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Effects of DC and AC electric field on the dielectric properties of PZT thin films

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Abstract – This work reports studies on the structural and dielectric properties of $Pb(Zr_{1-x}Ti_x)O_3$ (x = 0.47 and 0.50) thin films prepared by chemical method. Films were deposited on Pt/Ti/SiO2/Si(100) substrates and crystallized at 700°C for 1h. The nonlinear dielectric properties were obtained by using the measurements of the dielectric permittivity of the material as a function of the AC and DC "bias" electric field amplitude in the frequency range 100 Hz-1MHz at room temperature. The ε-E curves obtained for the ($Pb(Zr_{0.53}Ti_{0.47})O_3$ (PZT47) and $Pb(Zr_{0.50}Ti_{0.50})O_3$ (PZT50) thin films measured at 100 kHz under a small AC signal-test and the DC bias a typical butterfly curve.

Thin-film processing is quite important for the development of the miniaturization of electronic devices with low consumption of energy (low operating voltage). In this case, functional materials with desired properties are required for applications at a submicron level or less. Thin films processing techniques have also been receiving great attention for applications in semiconductor memories, optoelectronic devices, electronic components, display devices, magnetic devices, sensors and emerging areas. Low-temperature thin-film processing also requires precise control of chemical composition and high crystallinity. The various techniques available today for the fabrication of thin films are noticeably more varied in type and sophistication than those of several decades ago. Structural and thermal properties of PZT thin films prepared by chemical method have been reported previously [1]. The aim of this work is to investigate the structural and dielectric properties of the $Pb(Zr_{1-x}Ti_x)O_3$ (x = 0.47 and 0.50) thin films in a wide frequency range at room temperature. The non-linear dielectric properties of PZT thin films were investigated by the measurements of the dielectric permittivity as a function of the AC driving fields. The dependence of the dielectric permittivity on the AC and DC electric fields of PZT ceramics can be explained by the mechanisms of domain wall in which tetragonal PZT composition are attributed to 180° and 90° domain wall [2]. Although the description of the same phenomena in thin films is more complicated, these information were used as starting point to understand the results obtained for PZT thin films. The AC and DC electric field dependence of the dielectric constant were studied, based on ε-E measurements, in order to understand the polarization process in the PZT47 and PZT50 thin films prepared by a chemical method.

PZT thin films, with the molar composition Zr/Ti = 53/47 and 50/50, were synthesized by using a chemical method. Films were deposited on a $Pt/Ti/SiO_2/Si$ substrate by spin-coating at 6000 rpm for 40 s and crystallized in an electric furnace at 700 °C for 1 hour to obtain a film with ≈ 500 nm in thickness. Top Au contacts were deposited through a shadow mask by sputtering for dielectric measurements. Structural properties of the films were investigated at room temperature by using an x-ray diffraction (XRD) technique with an Rigaku Ultima IV diffractometer, radiation CuKα (λ = 1.5405Å) in the range of Bragg's angles 2θ ($20 \le \theta \le 60$) with a scanning rate of 2°/minute. The dielectric measurements were performed with help of Agilent 4284A LCR meter in the frequency range of 100 Hz–1 MHz. The applied electric field on the dielectric properties is in the range of amplitudes 200 mV–20 V. By using the bias feature of the bridge, a DC voltage could be superimposed as a signal to measure the permittivity at different polarization states.

Polycrystalline, and homogenous of $Pb(Zr_{1-x}Ti_x)O_3$ (x = 0.47 and 0.50) thin films were successfully prepared. Room temperature dielectric properties of PZT47 and PZT50 thin film were studied as a function of ac field at different frequencies. The influence of the ac electric fields on the dielectric properties, both the real and imaginary permittivity, shows dispersion with frequency at high ac electric fields. For x=0.47, the real permittivity was observed to increase from 276.5 to 325.1 at 100Hz with increase in amplitude of the ac electric fields i.e., from 3.3 kV/cm to 300 kV/cm. The effect observed in the real part of permittivity indicates that the permittivity reaches saturation with the increase of the ac electric field. The ε-E curves obtained for the PZT47 films measured at a dc bias featured a typical butterfly curve.

References

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