Pushing the Performance of Electro-mechanical Thin Films

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Today we are witnessing the advent of the 4th industrial revolution, and are heading towards a largely robotized world. Digital electronics is clearly the enabling technology for establishing the required intelligent machines, however, a lot of analogue electro-mechanical devices are required to add abilities for sensing, actuation, communication, fabrication, and man-machine and environment-machine interfaces. Piezoelectricity plays an important role in any electro-mechanical conversion and is used today in about 100 applications, including for instance ultrasonic imaging and mobile phone communication. The increasing importance of miniaturized devices results in a demand for piezoelectric thin films, which serve as integrated materials in micro and nano devices.

This talk will first introduce the phenomena of piezoelectricity and electrostriction in crystalline matter, and shortly mention their MEMS applications. Whereas the strongest piezoelectric effects are realized in ferroelectric phases of perovskite oxides such as $Pb(Zr,Ti)O_3$ (PZT), wurtzite thin films like aluminum nitride (AlN) are superior at GHz frequency applications because of their higher mechanical quality factors, and their extremely well reproducible and stable properties. AlN is the most preferred thin film material today to realize RF filters for mobile telecommunication working at 2 GHz and above. The most recent innovation in this thin film material is a solid solution with scandium nitride to obtain much larger piezoelectric coefficients. In this case, increasing efforts are made to find out about maximal achievable piezoelectric coefficients, quality factors, and process reproducibility. An interesting competition for property determination is observed between density functional theory and experiment. AlScN will fill a gap between AlN and PZT, and looks interesting for energy harvesting. For actuators, however, PZT or related materials in thin films form will remain the champions in force per voltage figures. An astonishingly high piezoelectric stress of 600 MPa can be produced in PZT thin films with only 30V/µm electric field. At least for thicker films, this limit was found to be governed by the mechanical resistance of PZT. Properties of ferroelectric thin films depend in a complex manner from film texture, grain structure, domain configuration and defects. As illustration, the imprinting of PZT thin films with interdigitated electrodes is discussed, and the question is raised, how we could profit from all our knowledge in ferroelectric domains as acquired by theoretical works and nanoprobe techniques to make domain wall contributions large and controllable above the micron scale in the domain of MEMS devices. A completely different phenomenon than the previously mentioned ones occurs in $(Ce,Gd)O_{2-x}$ thin films, hitherto known as oxygen ion conductor. Particularly prepared films of this material show a giant electrostrictive effect. In contrast to inorganic piezoelectric materials, the transverse effect shows a compressive stress. The effect is rather slow and not yet understood.