Novel method for strain measurements: moiré based technique by specimen design

Cherkashin, N.[1], Denneulin, T.[1], Cours, R.[1] and Hÿtch, M.J.[1]

[1] CEMES-CNRS, France

A bewildering number of techniques have been developed for transmission electron microscopy (TEM), involving the use of ever more complex combinations of lens configurations, apertures and detector geometries. In parallel, the developments in the field of ion beam instruments have modernized sample preparation and enabled the preparation of various types of materials. However, the desired final specimen geometry is always almost the same: a thin foil of uniform thickness. Most of the ingenuity and effort has been applied for the development of microscopy and imaging techniques. We explored changing this paradigm. The idea was to prepare the specimen in such a way as the electron microscopy itself becomes almost trivial and leads directly to the measurement we wish to perform. The specimen becomes the technique. Strain engineering is now an important feature of many research areas, from strained-silicon transistors to ferroelectrics and thermoelectric materials. Therefore, the example we have chosen to illustrate electron microscopy by specimen design is the measurement of strain in thin-films and devices.

For this, we proposed two sample preparation methods of "double lamella" samples that allow the formation of controlled moiré patterns for general monocrystalline structures in cross-section and at specific sites. The principal technique is based on tripod specimen preparation. We have developed also a site-specific method of preparation by FIB which allows a study of devices and localized structures. A cross-sectional lamella is prepared in the desired zone axis and carefully cut into two pieces that are put one upon the other. The upper lamella is displaced laterally until the substrate is superposed with the region of interest and rotated. The art relies in precisely controlling the parallelism of the two adjacent surfaces during superimposition and the in-plane rotation angle that determines the spatial resolution of the technique. The double lamella sample is thinned until reaching a thickness transparent for electrons. Finally, we developed moiré image analysis algorithms using an absolute correction of TEM projection lens and CCD camera distortions that allows strain measurements and mapping with a nanometer resolution and 10^{-4} precision. The technique offers m-large field of view and only needs the most basic conventional transmission electron microscope for the observations [N. Cherkashin et al., "Electron microscopy by specimen design: application to strain measurements", Scientific Reports 7**,** 12394 (2017)]. We will demonstrate quantitative mapping of homogeneous strain fields within fully relaxed or strained $Si_{1-x}Ge_x$ and Si:C layers, as well as inhomogeneous strain fields associated to devices and 3D objects such as single and correlated SiGe/Si and Al(In)GaAsP/GaAs quantum dots. We anticipate that the principle of specimen design can be extended to other types of measurement and to other types of epitaxial samples such as ferroelectric oxides, metals and ceramics.