Advanced transmission electron microscopy of thin films and heterostructures

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The structural characterization of heterostructures is necessary for better understanding the influence of their atomic structure on physical properties. One of the most informative methods for determining the morphology of heterosystems, the structure of interfaces and the atomic structure of thin layers and defects is a transmission electron microscopy (TEM). New methods of TEM and microanalysis have appeared in the last decade, which open up new possibilities for studying the structure of material. The spatial resolution of TEM with an accelerating voltage of 300 kV, which uses correctors of spherical aberration, achieved a resolution of 0.05 nm. Such a resolution is 3–4 times higher than point to point resolution obtained in TEM without correctors, and that is enough to obtain images with an atomic resolution of projections with low crystallographic indices for most of crystalline materials. Thus, it becomes possible to establish a three-dimensional atomic structure of interfaces. A corrector employed in scanning transmission electron microscopy (STEM) allows us to form an electron probe with a diameter of less than 0.1 nm and use it to obtain images using a High Angle Annular Dark Field (HAADF) detector. This detector registers inelastically scattered electrons intensity of which is proportional to $\sim Z^2$ (Z is an atomic number of element) and allows us to obtain Z-contrast images with an atomic resolution. Unlike the conventional high resolution TEM, which operates in a bright field mode, the use of Z-contrast imaging permits direct interpretation of high resolution images. On another side, such an electron probe can be used for atomic resolution electron energy loss spectroscopy and/or X-ray energy dispersive analysis.

These modern TEM techniques will be illustrated with examples of semiconductor Si/Ge heterostructures, hexagonal $LuFeO_3$ orthoferrite and superlattices based on different coupling between oxygen-ion conducting and insulating materials: CeO_2-YSZ and SDC-YSZ (where SDC is Sm-doped CeO_2 and YSZ is Y_2O_3-stabilized ZrO_2).