Princeton Instruments
X-RAY GROUP

Application Note #2

Coherent x-ray diffraction imaging

"…a lensless method that is wholly reliant on the use of a high-brilliance x-ray source (e.g., a third-generation synchrotron) and advanced computation"

Introduction

The use of coherent x-ray diffraction imaging is growing rapidly, facilitating numerous discoveries in the realms of biology and nanoscience as well as driving the need for high-brilliance x-ray sources. This note discusses the role of Princeton Instruments PI-LCX and PIXIS-XO cameras in such research.

Coherent x-ray diffraction imaging

In coherent x-ray diffraction imaging, a scientific-grade CCD camera is used to detect the continuous diffraction pattern that results from shining a pink x-ray beam on a noncrystalline specimen (see Figure 1).

Dr. Jianwei Miao, an associate professor in the Department of Physics and Astronomy and the California NanoSystems Institute at UCLA, explains that unlike microscopy techniques, which utilize physical lenses, coherent x-ray diffraction imaging is a lensless method that is wholly reliant on the use of a high-brilliance x-ray source (e.g., a third-generation synchrotron) and advanced computation.

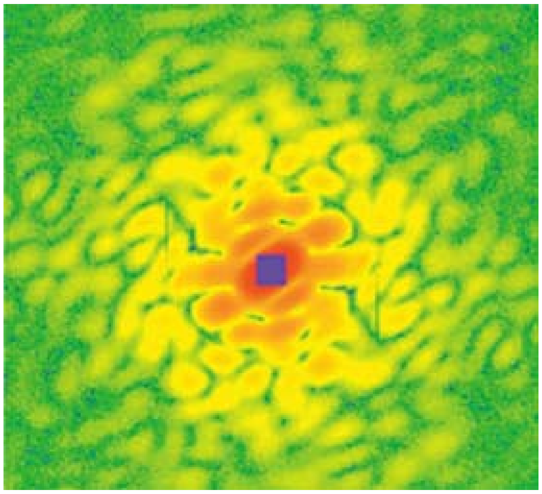


Figure 1. Unprocessed, far-field diffraction pattern acquired during coherent x-ray diffraction imaging experiment. Data courtesy of Dr. Jianwei Miao, University of California, Los Angeles.

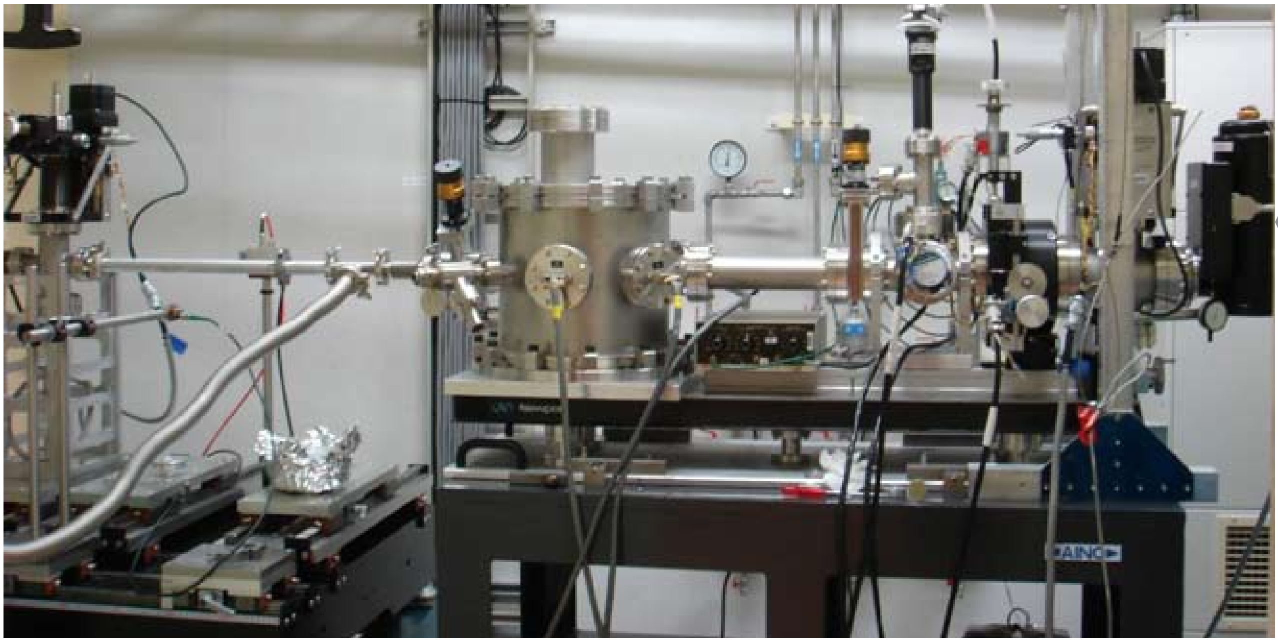
Exposure times from 0.1 to 0.2 seconds are typical for collection of low-resolution intensity data; high-resolution intensity data requires the accumulation of tens or hundreds of frames with exposure times up to a few minutes each in order to ensure wide dynamic range. An algorithm is then applied to reconstruct 2D or 3D images from the quantitative data set acquired. Direct phase recovery is achieved via oversampling.

Post-processing times vary. A single day may be sufficient to create relatively basic 2D images, while more detailed images can take 3 days. As many as 10 days may be needed to produce high-resolution images with extensive 3D information.

Application-specific requirements

In 1999, Dr. Miao became the first researcher in the world to employ coherent x-rays to image noncrystalline specimens in an experimental demonstration.[1] Over the course of the past decade, he has used coherent x-ray diffraction imaging to perform studies involving organic as well as inorganic samples (see Figure 2).

Dr. Miao has relied on advanced x-ray imaging instrumentation from Princeton Instruments since 1996, utilizing several PI-LCX and PI-SX (now known as PIXIS-XO) cameras in his work. Key detection technology criteria for coherent x-ray diffraction imaging include wide dynamic range, high sensitivity, high quantum efficiency, and an array comprising many pixels. Fast readout is also important, as samples are commonly probed by an x-ray beam at rates up to 120 pulses/sec (120Hz) in these experiments.



Princeton Instruments PI-LCX camera

Figure 2. An experimental setup for coherent x-ray diffraction imaging at SPring-8, Japan, currently the most powerful x-ray source in the world. Photo courtesy of Dr. Jianwei Miao, University of California, Los Angeles.

The characteristics of the specimen itself dictate the x-ray energy to be used.[2-9] One research area in which coherent x-ray diffraction imaging is proving to be highly valuable is nanoscience, especially the investigation of nanomaterials and nanostructure (see Figure 3).

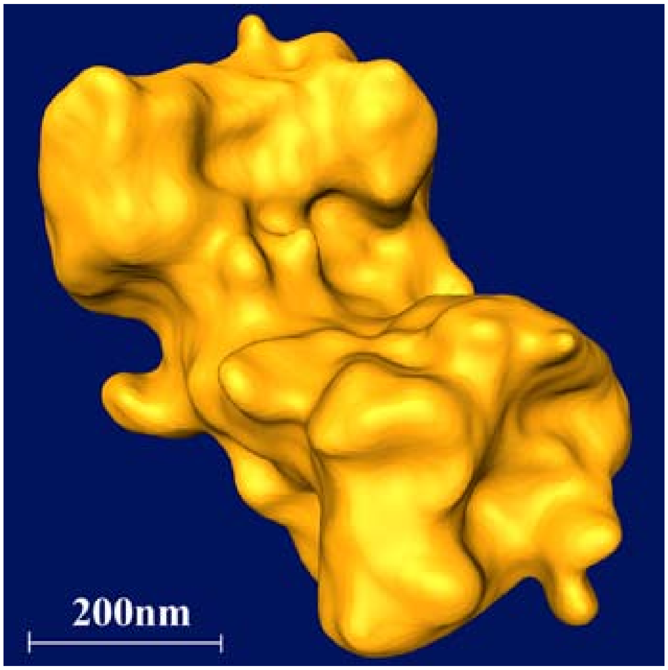


Figure 3. High-resolution 3D image of GaN particle created using coherent x-ray diffraction imaging. Image courtesy of Dr. Jianwei Miao, University of California, Los Angeles.

When imaging nanoparticles, hard x-rays in the 5keV to 7keV range are typically employed to achieve high resolution. Dr. Miao utilizes an LN_2-cooled PI-LCX with a 1340x1300-pixel array to detect the nanoparticle's diffraction patterns, owing to the camera's excellent sensitivity in this energy range.

Another popular area of research that utilizes coherent x-ray diffraction imaging is biology, specifically, the 3D imaging of cells and viruses. Biological specimens contrast more weakly than nanoparticles, so soft x-rays in the 500eV to 1keV range are often used. Dr. Miao utilizes thermoelectrically or LN_2-cooled PI-SX cameras (now known as PIXIS-XO cameras) for imaging biological samples, again due to excellent sensitivity in the energy range of interest.

PI-LCX

High-sensitivity, megapixel PI-LCX cameras from Princeton Instruments (see Figure 4) feature special front-illuminated CCDs and high-resistance silicon to enable direct imaging of low-flux x-rays (<3keV to >20keV). An optional beryllium window design reduces low-energy background, whereas a rotatable conflat flange design provides a UHV hard-metal-seal interface that affords researchers the ability to image x-ray energy as low as 700eV.

Figure 4. Princeton Instruments PI-LCX cameras are optimized for direct imaging of hard x-rays.

The camera's software-programmable, high-capacity or high-sensitivity amplifier allows the PI-LCX to offer x-ray photon counting capabilities with up to 16-bit dynamic range. A thermoelectrically cooled option provides maintenance-free operation, while an LN_2-cooled option ensures extremely low dark current for long exposures.

PIXIS-XO

High-sensitivity, megapixel PIXIS-XO cameras (formerly known as PI-SX cameras) from Princeton Instruments are equipped with special back-illuminated CCDs that lack anti-reflective coating, thus enabling direct imaging of low-energy x-rays (<30eV). A rotatable conflat flange design provides UHV hard-metal seals and the ability to align the CCD.

Figure 5. Princeton Instruments PIXIS-XO cameras are optimized for direct imaging of soft x-rays.

Like the PI-LCX, the PIXIS-XO (see Figure 5) offers researchers x-ray photon counting capabilities with up to 16-bit dynamic range via a software-programmable, high-capacity or high-sensitivity amplifier. Also like the PI-LCX, a thermoelectrically cooled option provides maintenance-free operation, while an LN_2-cooled option ensures extremely low dark current for long exposures.

References

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Resources

For more information about high-performance x-ray cameras from Princeton Instruments, please visit: **www.princetoninstruments.com**

For more information about Dr. Miao's research, please visit: **www.physics.ucla.edu/research/imaging**

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