Piezoelectric and ferroelectric properties of lead zirconate titanate thin films

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The purpose of this research has been to characterize piezoelectric and ferroelectric properties of lead zirconate titanate (PZT) thin films for microelectromechanical systems (MEMS) applications. For systematic and comprehensive analysis of the electromechanical properties, a highly sensitive double beam laser interferometer system and a robust chemical solution deposition (CSD) process have been developed. The piezoelectric, ferroelectric and dielectric response phenomena have been investigated in context with microstructural and texture analysis.

Systematic studies included major influencing variables such as Zr to Ti composition, orientation, thickness effects of PZT films. A highly sensitive double beam laser interferometer system has been developed to accurately characterize the piezoelectric properties. The measured d_{11} value of X-cut quartz sample was approximately 2.2 pm/V, which is within 5% of the table value for the quartz. The resolution and system stability have shown promising potential for characterization of piezoelectric properties even in low magnitude piezoelectric thin films. A chemical solution deposition process based on methanol and alkanolamine system has been developed for PZT thin film preparation. The isolation and control of individual parameter have been achieved without distinct microstructural change. By controlling PZT nucleation on platinum substrates via thermal process and/or substrate type, (111) or (100) oriented PZT films were grown.

The piezoelectric, dielectric, and ferroelectric properties of highly textured

polycrystalline PZT films with Zr/Ti composition have been investigated. Distinct peak of piezoelectric coefficient at the morphotropic phase boundary (MPB) observed in bulk PZT ceramics has not been found in thin film PZTs. From the result of nonlinear behavior between piezoelectric response and ac amplitude, extrinsic contribution (non-180^o domain wall motion) in these films has been found to be negligible, indicating that extrinsic contribution in room temperature dielectric constant is dominated by only 180^o domain wall motion. The semi-empirical phenomenological equation for piezoelectric coefficient has been demonstrated to account very well for the quantitative estimation in these PZT thin films when extrinsic contribution (domain wall motion) is negligible. This equation has been found to be very useful to identify most dominant parameter determining d_{33}. Small deviation between calculated and measured piezoelectric coefficients as well as the dependence of piezoelectric and polarization behavior on the external dc field, i.e., hysteresis loop, have been suggested primarily due to backswitching of 180^o domains. To support this hypothesis, temperature dependence of polarization behavior and poling effects on the dielectric and piezoelectric behavior have been examined. These results have shown that backswitching of 180^o domain is the important factor in a polydomain structure.

The orientation and thickness effect of these PZT films have also been investigated. The results have shown that the effect of polydomain structure should be approached in terms of a tilted polarization axis (misfit grains), interfacial layers, internal bias, defects, microstructure and residual stress. These parameters have been found to affect both intrinsic and extrinsic contributions. Engineering implication for successful incorporation PZT thin films into an electromechanical device is that designing PZT systems for maximization of intrinsic contribution is more important than controlling non-180^o domain wall activity like bulk ceramics.