

Fundamentals and new developments in piezoresponse force and electrochemical strain microscopies

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Over the last decades the field of polar materials and their applications has been experiencing a significant development. This is partly due to recent processing and nanotechnology advances allowing the synthesis of complex structures of high quality and their patterning with a nm resolution. This is especially true for ferroelectric and multiferroic oxides which polarization had to be studied down to the nano- and atomic scales. Therefore, Piezoresponse Force Microscopy (PFM) proved to be an indispensable tool for high-resolution characterization of polar materials, from simple ferroelectric perovskites to self-assembled biomimetic nanostructures. Versatility of PFM, which allows combined measurements of polarization with other relevant properties such as conductivity or mechanical stiffness, made it a method of choice for addressing various problems of solid state physics and nanotechnology. Standard implementation of this technique where an electrically biased tip scans over the surface to visualize the polarization behavior is now about 20 years old. However, recent years witnessed development of advanced modes of PFM such as resonance-enhanced PFM, switching and time spectroscopies, temperature measurements and so on. This tutorial will briefly cover the physical, instrumental and interpretation aspects of a conventional PFM technique as well as advanced PFM modes for the investigation of the polarization and its dynamics in ferroelectric nanostructures.

Also, the basic measurement and imaging principles used in the Electrochemical Strain Microscopy (ESM) will be discussed. This technique can be applied to image concentration distribution, dynamics of mobile ions, and surface electrochemical activity of ionic conductors with a nm spatial resolution. This method is based on the electromechanical coupling between the ionic motion and surface displacement and is similar to the surface displacement detection measured by PFM. In the ESM mode, the scanning probe concentrates electric field and causes nanometer-scale changes of local concentration of mobile ions through electromigration and diffusion. The amount of local concentration change and, correspondingly, the electromechanical response are determined by local ion concentration and materials properties. Examples of the ESM imaging experiments with Li intercalation electrodes will be shown. We will also discuss possible complexities associated with the method.