CHARGING EFFECTS ON FERROELECTRIC SBT THIN FILMS IMAGED BY NONCONTACT ELECTROSTATIC FORCE MICROSCOPY

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The research on SBT ($SrBi_2Ta_2O_9$) thin films is focused on their integration into non-volatile Ferroelectric Random Access Memories (FeRAMs). The functionality of SBT in memories of this category is mainly based on its polarization properties. Noncontact Electrostatic Force Microscopy (nc-EFM) is a technique based on Atomic Force Microscopy and a tool to study these polarization properties on the nano and micrometer scale. In AFM experiments the FeRAM capacitor is imitated by replacing the top electrode with an AFM-tip. Scanning in contact over the surface with a voltage shift between tip and bottom electrode polarizes the SBT in the scanned area. A second step is applied to image the polarization with nc-EFM by detection of the phase shift of an oscillating tip. As a result the total electrostatic field of the polarized area is imaged by this method. However, the electrostatic field after the polarization step has different origins. One is charge which is representative of permanent polarization and reflects the polarization properties of SBT. Another is overcharge due to the polarization step with the AFM tip. Overcharging can easily be mistaken for permanent polarization and distort the polarization characteristics of SBT layers.

To characterize these charging effects, polarized SBT films were exposed to different conditions and the resulting electrostatic fields were imaged by nc-EFM:
SBT films with different remanent polarization were polarized in a $(1{,}5\ \mu m)^2$-field. The resulting electrostatic field of the film with high remanent polarization is fixed due to the strong attractive force between permanent polarization and surface charge. In contrast the electrostatic field on the film with low remanent polarization spreads around the $(1{,}5\ \mu m)^2$ field. It cannot be representative of permanent polarization, it is a kind of overcharge effect (Fig. 1). In a further experiment the electrostatic field of a polarized SBT-film could be reduced drastically by contact scanning with a grounded tip (Fig. 2). A polarization loss due to grounding is not probable. Most of the detected electrostatic field before grounding is assumed to be overcharging and is not attributable to the polarization properties of the SBT layer. Displacement of electrostatic fields by a contact scan with an AFM-tip near grounding potential was also observed. A polarized $(1{,}5\ \mu m)^2$-area (U_{pol} = 4 V) was scanned twice with a tip potential of opposite sign to the polarization voltage of about -20 mV. The scan-area was $(2{,}5\ \mu m)^2$. A part of the former electrostatic field is displaced from the inner $(1{,}5\ \mu m)^2$-area into the larger $(2{,}5\ \mu m)^2$-area under these conditions. The source of the shifted electrostatic field is not permanent polarization but overcharging. Time dependent experiments also showed unexpected results. 22 h after polarization of an SBT film with U_{pol} = 4 V and –4V the electrostatic field was reduced significantly. This result was in contrast to polarization loss of SBT integrated in capacitor units where no reduction of polarization could be observed in such a short period of time. In FeRAM capacitors polarization is retained for years. Annealing polarized SBT films without top electrode also revealed a loss of polarization which is in contrast to SBT characteristics in capacitors with top and bottom electrode. A decrease of the electrostatic field was found after annealing polarized SBT films for 1 h at 80 °C and 100 °C, respectively . At 140 °C the electrostatic field vanished completely (Fig. 3). After immersion in isopropanol a decrease of the electrostatic field on polarized SBT surfaces was observed, in some SBT films no electrostatic filed was detectable after the isopropanol dip.

All experiments showed the important role of charging effects on SBT films for nc-EFM investigations. Overcharging seems to be imaged mainly by this AFM mode because charging which represents permanent polarization is assumed to show a more stable behaviour on SBT films under the conditions described above. But the ability of fixing surface charge on polarized SBT thin films can be used for assessment of their polarization properties. It has to be taken into account that the nc-EFM method only images a mixture of charging, of which one is due to overcharging and one is representative of permanent polarization.

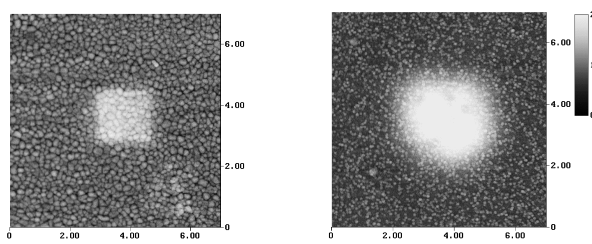

Fig. 1. Electrostatic field of two polarized SBT films with high remanent polarization (left) and with low remanent polarization (right), respectively. U_{pol} = 4V

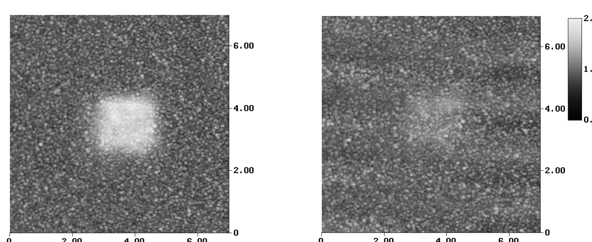

Fig. 2. EFM image of a polarized SBT film after grounding with an AFM tip. Electrostatic field after 2 (left) and 10 grounding scans (right), respectively.

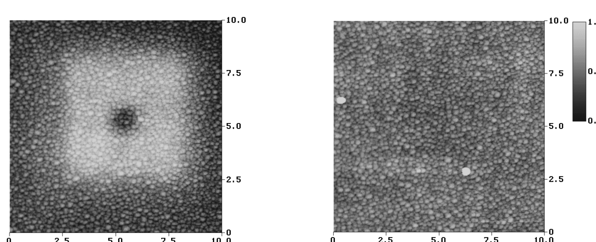

Fig. 3. Decrease of electrostatic fields. EFM reference image (left), EFM image after annealing at 140 °C (right) of a 167 nm thick polarized MOCVD SBT film.