X-RAY OPTICS FOR A 3-D X-RAY CRYSTAL MICROSCOPE: SUBMICRON DIFFRACTION FROM POLYCRYSTALLINE MATERIALS

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The behavior of polycrystalline materials is strongly influenced by the anisotropic behavior of misoriented crystal grains, by non-uniform stress tensor distributions and by deformation induced stored energy. Here we describe a scanning x-ray microscope that allows high-resolution nondestructive three-dimensional (3-D) investigations of these distributions with submicron spatial resolution. This new class of x-ray instrumentation is based on intense synchrotron sources and advanced x-ray optics. It uses the oldest x-ray technique, white-beam Laue diffraction, to simultaneously collect the Laue patterns from every grain along the incident beam. With a beam size smaller than the typical grain size in most materials, only a few grains are simultaneously illuminated and software and/or special experimental techniques can be used to disentangle the overlapping Laue patterns.

We describe the emerging x-ray optics that allow for these 3-D resolved measurements of crystallographic properties in complex polycrystalline samples. Some of the design considerations and tradeoffs inherent in this new class of instrumentation are discussed. Current devices have demonstrated submicron resolution in three dimensions with sensitivity to grain orientation (<0.01º), strain (<1x10⁻⁴) and deformation. Even more advanced instruments on the horizon will allow for spatial resolution below 10⁻³ µm³.

Several technical advances have been addressed to reach the current state-of-the-art. For example, new ways of preparing high-performance x-ray mirrors have allowed for low-divergence focused polychromatic x-ray beams as small as 0.4x0.5 µm². Similarly, specially designed x-ray monochromators allow for co-linear polychromatic and monochromatic x-ray beams that are focused to the same spot on a sample. Together with advanced software this allows for automated interpretation of overlapping and 3-D resolved diffraction data to recover the full strain tensor for every volume element (voxel) of the sample.

Compared with alternative probes of crystalline phase, texture and strain, x-ray microdiffraction provides for better strain resolution, superior spatial resolution in thick samples and allows for three-dimensional measurements deep below the sample surface. This new capability is certain to revolutionize our understanding of polycrystalline materials.