Nanoscale characterization and local electromechanical properties of ferroelectric films for MEMS

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Ferroelectric films are intensively investigated due to their promising characteristics useful for various microelectronic devices ranging from ferroelectric nonvolatile memories to microelectromechanical systems (MEMS). For MEMS applications, the sensing and actuating capabilities of ferroelectric films based on their high piezoelectric and electrostrictive coefficients are of crucial importance. Both are determined by the domain arrangements and polarization switching under applied electric field. Since the feature size of ferroelectric MEMS is currently approaching to the submicron dimensions, the local characterization techniques are becoming increasingly important in order to meet the requirements of microelectronic industry. Due to the ferroelectric nature of the films, the local properties are expected to deviate from their macroscopic average values due to various size effects and influence of defects. Scanning Force Microscopy (SFM) has recently proved to provide high-resolution domain imaging and capability to detect local electromechanical response (either piezoelectric or electrostrictive) directly related to the performance of ferroelectric-based MEMS.

In this presentation, the local piezoelectric and electrostrictive properties of Pb-based ferroelectric films: $Pb(Zr,Ti)O_3$ – PZT, $PbTiO_3$:Ca – PCT, $PbTiO_3$:La – PLT, $PbMg_{1/3}Nb_{2/3}O_3$ – PMN, which are currently the main candidates for ferroelectric MEMS, will be analyzed and compared with the respective macroscopic properties derived using conventional techniques. Grain size effect [1], local hysteresis and non-linearity [2], aging after poling [3] will be, in particular, addressed with the special emphasis on the effect of the SFM instrumentation on the measured response. It will be shown that the inhomogeneous electric field and mechanical stress distributions caused by the SFM tip should be taken into account for the proper interpretation of the experimental data. Local variation of piezoelectric properties of PZT and PCT films will be linked to different orientation, crystallinity, and morphological characteristics of the individual grains. Based on these observations, the difference between the local and averaged macroscopic properties will be accounted for. The effect of local polarization switching by pure mechanical stress exerted by the SFM tip will be demonstrated (see Figure 1) [4, 5]. This effect has been never observed in bulk materials and may apparently limit the functionality of ferroelectric materials in MEMS where mechanical stress is essential. On the other hand, it will be shown that in ferroelectric films mechanical clamping and misfit strain can cause polarization states forbidden in bulk materials and the piezoelectric coefficients of the films can be very high near the expected phase transitions between different phases [6].

In the second part of the talk, the local electromechanical properties of ferroelectric relaxors such as PMN and its solid solutions with $PbTiO_3$ will be discussed. In these materials, the remanent polarization is absent on the macroscopic level resulting in extremely small hysteresis and high temperature stability. It will be shown, however, that on the microscopic scale the properties of relaxors are completely different and the material is actually a composite comprising highly polarized regions/grains with high piezoelectric effect embedded in non-polar matrix (see, Figure 2 as an example). The microscopic nature of relaxor materials and its implications for future nanodevices will be discussed.

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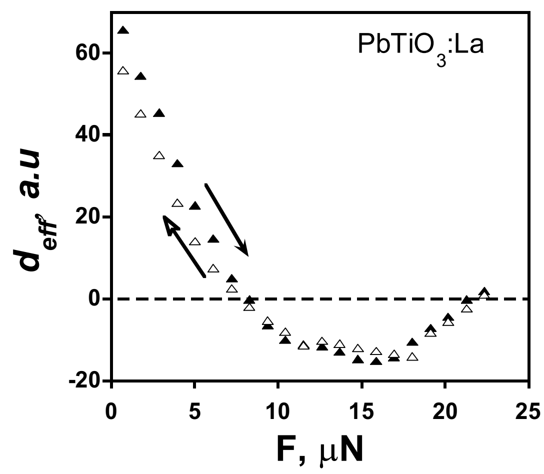

Fig. 1. Effect of polarization switching by the mechanical force exerted by the SFM tip in $PbTiO_3$:La films.

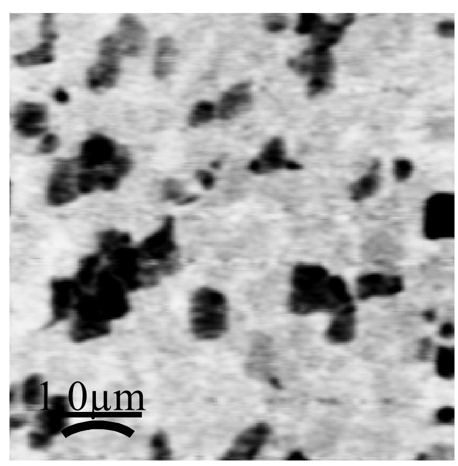

Fig. 2. SFM piezoelectric image of PMN-10%PT relaxor film. Highly polarized areas are presented as dark spots.

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