Improving Reliability in Piezoelectric Films

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Ferroelectric thin films are finding increased usage in a wide variety of microelectromechanical (MEMS) devices, including ink jet printers, adjustable optics, ultrasound transducers, resonators, energy harvesters, etc. One of the keys for development of piezoelectric (PZT) based MEMS devices is understanding reliability, including changes in piezoelectric properties over time (aging) and degradation (time dependent breakdown). There are many possible factors that cause local internal electric fields in ferroelectric films, such as defect dipoles, composition gradients, and Schottky barriers at interfaces. When these fields are randomly arranged, significant aging is observed in piezoelectric property along with pinching of the hysteresis loops. When local electric fields are aligned, piezoelectric properties are very stable and strongly imprinted loops are observed. Of the many mechanisms that could produce these internal fields, the most likely is associated with oxygen vacancies that are often the only mobile ionic defects in material and are responsible for large space charges when they are free to migrate across a sample and pile up at an electrode interface. The objective of this work is to understand the effect of internal field that are associated with oxygen vacancies on the lifetime and degradation characteristics of PZT thin films. In this study, 2% Mn-doped (PMZT) and 2% Nb-doped (PNZT) lead zirconate titanate films with a Zr/Ti ratio of 52/48 were deposited on Pt coated Si substrates by the sol-gel method; all of these films had thicknesses near 0.4 μm. The films were poled at 150°C under an electric field of -240 kV/cm to generate internal field. Then, Highly Accelerated Lifetime Testing (HALT) was conducted to understand the mechanisms governing electrical degradation in PZT films. A polarity dependence of breakdown was found for both Mn and Nb doped PZT films. The lifetimes of both Mn and Nb doped PZT films were higher when the applied field and poling field are antiparallel to each other. This asymmetry in lifetimes is smaller in donor (Nb) doped PZT films than it is for acceptor (Mn) doped PZT films. To understand the polarity dependence of breakdown events and the effect of oxygen vacancies on this difference, Thermally Stimulated Depolarization Current (TSDC) analysis was performed after electrical degradation under electrical field of 400 kV/cm parallel and antiparallel to internal field for 3, 6 and 16h. TSDC results exhibit a single relaxation event around 200°C, associated with oxygen vacancy migration. The activation energy of the oxygen vacancy migration was determined to be 0.7±0.1 eV for PZT films. No TSDC peak was observed for Mn doped PZT films when the applied field and poling field are antiparallel to each other, suggesting that oxygen vacancies were trapped in Mn doped films.