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Domains in Ferroelectric Nanostructures[1]

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Ferroelectric materials have great potential in influencing the future of small scale electronics. At a basic level, this is because ferroelectric surfaces are charged, and so interact strongly with charge-carrying metals and semiconductors - the building blocks for all electronic systems. Since the electrical polarity of the ferroelectric can be reversed, surfaces can both attract and repel charges in nearby materials, and can thereby exert complete control over both charge distribution and movement. It should be no surprise, therefore, that microelectronics industries have already looked very seriously at harnessing ferroelectric materials in a variety of applications, from solid state memory chips (FeRAMs) to field effect transistors (FeFETs). In all such applications, switching the direction of the polarity of the ferroelectric is a key aspect of functional behavior. The mechanism for switching involves the field-induced nucleation and growth of domains. Domain coarsening, through domain wall propagation, eventually causes the entire ferroelectric to switch its polar direction. It is thus the existence and behavior of domains that determine the switching response, and ultimately the performance of the ferroelectric device. A major issue, associated with the integration of ferroelectrics into microelectronic devices, has been that the fundamental properties associated with ferroelectrics, when in bulk form, appear to change quite dramatically and unpredictably when at the nanoscale: new modes of behaviour, and different functional characteristics from those seen in bulk appear. For domains, in particular, the proximity of surfaces and boundaries have a dramatic effect: surface tension and depolarizing fields both serve to increase the equilibrium density of domains, such that minor changes in scale or morphology can have major ramifications for domain redistribution. Given the importance of domains in dictating the overall switching characteristics of a device, the need to fully understand how size and morphology affect domain behaviour in small scale ferroelectrics is obvious. In this talk, observations from a programme of study examining domains in meso and nano-scale $BaTiO_3$ shapes, that have been cut directly from bulk single crystal using focused ion beam milling, will be presented. In general, the equilibrium static domain configurations that occur appear to be the result of a simultaneous desire to minimize both the macroscopic strain and depolarizing fields developed on cooling through the Curie Temperature. While such governing factors might be obvious, the specific patterns that result as a function of morphology are often non-intuitive, and a series of images of domains in nanodots, rods and wires will be presented and rationalised. In addition, the nature in which morphological factors influence domain dynamics during switching will be discussed, with particular focus on axial switching in nanowires, and the manner in which local surface perturbations (such as notches and antinotches) affect domain wall propagation. In collaboration with Alina Schilling, Li-Wu Chang, Mark McMillen, Raymond McQuaid, and Leo McGilly, Queen's University Belfast; Gustau Catalan, Universitat Autonoma de Barcelona; and James Scott, University of Cambridge.

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