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Fabrication and Characterization of Ultra-thin and Smooth $Pb(Zr,Ti)O_3$ Films for Miniaturization of Microelectronic Devices

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As the miniaturization of microelectronic devices is continued, investigations of the scaling effects in electronic materials like ferroelectrics acquire great practical importance. Because of the use of ferroelectric film in modern nonvolatile random access memories (FeRAM), the size effect on ferroelectricity in thin films is of special interest. Also, increasing demand for ultrahigh density information storage devices has brought about significant interest in the use of atomic force microscopy (AFM) for nanoscopic read/write operations with ferroelectric media.

$Pb(Zr_{0.52}Ti_{0.48})O_3$ (PZT) thin films were fabricated on Pt(111)/TiOx/SiO2/Si substrates at 375℃ by radio frequency (RF) magnetron sputtering. The mixture of (110) and (100) orientations were found in all PZT thin films. However, in-plane grain size increased with increasing film thickness, all films had smooth surface and the r.m.s. roughness of PZT films was in the range of 1 and 1.5 nm. As film thickness increased, decreased residual stress and volume density of PZT films were observed. PZT films become poorly crystallized with decreasing film thickness observed by TEM. The magnitude of maximum displacement from AFM assisted in local piezoresponse hysteresis mode increased from 187.25 μV (9.363 pm/V) in 40 nm to 418.5 μV (20.925 pm/V) in 152 nm. Especially, 40 nm thick PZT films had combined the microstructure of a rosette structure and a poorly crystallized structure surrounding these the rosettes rosette. The poorly crystallized structure had a rougher surface than the rosette structure. The maximum signal amplitude of the rosette and poorly crystallized structures was 216.8 §Å and 68.0 §Å, respectively.

We discussed that the degradation of piezoelectric properties with decreasing film thickness resulted from the crystallinity degradation observed using TEM analysis, size effects derived from grain size and the residual stress evaluated using a laser reflectance method. We also deduced that the degraded piezoelectric response of the poorly crystallized structure in 40 nm thick PZT films should be was related to either nanocrystalline second phases, locally inhomogeneous crystallization or very thin layers between Pt and PZT.