $Zn_{0.6}O$. Temperature shouldn't cause the dielectric losses to rise noticeably. This is essential both when the insulator is used at room temperature and when it may need to function at a high temperature due to the inevitable occurrence of certain losses that heat the dielectric. As the temperature rises, the present system's raised values of its features at some point drop, Overcoming the material's internal friction forces, it will become less and cause some of the dipole molecules to rotate, resulting in quick activation and an increase in the dielectric loss factor(25,26).

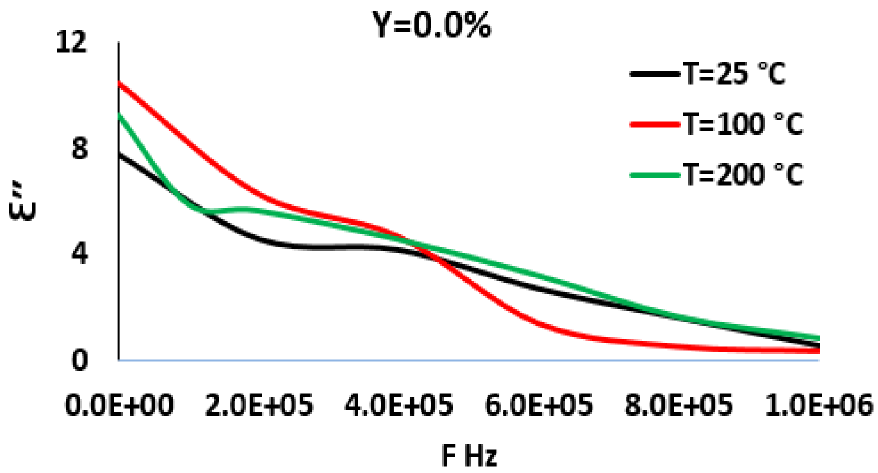

Figure 8. Loss factor as a function of frequency for the PbSr2Ca2Cu3O base compound as a function of temperature.

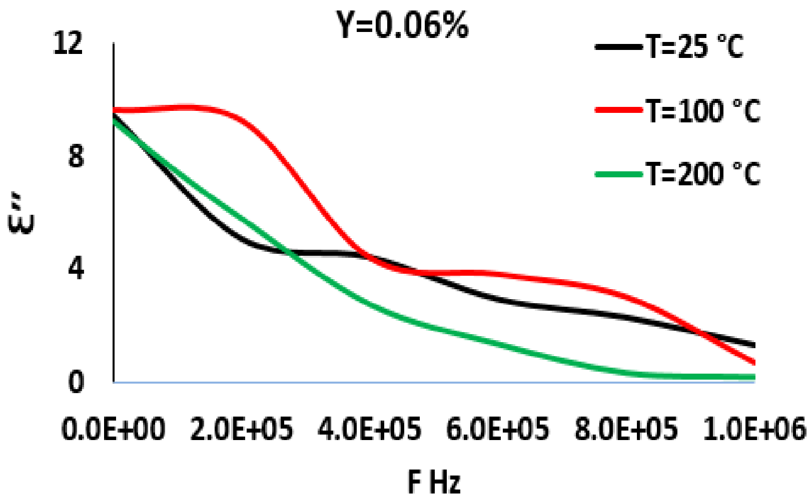

Figure 9. Loss factor as a function of frequency for the $PbSr_2Ca_2Cu_{2.4}Zn_{0.6}O$ compound as a function of temperature

Tanδ may be affected by the crystal structure, and impurities and also significantly improve dielectric loss in addition to increasing the compound's conductivity. Increasing the mobility of the cation also increases dielectric loss. As indicated in **Figures 10. , 11**. The temperature range (25-200) degrees Celsius is monitored to determine the tanδ values of the basic compound, the compound, and $PbSr_2Ca_2Cu_{2.4}$ $ZN_{0.6}O$. The drop in viscosity that results from raising the measurement temperature is responsible for the increases in tanδ readings, When the dipole spins at a unit angle, the energy required to overcome the viscous medium's resistance (the material's internal friction) decreases with increasing dipole direction, increasing dipole packing and causing initial losses to appear(25,26).

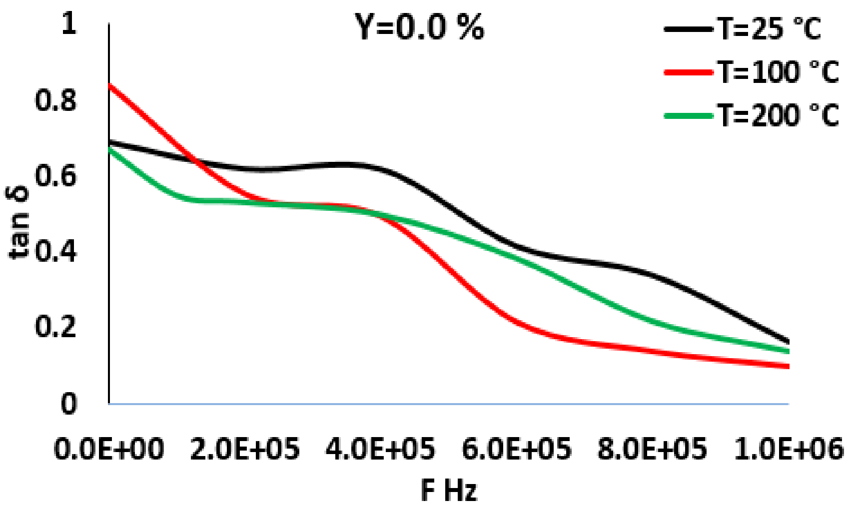

Figure 10. Tangent as a function of frequency for the $PbSr_2Ca_2Cu_3O$ compound

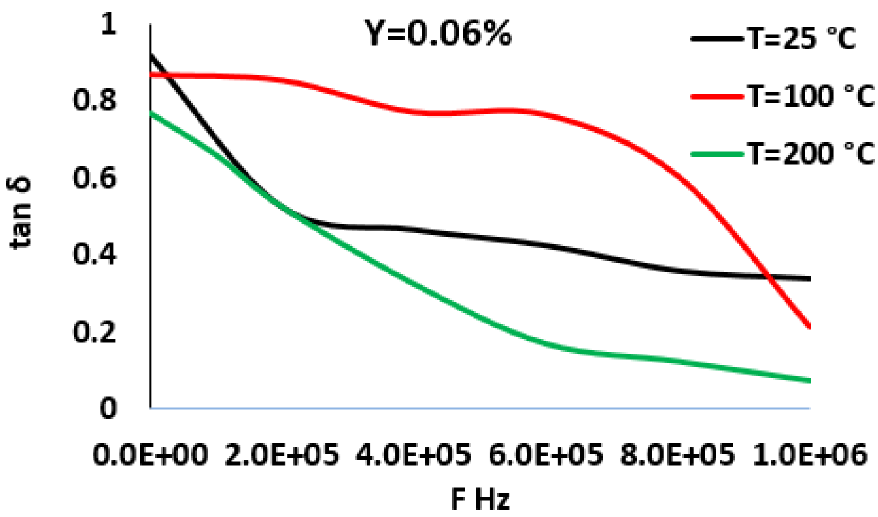

Figure 11. Tangent as a function of frequency for the $PbSr_2Ca_2Cu_{2.4}Zn_{0.6}O$ compound

Figures 12. and **13.** show in general it was discovered that the values of alternating electrical conductivity ($\sigma_{a.c}$) increase as the temperature rises to 200 degrees Celsius. **Figures 12. ,13.** show the values of ($\sigma_{a.c}$) with temperature measurement (R.T-200) C for the base compound and the compound and $PbSr_2Ca_2Cu_{2.4}$ $ZN_{0.6}O$ experimentally.

Higher temperatures are thought to cause ions and the Crystal low to shift, which raises the σa.c values. The DC's conductivity also rises with temperature. The combined effects of the ion jump direction and the space charge effects resulting from an increase in charge carrier concentration are expressed by a rise in dielectric loss with rising temperature (27,28).

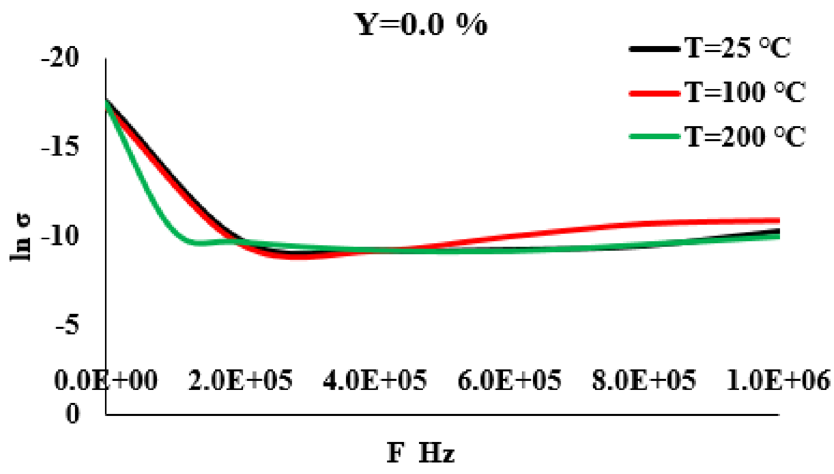

Figure 12. Electrical Conductivity as a function of frequency for the $PbSr_2Ca_2Cu_3O$ compound

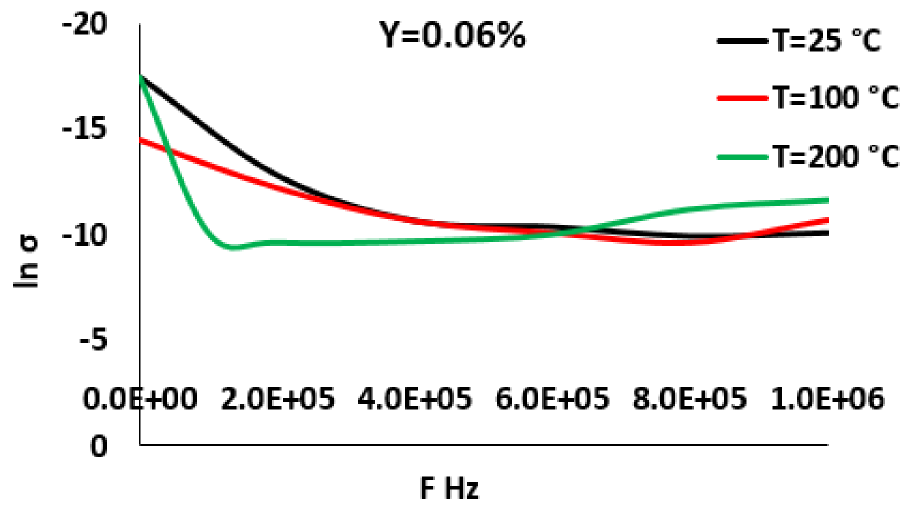

Figure 13. Electrical Conductivity as a function of frequency for the $PbSr_2Ca_2Cu_{2.4}Zn_{0.6}O$ compound.

4. Conclusions

Two crystalloids with dielectric constants (11.23 and 10.30) that were created using the solid-state reaction method are visible in the sample of the basic compound, the compound, and $PbSr_2Ca_2Cu_{2.4}Zn_{0.6}O$, dielectric loss factor (7.76 and 9.45) and tangent loss tanδ (0.69 and 0.91), Alternating electrical conductivity ($\sigma_{a.c}$) $(\Omega.cm)^{-1}$ indicates that the produced samples are suitable for use as electronic substrates and have acceptable temperature stability in their dielectric characteristics, it ranges between (25-200) °C in terms of temperature and frequency (50 to 10^6 Hz). The sample exhibits this characteristic, which allows it to be used at high temperatures.

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None

Conflict of Interest

The authors declare that they have no conflicts of interest.

Ethical Clearance

The project was approved by the local ethical committee at the University of Baghdad.

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