1. Name of innovation.

3-D x-ray crystal microscope

2. Describe the innovation in a few sentences.

This innovation utilizes microfocusing x-ray optics and computer pattern analysis to determine never-before-seen microscopic properties of structural materials. This “crystal microscope” allows for the first time nondestructive 3-D sub-micron imaging of the shape, crystal orientation, and stress level of individual grains in polycrystalline materials. Just five years ago the successful demonstration of such a device was generally considered an impossible dream by x-ray scientists.

3. How does the innovation work?

The microscope is based on a well-known x-ray diffraction technique called polychromatic Laue diffraction. However the microscope is made possible by utilizing an ultra-brilliant synchrotron radiation source and by pioneering three major and essential technical advances: (1) novel achromatic focusing mirrors that allow the microscope to achieve high spatial resolution with broad spectrum x-ray beams; (2) an innovative x-ray scanning monochromator that allows for the rapid measurement of absolute crystal stresses; and (3) specialized pattern analysis software that determines the type, orientation, and stress of individual grains from overlapping multi-grain x-ray scattering patterns. Since broad-spectrum x-ray diffraction patterns contain detailed information on the structure, orientation, and distortions from each grain illuminated by a submicron x-ray microbeam, collection and analysis of CCD diffraction images allows automated mapping of crystal structure and stress at a spatial resolution that is below the size of grains in most polycrystalline materials.

4. What problem did this innovation solve?

Stress in the form of local (tensorial) forces on individual grains is known to be one of the most important factors determining materials performance and failure. Unfortunately, measurements of local stress and strain (crystal distortion) is difficult in polycrystalline materials and virtually impossible when the grain size is less than 20 µm. This microscope now allows 3-D, nondestructive imaging of the crystallographic evolution of individual grains in structural and electronic materials with sufficient spatial resolution to study real materials evolution and failure mechanisms. Electron microscopy (TEM) has long provided detailed information down to Ångstrom scales on submicron slices of material; scanning electron microscopy (SEM) techniques provide 2-D structure of surfaces. This new x-ray technique fills a longstanding gap in our ability to nondestructively probe the behavior of materials in the three-dimensional form in which they are employed in technological applications of society.

5. Why is it important?

The mechanical behavior of virtually all materials is determined by the 3-D structure and evolution of individual grains on so-called mesoscopic length scales of less than 100 microns. The activity of individual grains below the surface has been invisible until now and such information inferred from post mortem dissection and electron microscopy.

This instrument provides direct subgrain information about the driving forces and response during materials evolution.

6. How will this innovation benefit the average consumer or the public in general?
Virtually all structural materials used in our society are composed of interconnected polycrystalline grains with individual sizes of less than a few tens of microns. This includes metallic materials ranging from bridge girders, to automobile frames and engine parts, to electrical power cables, and ceramic materials from pots to building materials, as well as many of the key components of advanced electronics and microchips. This is the first device capable of studying the local stress and behavior of individual grains in the interior of such three-dimensional materials under stresses similar to those encountered in actual use. Such in-situ information combined with emerging mesoscale theories is needed to replace the expensive and time consuming testing of ever increasing numbers of materials combinations to achieve new technological properties such as stronger materials and faster more reliable computers. The crystal microscope opens a new frontier in materials science with the promise of revolutionizing our understanding of just how materials evolve and fail under actual use. The benefits of this new understanding will touch consumers at every level including more reliable electronic and integrated circuits, stronger lighter more efficient and durable transportation and building materials and more efficient materials for energy production.

7. When was this innovation developed, released or launched?

The development was initiated in 1996, with the first papers describing the theory behind the microscope appearing in 1998, and the first description of an operational three-dimensional x-ray crystal microscope reported in 1999.

8. Is any informatio about this innovation available on the Web? If so, please give a URL: No

9. Who came up with this innovation (list all)?
Gene E. Ice, Bennett C. Larson, Jin-Seok Chung, Nobumici Tamura, Jonathan Z. Tischler, John D. Budai, and Walter P. Lowe.

10. Of these people, who is the person MOST responsible for its development? (We realize that most innovations are the work of a team of people, but we require the name of the ONE researcher, scientist, or engineer most responsible.) If selected as a finalist, the ONE person listed here will be featured in Discover And invited to attend the awards ceremony.

Gene E. Ice