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Studies of thin film ferroelectrics with charge-compensated substitutions in BST

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ABSTRACT

Thin films were prepared from bulk targets by pulsed-laser deposition techniques. The targets were composed of $Ba_{0.6}Sr_{0.4}TiO_3$ with charge-compensated substitutions for Ti^{4+}. Results of the dielectric characterization measurements will be discussed and compared to the results of similar measurements in bulk materials with the same composition.

INTRODUCTION

Temperature dependence of thin film dielectric constants for $Ba_{0.6}Sr_{0.4}TiO_3$ (BST) and similar materials are of interest for frequency-agile applications due to the low voltages required to change capacitance and potential for adjustments to impedance for the purpose of matching properties to circuits in microwave devices. The temperature-dependent dielectric constants are typically broadened relative to those for the bulk samples [1]. This paper describes studies of thin films of $Ba_{0.6}Sr_{0.4}(YTa)_yTi_{1-2y}O_3$ which build on the successes of reduction in sensitivity to temperature variation for both dielectric constant and tunability in the bulk material $Ba_{0.6}Sr_{0.4}(YTa)_yTi_{1-2y}O_3$ compared to BST [1]. Using $Ba_{0.6}Sr_{0.4}(YTa)_yTi_{1-2y}O_3$ films deposited by pulsed-laser deposition and characterized by x-ray diffraction analysis, capacitance measurements, and estimated dielectric constants, the potential of these thin-film materials for device applications is studied.

EXPERIMENTAL DETAILS

Targets of $Ba_{0.6}Sr_{0.4}(YTa)_yTi_{1-2y}O_3$, $0 < y \leq 0.04$ and a comparison sample of $Ba_{0.6}Sr_{0.4}(AlTa)_{0.03}Ti_{0.94}O_3$ were synthesized as described in [1] and references therein. Using a KrF laser, the samples were pulsed-laser deposited onto MgO(100) substrates that were heated to 700 °C or 750 °C in 350 mTorr O_2. Subsequently, the samples were cooled to room temperature in ~ 700 mTorr O_2 atmosphere. For selected samples, a pre-deposition calibration was made using a shadow mask. Then thickness was measured using a Tencor P-10 profilometer which was used, along with the number of laser shots, to calibrate the deposition rate. In this way, the average thickness of deposited films was determined to be 0.5 μm. The θ-2θ x-ray diffraction spectrum for Cu Kα1 radiation was obtained for selected samples. Using the log plot of the results the 200 and 400 peaks for the MgO(100) substrate were identified. Due to the limited number of (h00) lines for the films, it was not possible to determine the lattice constant with great accuracy. However, peaks consistent with (100), (200), and (400) BST were identified, and the lattice constants were nominally the same as bulk BST. Using electron beam evaporation, interdigitated capacitor structures (IDC) were deposited onto the films. The structures had fingers of 150 μm width, 200 μm length, and 5 μm gap. The capacitance was then measured at 1 MHz in the temperature range -75 °C $\leq$ T $\leq$ 60 °C using an applied dc bias of V $\leq$ 30 V.

DISCUSSION

The exact method for obtaining the dielectric constant involves the use of conformal mapping techniques as discussed in [2] and references therein. For the IDC structure used in this work, we assume that the electric field is nearly uniform and mostly confined to the gap area between the fingers of the IDC. The expression relating the capacitance to the dielectric constant can then be reduced to

$$C = \frac{\varepsilon_0 \varepsilon \cdot A}{d}, \tag{1}$$

where A is the area given by the film thickness multiplied by the length, L (see Fig. 1), and the d = b (see Fig. 1) is the gap between fingers.

The dielectric constant of BST with charge-balanced substitutions, $y \leq 0.04$, of YTa is shown in Fig. 2. These are found to be significantly lower relative to the bulk values for similar y [3]. The dielectric constant of the $y = 0.01$ thin film ($T_c \sim -20$ °C) shows broadening similar to that typically observed for BST depositions on $LaAlO_3$ or MgO substrates [4] and was found to be comparable to that of the $y = 0.03$ bulk sample. For $y = 0.02 - 0.04$, the dielectric constant is quite low and extremely broadened so that, in the temperature range of measurement, no ferroelectric T_c was observed. The similarity in magnitude of the dielectric constant curves for

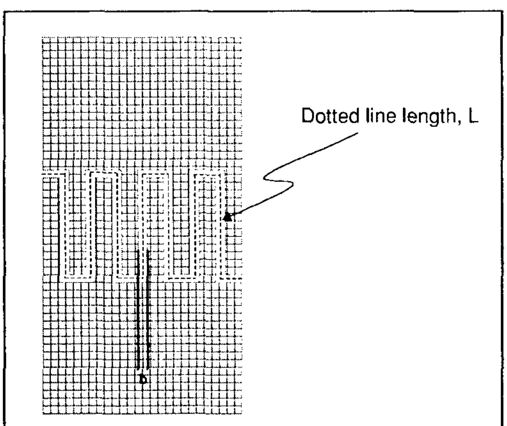

Figure 1. Dimensions of the interdigitated capacitor (IDC) structure that are used to estimate the dielectric constant.

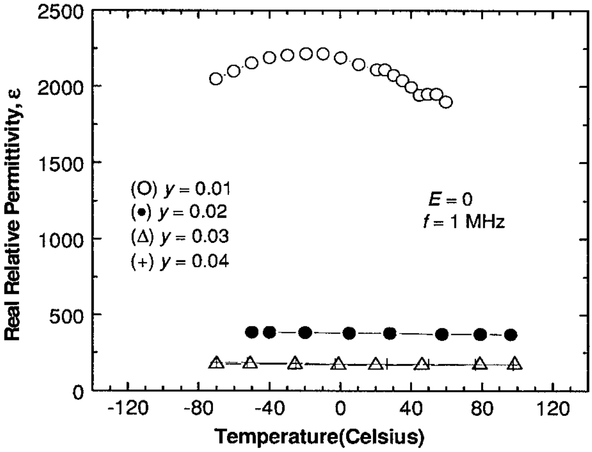

Figure 2. Dielectric Constant vs Temperature for $Ba_{0.6}Sr_{0.4}(YTa)_yTi_{1-2y}O_3$, for $0 < y \leq 0.04$.

the $y = 0.03$ and 0.04 films implies that, near these concentrations, a lower limit is achieved in the dielectric constant of ~ 200. Tunability measurements were also attempted, but capacitance changes were only obtained for the $y = 0.01$ sample (Fig. 3). The tunability of the $y = 0.01$ sample at 6 V/μm over the temperature range –75 °C ≤ T ≤ 60 °C was ~ 20 % - 32 % at 6 V/μm (applied voltage of 30 V and gap of 5 μm) which gives a range of the electric-field normalized

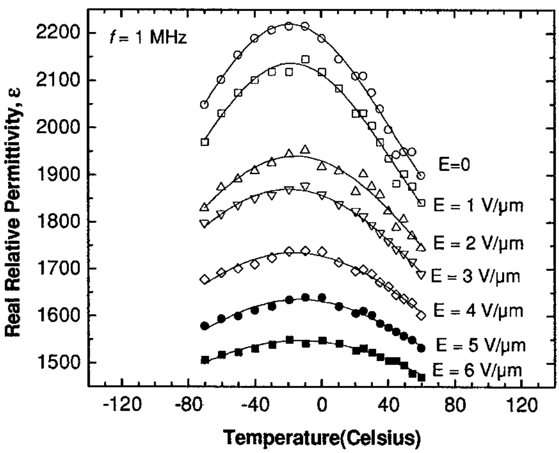

Figure 3. Variation of dielectric constant in $Ba_{0.6}Sr_{0.4}(YTa)_{0.01}Ti_{0.98}O_3$ for $0 \leq E \leq 6$ V/μm.

value of 3.3 - 5.3 %–μm/V. The figure of merit is estimated to be ~ 31 °C–μm/V, comparable to the values reported for bulk $Ba_{0.6}Sr_{0.4}(YTa)_yTi_{1-2y}O_3$ samples with $0 \leq y \leq 0.10$ sintered at 1450 °C ≤ T ≤ 1550 °C discussed in Reference [3]. A similarly deposited $Ba_{0.6}Sr_{0.4}(AlTa)_{0.03}Ti_{0.94}O_3$ sample with T_c ~ -60 °C had a peak dielectric constant, tunability range, and figure of merit of 975, 1.3 - 4.5 μm/V and 22.6 °C-μm/V, respectively.

CONCLUSIONS

$Ba_{0.6}Sr_{0.4}(YTa)_yTi_{1-2y}O_3$ films with $0 < y \leq 0.04$ have been successfully deposited on MgO(100) by the pulsed-laser deposition technique. The reduction in dielectric constant with increase in y mimics that of similar bulk samples, except it reaches an apparent minimum of ~ 200 for $y = 0.03$ and 0.04. Only the $y = 0.01$ film has a measurable capacitance change due to applied bias $V \leq 30$ V. The figure of merit is comparable to those obtained for bulk samples of $Ba_{0.6}Sr_{0.4}(YTa)_yTi_{1-2y}O_3$ with $0 \leq y \leq 0.10$ sintered at temperatures in the range 1450 °C ≤ T ≤ 1550 °C.

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