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# Fabrication and characterization of ferroelectric $Ba_{0.6}Sr_{0.4}TiO_3$ thin film for infrared detection application

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Perovskite phase $Ba_{0.6}Sr_{0.4}TiO_3$ thin film has been prepared using sol-gel technique. IR transmittance spectrum shows that the bands are located in the range of 1100 and 400 $cm^{-1}$. These bands could be due to Ba-O-Ti, Sr-O-Ti or $TiO_3$ bonds. The response of $Ba_{0.6}Sr_{0.4}TiO_3$ film to IR radiation has been investigated using capacitance-voltage (C-V) and current density-voltage (J-V) characteristics, the results show the capacitance slightly increase as the frequency of the IR radiation decreases, however, no appreciable change on the leakage current curve is observed.

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*Keywords:* BST, Ferroelectric, FTIR, IR detection

In past few years, barium strontium titanate (BST) has been proved to be on of the most suitable materials for many applications such as ferroelectric field effect transistors (FeFET), dynamic access random memory (DRAM) and microwave (MW) applications due to the desirable properties such as high permittivity, relatively low dielectric loss tangent, and composition-dependent Curie temperature, which can be controlled by adjusting the barium-to-strontium ratio [1, 2]. In this letter, the response of BST thin films for infrared (IR) radiation has been investigated in order to study the ability of using BST in IR detection application. For this matter, ferroelectric $Ba_{0.6}Sr_{0.4}TiO_3$ thin film has been fabricated as Metal-Ferroelectric – Insulator - Semiconductor (MFIS) configuration using sol-gel technique. The film response for IR radiation has been studied using capacitance-voltage (C-V) and leakage current density (J-V) characteristics.

BST solution was prepared using barium acetate, strontium acetate and titanium (IV) isopropoxide as starting material, the preparation details for the solution can be found somewhere else [3]. P-type Si (100) wafer was cleaned using RCA cleaning technique and diluted hydrofluoric acid in order to remove any native thin oxide layer on the Si surface. After cleaning the surface, 20 nm layer of $SiO_2$ was grown on the wafer surface using dry oxidation process at 1000 °C. $Ba_{0.6}Sr_{0.4}TiO_3$ thin film was deposited on the prepared substrate via spin-coater at 5000 rpm for 20 s, followed by baking at 200 °C for 10 min to vaporize any organic solvent and then heating at 500 °C for 20 min in an $O_2$ atmosphere. Finally, the film was annealed at 900 °C for 2 h in an $O_2$ atmosphere. The film thickness was measured and it is found to be 135 nm. The crystallization of the film was determined using X-Ray diffractometer (XRD) with CuKα radiation source (λ = 1.54 Å), operated at a voltage 40 KV and current of 40 mA. Fig. 1 shows XRD patterns of $Ba_{0.6}Sr_{0.4}TiO_3$ film. It can be seen that the film is well-crystallized with dominant peak corresponding to (110) reflection, the measured a-axis and c-axis lattice parameters are equal, a = c = 3.965 Å, indicating that the film is crystallized with the cubic Perovskite structure phase.

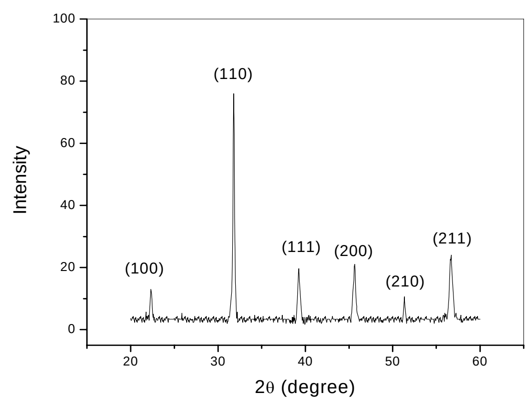



*Fig. 1. XRD patterns of $Ba_{0.6}Sr_{0.4}TiO_3$ film annealed at 900 °C for 2 h.*

In order to measure the ferroelectric and dielectric properties for $Ba_{0.6}Sr_{0.4}TiO_3$ film, $Al/BST/Pt/SiO_2/Si$ (MFMIS) structure was prepared. The top electrode of area $7.85\times10^{-3}$ $cm^2$ was deposited on top of the film using a shadow mask. The ferroelectric hysteresis loop of the MFM capacitor was measured by the Sawyer–Tower circuit with a 50 Hz sinusoidal wave. A typical hysteresis loop is shown in Fig. 2. The value of the remnant polarization of the film is 0.82 μC/$cm^2$.

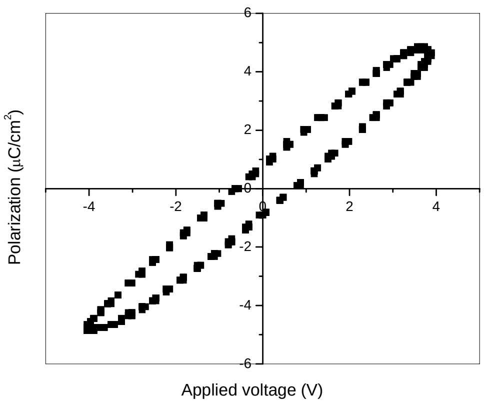
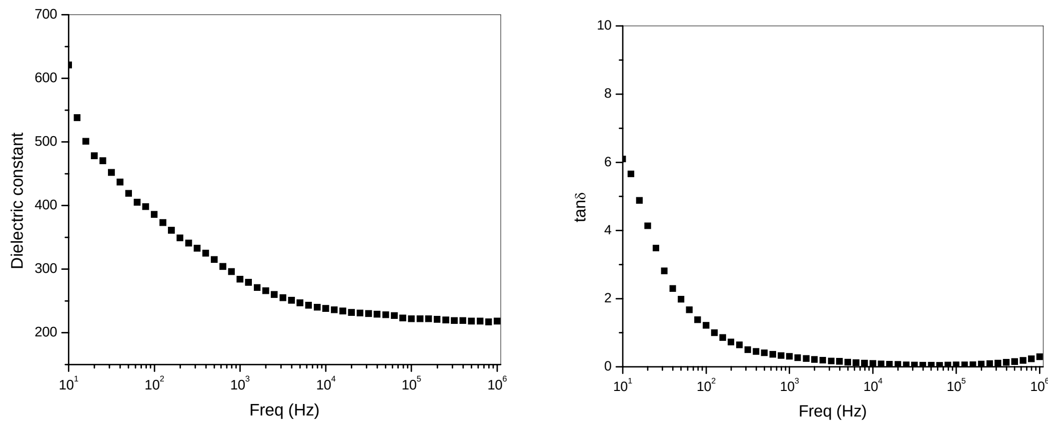



*Fig. 2. Ferroelectric hysteresis loop for $Ba_{0.6}Sr_{0.4}TiO_3$ film.*

The dielectric characteristics were measured by impedance/gain-phase analyzer (Solartron 1260) in the frequency range of 10 Hz to 1 MHz at room temperature. Fig. 3(a) shows the frequency dependent plot of the dielectric constant. It is observed that the value of the dielectric constant decreases as the frequency increases and it attains a constant limiting value. The measured dielectric constant of the film at $10^5$ Hz is 225. The high value of dielectric constant at low frequencies can be explained as the accumulation of charges at the grain boundaries and at the interfaces between the sample and the electrodes, i.e., space charge polarization [4]. The variation of dielectric loss with frequency is shown in Fig. 3(b). tan δ is the energy dissipation in the dielectric system, which is proportional to the imaginary part of dielectric constant ε". The value of the dielectric loss of the film at $10^5$ Hz is 0.054. The ferroelectric and dielectric measurements indicate that the film used in this study has relatively good quality.




(a) (b)

*Fig. 3. Variation of the dielectric constant (a) and dielectric loss (b) with frequency for MFM capacitor.*

The infrared transmittance spectrum for the film was measured using Fourier Transform Infrared Spectrophotometer FTIR (PerkinElmer, Spectrum 400) in the wave number range of 4000 to 400 $cm^{-1}$. In order to achieve this spectrum, a spectrum for each of $SiO_2$/Si substrate and BST/$SiO_2$/Si film were measured, and then they were subtracted. The final IR spectrum for $Ba_{0.6}Sr_{0.4}TiO_3$ film is shown in Fig. 4. The entire spectrum can be divided into two main regions, namely, from 400 to 1100 $cm^{-1}$ and from 1100 to 4000 $cm^{-1}$. It is known that the absorption peaks which appear below 800 up to 400 $cm^{-1}$ are caused by the different kinds of metal oxygen bonds present in the sample; whereas, the absorption peaks appearing beyond 800 $cm^{-1}$ are due to the different kinds of organic legands [5]. It can be observed from the figure that the bands are located in the range of 1100 and 400 $cm^{-1}$. These bands could be due to Ba-O-Ti, Sr-O-Ti or $TiO_3$ bonds. There are no appreciated peaks observed in the range of greater than 1100 $cm^{-1}$, this is attributed to the high annealing temperature for the film which is able to vaporize any kind of organic solvent.

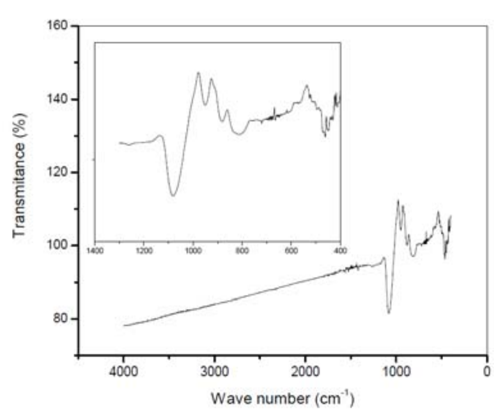



*Fig. 4. FTIR spectrum of $Ba_{0.6}Sr_{0.4}TiO_3$ film annealed at 900° C for 1 h.*

In order to study the effect of IR radiation on the electrical properties of the film, a top electrode of donut shape and total area of $7.06\times10^{-3}$ $cm^2$ was fabricated on $BST/SiO_2/Si$ sample using the left-off process, where Al was used as a metal and photoresist as a sacrificial layer. The backside of the silicon substrates was etched using diluted hydrofluoric acid and it was metallized by depositing a 140 nm thick Al layer. Thus, the electrical measurements were carried out on $Al/BST/SiO_2/Si/A1$ (MFIS) capacitor structures. The capacitance-voltage (C-V) and the current-voltage (I-V) curves were measured using Keithley 4200 semiconductor parameter analyzer in the presence of IR radiation, FTIR was used as a source.

Fig. 5 shows the C-V characteristics for $Al/BST/SiO_2/Si$ junction at different frequencies of IR radiation. The frequency values represent the band frequency in Fig. 4. The figure shows that the capacitance values increase as the film is exposed to IR radiation. This increment could be due to the increase of the dielectric constant during irradiating the sample to the IR source. It is well known that the IR radiation induces atomic vibrations in molecules and crystals, and polarization processes result from the dipolar moment induced by distortion of the positions of nuclei. These polarization processes are called atomic polarization [6]. When the frequency of the IR radiation agrees to the resonance frequency of the material, i.e., a band occurs in the IR spectrum in Fig. 4, the atomic polarization of the material becomes more active, which in turn increases the dielectric constant value. However, it can be observed from Fig. 5 that capacitance values increase as the frequency decreases. That is attributed to the nature behavior of the dielectric constant with frequency. As the frequency increases the dipoles become unable to follow the applied field [7], thus lower dielectric constant will be obtained. Furthermore, the C-V curve as the sample irradiate to whole spectrum used in this study shows the maximum increment. This could be due to different atomic polarization magnitude resulting from different type of molecules within the film.

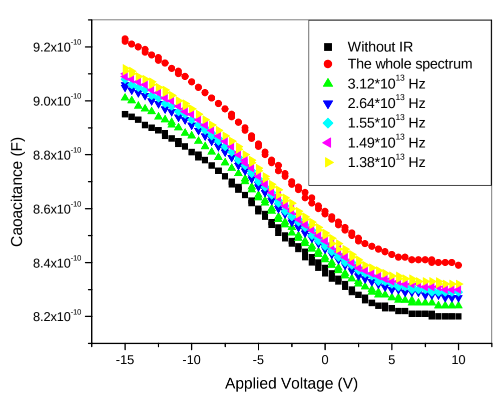



*Fig. 5. C-V characteristics for $Ba_{0.6}Sr_{0.4}TiO_3$ thin film at different frequencies of IR radiation.*

Fig. 6 shows the leakage current density (J) of the film used in this work as a function of applied voltage at different values of the IR radiation frequencies and for voltage swept from zero up to 5 V. It can be seen that at all IR frequencies the leakage current density is of order $10^{-8}$ $A/cm^2$ at applied voltage of 5 V. These values of the current density are relatively low, leading to good interfaces situation. Furthermore, there is no appreciable difference in the leakage current density with the IR radiation is observed.

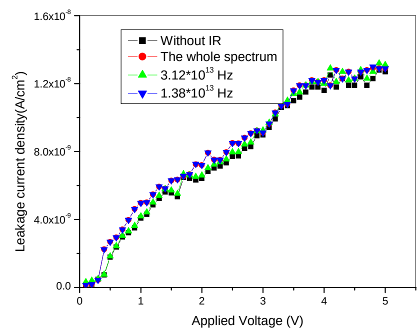



*Fig. 6. Leakage current density (J) as a function of applied voltage (V).*

In summery, perovskite phase $Ba_{0.6}Sr_{0.4}TiO_3$ thin film with relatively good ferroelectric and dielectric properties has been prepared using sol-gel technique. The response of $Ba_{0.6}Sr_{0.4}TiO_3$ film to IR radiation has been investigated using C-V and J-V characteristics, the results show the capacitance values slightly increase as the frequency of the IR radiation decreases, however, no appreciable change on the leakage current curve is observed. C-V characteristics can be used to study the response of the BST for IR radiation. BST thin films are able to be used in IR detection applications.

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