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Investigation on Magneto Dielectric Properties of $Y_{0.95}Sr_{0.05}MnO_3$/SNTO Thin Film Device

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Abstract

In this communication, $Y_{0.95}Sr_{0.05}MnO_3$ (YSMO) thin film having a 300nm thickness, deposited on single crystal Nb:$SrTiO_3$ (SNTO) substrate by pulsed laser deposition (PLD) technique, has been studied for its magnetodielectric and anisotropic properties. XRD measurement was performed for the YSMO/SNTO film which reveals the single phasic nature without any detectable impurity within the measurement range studied. To understand the possible anisotropic magnetodielectric behavior of the presently studied YSMO/SNTO film, frequency (20Hz - 2MHz) dependent dielectric constant was recorded at room temperature under zero field and 1T applied magnetic field dependent dielectric constant was recorded with two aspects: (i) field H parallel to the film's ab plane and (ii) field H perpendicular to the film's ab plane. Variation in the dielectric constant, as well as a magnetodielectric effect with applied magnetic field and field direction, has been discussed in detail.

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Keywords: PLD, Manganites, Dielectric, Magneto anisotropy

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1. Introduction

Rare earth manganites are enormously popular for their profound properties like colossal magnetoresistance (CMR) phenomenon. Most of the manganites possess crystal structure of perovskite family with its basic crystal formula: ABO_3. Manganites have fundamental properties like metal to insulator transition temperature T_P, ferromagnetic to paramagnetic transition at temperature T_C, charge ordering (CO), orbital ordering (OO), spin ordering (SO), etc [1-4]. Manganites possess four degrees of freedom, 1-Spin, 2-Charge, 3-Lattice, 4-Orbital; by altering any of these by means of doping, pressure, radiation, heat, irradiation, implantation, etc. one can modify their different properties. Doping at A-site by mono or di-valent element alters valance state of manganese ions in manganites and it also introduces structural strain in the materials, due to size variance of ionic radii. This type of strain has very importance when material is deposited on single crystal substrate by thin film deposition methods. Techniques used for deposition are Chemical Vapor Deposition (CVD), Pulsed Laser Deposition (PLD), Atomic Layer Deposition (ALD), Chemical Solution Deposition (CSD), etc. There is strain present at interface between deposited film and single crystal substrate as compared to parent material. Due to mismatch between their lattice parameters, electrical and magnetic properties can be modified. K.N. Rathod et al [5] have done dielectric study on nanostructured $Y_{0.95}Zr_{0.05}MnO_3$. Gadani et al [6] have studied the irradiation on YSMO/SNTO device for dielectric properties due to structural modifications by irradiation of different flounce. There is role of A-site doping of similar valance state rare earth element in governing the structural and dielectric properties, as reported by Udeshi et al [7], Size induced alteration in dielectric properties of bulk $Y_{0.95}Ca_{0.05}MnO_3$ have been studied by Shah et al [8]. Magnetoelectric properties of pure $YMnO_3$ have investigated by Joshi et al [9]. Rare-earth manganites have many practical applications such as resistive switching device [10], magnetic tunnel junction [11], field effect transistor [12], etc.

In this communication, we have studied anisotropic magneto-dielectric properties of $Y_{0.95}Sr_{0.05}MnO_3$ (YSMO) film of 300nm, which is deposited on n-type semiconducting single crystal $Nb{:}SrTiO_3$ (SNTO) substrate by PLD method. Alteration in deictic constant with respect to direction of applied magnetic field (1T) has been tried to understand by dielectric relaxation model and Universal Dielectric Response (UDR) model.

2. Experimental Detail

Highly pure precursors of yttrium oxide (Y_2O_3), strontium carbonate ($SrCO_3$), manganese dioxide (MnO_2) ware used in exact stoichiometric proportions for synthesizing of single phasic polycrystalline target by solid state reaction method (SSR). Well mixed precursors were calcinated for 3h, sintered at different temperatures between 950-1350°C for different time duration between 24-72h. $Y_{0.95}Sr_{0.05}MnO_3$ (YSMO) target was deposited by Pulsed Laser Deposition (PLD) technique on n-type semiconducting single crystal $Nb{:}SrTiO_4$ (SNTO) substrate. X-Ray Diffraction (XRD) measurements were performed at room temperature to identify structural phases by using Cu Kα radiation source. Dielectric measurements were performed in frequency range of 20Hz to 2MHz at room temperature with and without magnetic field of 1T. Direction of magnetic field during dielectric measurements was kept parallel and perpendicular to ab-plane of film, respectively, to find magneto anisotropy in YSMO/SNTO thin film device. (See Table 1)

Table 1. PLD deposition parameter of film.

Laser	KrF Excimer
Target	YSMO
Single Crystalline Substrate	SNTO
Laser Energy	~1.80 J/cm
Repetition rate	10Hz
Substrate Temperature	700°C
Oxygen partial pressure	$1*10^{-5}$Torr
Substrate to target distance	5.5 cm

3. Result & Discussion

3.1. Structural Properties

Single phasic growth of YSMO film on single crystal SNTO (100) substrate was identified by XRD measurement. As shown in figure. 1, XRD pattern of YSMO thin film has growth in same orientation as SNTO (*100*) substrate. There is positive value of strain (+1.75%) between deposited YSMO film and SNTO substrate, due to mismatch between lattice parameters of YSMO film and SNTO substrate. Positive value of strain shows presence of tensile strain at the interface. Strain at interface has been calculated by an equation, δ (%) = $[(d_{substrate} - d_{film}) / d_{substrate}] \times 100$, where d_{film} and $d_{substrate}$ is the value of lattice spacing of YSMO film and SNTO substrate, respectively[13, 14].

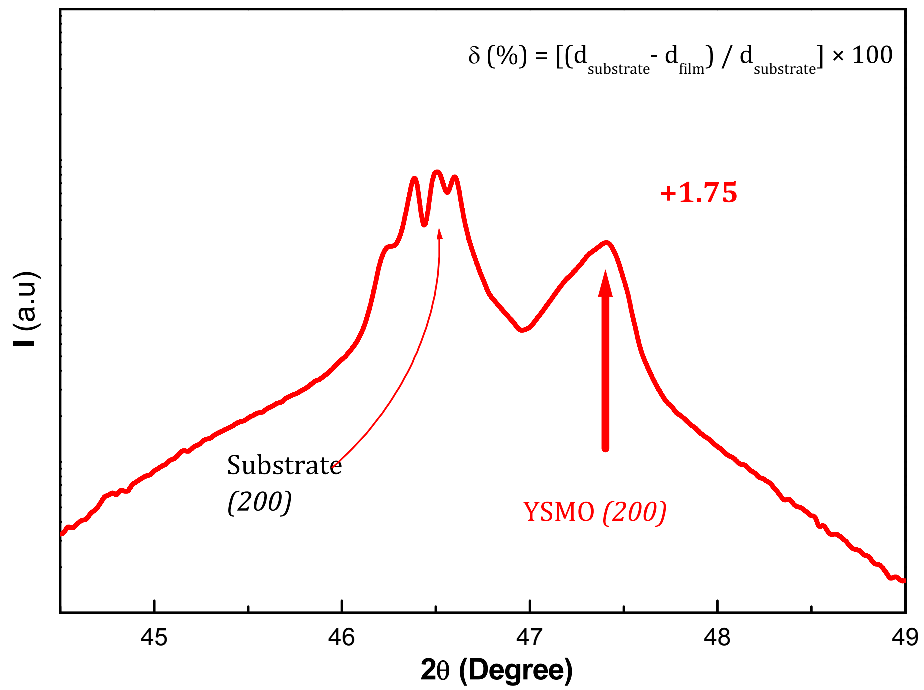

Figure 1. XRD of YSMO thin film with calculated value of strain.

3.2 Dielectric properties

Dielectric constant decreases with frequency, due to delay in alignment of dipoles with respect to changing electric field [15, 16] as shown in figure 2. Dielectric constant is found to increase upon an application of magnetic field in the parallel direction to the ab film plane. This can be understood as: when magnetic field is applied parallel to the ab film plane, large number of MnO_6 octahedra gets affected. As a consequence, magnetostriction effect is introduced [17, 18], as a result of which the affected MnO_6 octahedra realize the non-centrosymmetry through its structure distortion (which has been accommodated within the structure by application of external magnetic field of 1T). This dissertation can be expected by a slight variation in the position of magnetic ions in the lattice. This, as a consequence, incorporates microstrain (stress) in the structure that enlaces the polarization of the material. In this context, dielectric is found to be enhanced upon application of 1T magnetic field in the parallel direction of ab film plan. The similar effect can also be expected when the external magnetic field is applied to the perpendicular direction of ab film plane. Though, number of affected MnO_6 octahedra is less for this later case as compared to parallel direction, the enhancement in dielectric constant is found to be less for perpendicular direction, compared to parallel one. It is note that at lower frequency region (below 0.2 MHz) no remarkable variation in the dielectric constant has been observed which can be attributed to the fact that required electric field (ac) intensity to introduce magnetostriction effect in the film may be higher than this frequency value.

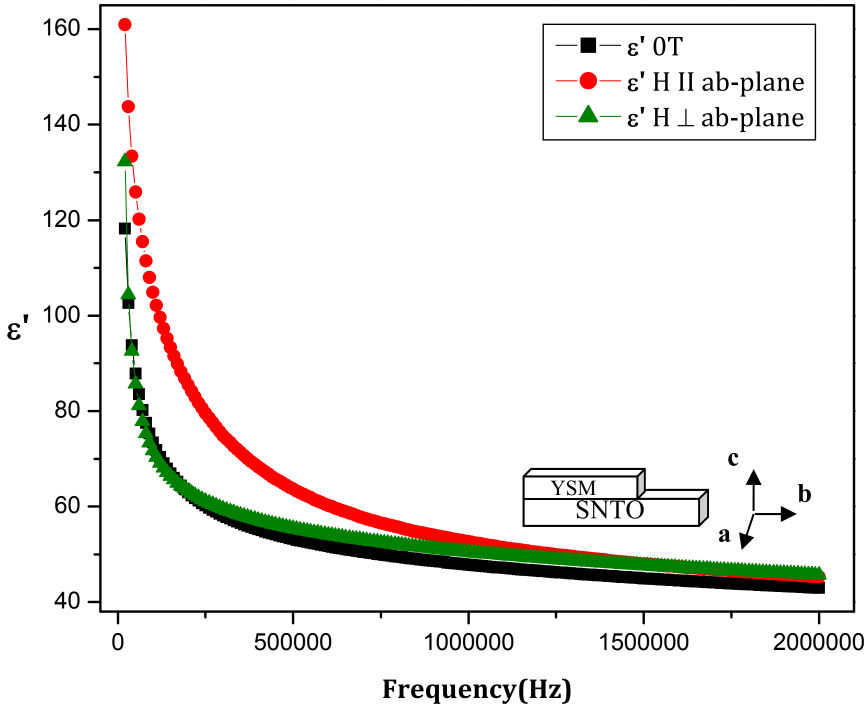

Figure 2. Frequency dependant Dielectric with and without magnetic field

Obtain dielectric behaviour of fig. 2 for zero field and 1T parallel and perpendicular fields have been theoretically fitted using the relaxation model in fig. 3. This model can be expressed as

$$\varepsilon = \varepsilon_\infty + \frac{(\varepsilon_S - \varepsilon_\infty)}{(1 + (j\,f\tau)^{1-\alpha}}$$

Where, ε_∞ and ε_S are the high frequency (2MHz) and static dielectric constants, respectively, τ is relaxation time and α is the measure of the distribution of a relaxation time. It found that above expression/theory has been fitted well with the dielectric data throughout the frequency range studied. Obtain value of τ are 140, 20 and 120 μS for zero field, parallel field (1T) and perpendicular field (1T), respectively. These values can be correlated with the obtain dielectric constant values, shown in Figures 3(a),3(b),3(c), one can find an inverse relation between τ and ε' for YSMO/SNTO device. In addition, α is found to be lesser for parallel direction based field induced dielectric behaviour ~ 0.48 which gets suppressed for perpendicular direction ~ 0.33 follow by α ~ 0.28 for zero field result.

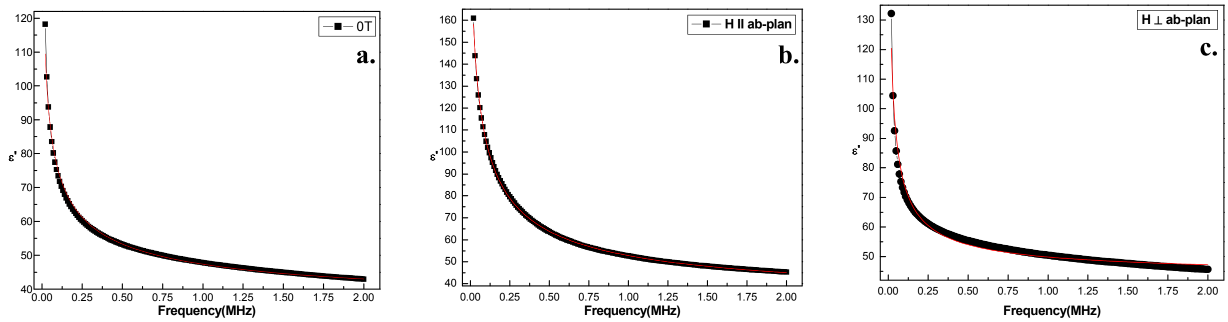

Figure 3. Dielectric relaxation model fitted with a. 0T, b. H ∥ ab-plane, c. H ⊥ ab-plane

For proper understanding of dielectric constant over whole range of frequency, UDR model was tried to fit. There is proper linear fit over whole range of frequency as observed in figure 4(b), where direction of magnetic field is parallel to ab-plane. While, UDR model fitted in two regions as shown in figure 4(a), where magnetic field was set to zero and in figure 4(c), where direction of magnetic field is perpendicular to ab-plane of film. UDR linear fit in two different regions shown different polarization and relaxation mechanisms dominated at different frequency ranges. This can be understood in terms of the magnetostriction effect, which is found to be largest for the field parallel case amongst all above three cases. As a result one can expect some dominant polarization and relaxation mechanisms for parallel case which do not affected by the frequency for complete range studied.

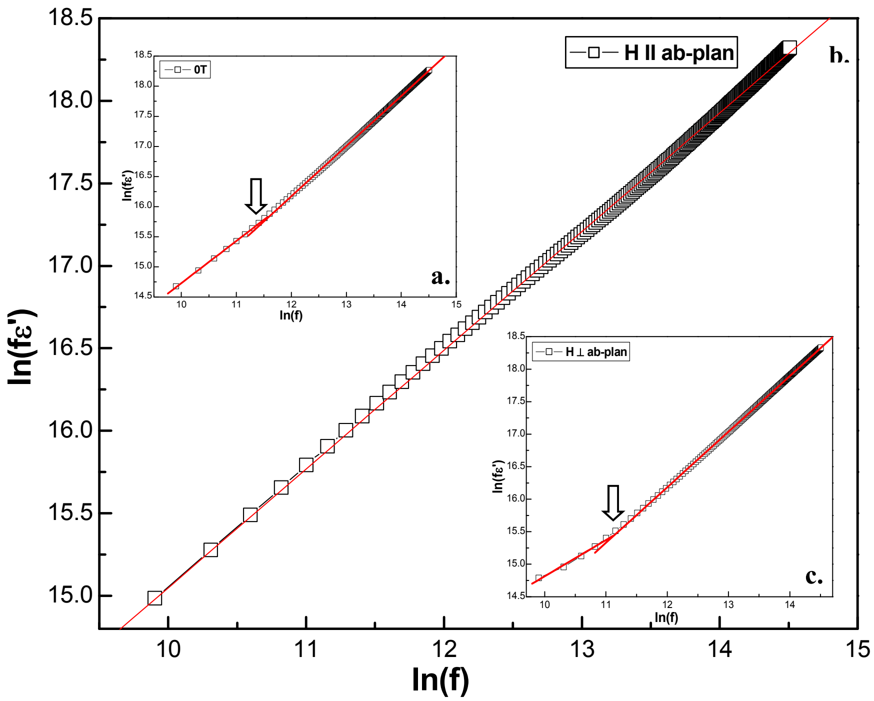

Figure 4. UDR model fitted with **a**. 0T, **b**. H II ab-plane, **c**. H ⊥ ab-plane

Conclusion

The YSMO material, without any detectable impurity, synthesized by SSR method, then film was successfully deposited on single crystal SNTO substrate by PLD film deposition method in oxygen atmosphere. Deposited film is found to be grown in the same orientation as of SNTO substrate which has been identified by XRD measurement. Magnetic field direction dependent dielectric measurements were performed in frequency range of 20Hz to 2MHz at room temperature. Dielectric constant decreases with increase in frequency which has been related to the delay in alignment of dipoles with changing electric field (frequency). There is a strongly affected by field direction due to magnetostriction phenomenon introduced by magnetic field. Dielectric relaxation model was fitted over whole frequency range studied. Values of relaxation time and distribution factor show the dominance of directional dependent magnetic field on dielectric properties of YSMO/SNTO device. UDR relaxation model was fitted on dielectric behaviour over a whole range to understand dominant polarization and relaxation mechanisms.

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