Photonic Science

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X-RAY VHR CAMERA

Small Molecule and Protein Crystallography technique helps engineering of future drugs and chemical formulas produced by the pharmaceutical and chemical industry.

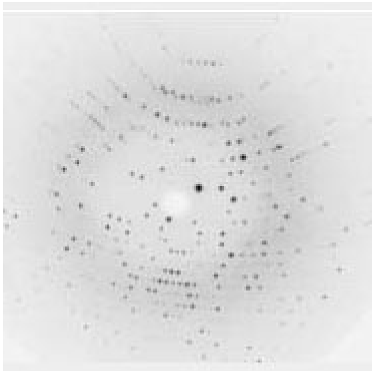
Small molecules (unit cell containing 100 atoms or less) and macromolecular (unit cell containing 10000 atoms or more) are crystallized and exposed to high brilliance X-ray beam on a synchrotron or X-ray lab source.

The experimental set up consists of gradually rotating the samples over 0.1 to 0.25 degrees in order to record Bragg reflections from each orientation of the crystal.

A good dynamic range is required, typically > 15,000:1 with potentially the possibility to read and expose at the same time in order to be able to rotate the sample at continuous speed over fine angular ranges: this is the fine Phi slicing technique.

Depending on beam delivery conditions as well as crystallization quality, the data collected can reveal conformal properties of a material in addition to its electron density that will shed some light onto binding mechanisms of enzymes or proteins.

Large area detectors up to 270x270mm and 16 megapixel resolution can be used in synchrotrons, whereas 165mm diagonal detectors are more commonly used with laboratory sources.



Small Molecule and Protein Crystallography

X-ray Phase Contrast technique is used to unveil edge contrast in low Z materials that are barely detectable using conventional X-ray transmission imaging technique.

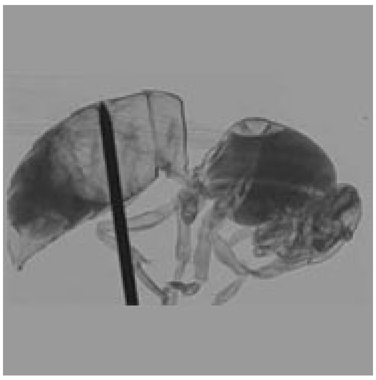
The contrast in X-ray images is normally generated by the difference in X-ray absorption for different materials.

The X-ray absorption coefficient is roughly proportional to the fourth power of the atomic number Z, making the imaging of objects consisting of low-Z elements like carbon, nitrogen and oxygen difficult. For nearly all elements the real part d of the complex index of refraction n ($n = 1 - d + ib$) in the X-ray region is larger than the imaginary part b.

As a consequence, a very subtle variation (phase shift) is introduced in the X-ray path, resulting in contrast changes around the edges of an object as light and dark fringes. Those are high spatial frequencies that can only be sensed by a very high resolution detector with excellent MTF response and good dynamic range as we are trying to image subtle intensity changes over a large background.

A highly spatially coherent X-ray source combined with a very high resolution detector are used to produce a phase contrast imaging set up.

Phase retrieval software can be offered for recovering quantitative information of a sample with known density, thus helping refining 3D tomographic reconstructions.



X-ray Phase Contrast Imaging

APPLICATION NOTE

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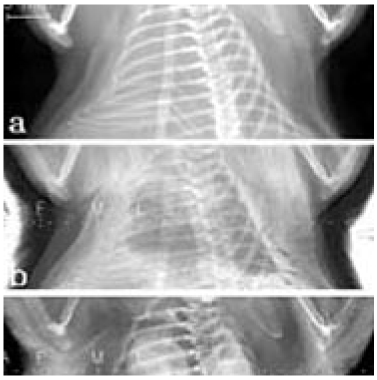
Diffraction Enhanced Imaging is used to unveil edge contrast in biological samples thanks to the detection of very subtle X-ray scattering changes.

An analyzer crystal is positioned between the sample and the image detector. The narrow angular acceptance of the analyzer allows to characterize the refracted and scattered X-rays going through the sample.

Scattering angles larger than the angular acceptance of the analyzer, typically few micro radians, will not be transmitted by the analyzer, this provides extinction contrast.

Equally, only the density variations across the sample that leads to micro radian refracted X-rays will go through the analyzer, this provides refraction contrast. Those subtle differences in scattering and refracting angles produced by the samples will be converted into intensity differences, which are then detected by a high resolution X-ray detector.

Sufficiently bright source must be used in order to collect enough flux after a low acceptance solid angle analyser, equally, a very high resolution detector must be used in order to sense very subtle edge contrast changes over a range of high spatial frequencies.



Diffraction Enhanced Imaging

X-ray Topography reveals cracks in single crystal substrates using X-ray beams that have been Bragg-diffracted by a crystal to image it.

X-ray topographs will show the distribution of various singularities that affect the Bragg reflection used in particular crystal defects such as precipitates, individual dislocations, stacking faults, domain or phase boundaries.

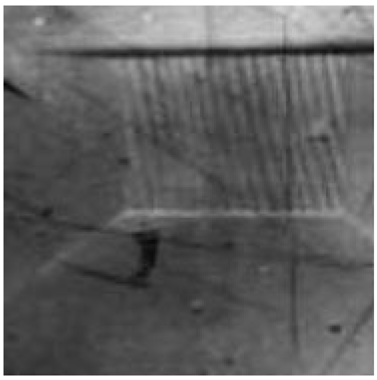
Topography relies on the fact that singularities or inhomogeneities can affect the spatial distribution of diffracted intensity and hence result in contrast.

In its usual meaning, topography can only be performed on single crystals, or on single grains within a polycrystal.

There is a wide range of variants: in transmission or in reflection, with a monochromatic beam, 8keV or with a white beam up to 100 keV, with a divergent beam or very well collimated beam, depending on the sample thickness and material.

A high resolution detector is necessary in order to record intensity changes produced by subtle diffracted beam path differences.

Scanning over large areas such as with Silicon wafers requires the use of detectors with good sensitivity, 100% duty cycle in order to maintain good inspection throughput.



X-ray Topography

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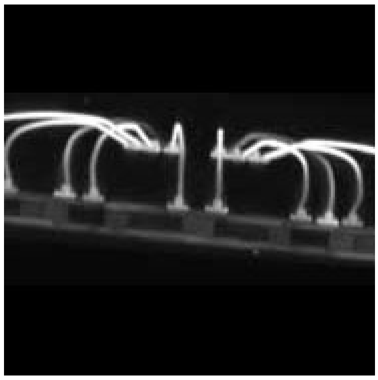
X-ray Micro and Nano Tomography allows a 3D reconstruction from a series of radiographs for different angular positions of the sample down to sub micron resolution.

Typically a full tomographic data set will require in the order of few hundreds to a few 1000s radiographs using a 3D reconstruction Feldkamp algorithm. Optical Cone beam / fan beam reconstruction are used, with the sample rotating in a fixed plan / helicoidally around an axis perpendicular to the beam.

The total acquisition time is in the range of few seconds per frame, it depends very much on the source brilliance / geometry. 100% duty cycle detectors with simultaneous read out / exposure allows to save up to 50% of the scanning time.

Resolution down to a few hundred nanometers can be achieved by using a small focal spot source and reasonable geometric magnification. The recorded data is often several Gigabytes and can be processed using the massively parallel calculation capacity of GPUs.

Microtomography can be combined with phase contrast imaging, either in a qualitative way (“edge enhancement”) or, more quantitatively, including phase retrieval (“holotomography”). Very high resolution cameras allows the build of scanners with sub micrometer spatial resolution whilst keeping compact dimensions and good sensitivity.



X-ray Micro and Nano Tomography

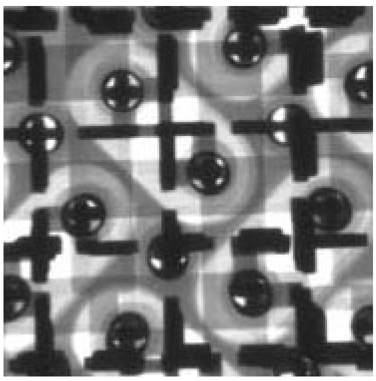
Industrial PCB X-ray Inspection / Digital X-ray Radiography cameras are used to detect porosity, inclusions, cracks and even grain structure within a variety of cast components and in welded joints.

With the increasing production of many new types of components such as BGA and flip-chip devices, it is important to produce good quality real-time X-ray images to isolate dry joints, bridging/shorts, voiding, misplacement / misalignment problems down to few microns or less resolution.

A high resolution camera is used in conjunction with high geometric magnification in order to keep a compact system that includes moving stages. The same kind of set up can be used for inspection of the latest ceramic, plastic and composite structures as well.

The cameras required for this kind of routine exposure time of < 500ms per frame and good enough resolution: typically better than 25 microns minimum feature detection capability in order to keep the geometric magnification requirements.

This keeps the overall instrument dimensions as low as possible. Simultaneous read out and exposure cycles are usually necessary for keeping duty cycle as close as possible to 100%, thus enabling higher board inspection throughput.



Industrial PCB X-ray Inspection / Digital X-ray Radiography.

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X-ray Gated Respiratory experiments allows to refine Small Animal models / cardiac drug monitoring.

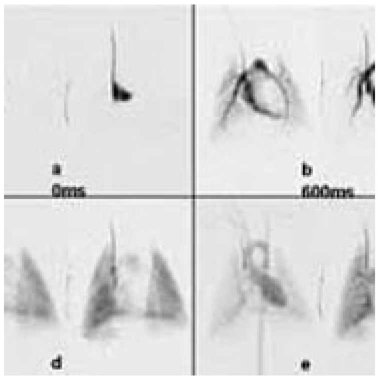
Cardiopulmonary imaging using Micro-Computed Tomography (CT) is a challenging task due to both cardiac and pulmonary motion and the limited fluence rate available from micro- focus X-ray tubes.

Successful imaging in mice requires recognition of both the spatial and temporal scales. The geometry must be optimized to match focal spot blur with detector pitch and the resolution limits imposed by the reproducibility of gating.

Motion is minimized for any single projection with 10 ms exposures that are synchronized to both cardiac and breathing motion.

High resolution detectors with good shuttering capability, fast read out and good dynamic range are the preferred solution for this type of application. Typical input size of 90x60mm matching the animal size with about 50 microns resolution FWHM and > 10,000:1 dynamic range is a good work horse solution that can be operated at up to 10fps on a optimized region of interest.

Synchronized acquisition using two detectors would allow stereoscopic acquisition without compromising acquisition speed.



X-ray Gated Respiratory, Small Animal X-ray Imaging

Transmission Electron Microscope Imaging.

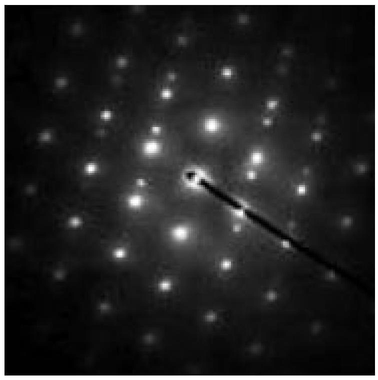
The TEM is used heavily in both material science / metallurgy and biological sciences. In both cases the specimens must be very thin and able to withstand the high vacuum present inside the instrument.

Electrons are transmitted through an ultra thin specimen, interacting with the specimen as it passes through it.

An image is formed from the electrons transmitted through the specimen, magnified and focused by an electron lens and appears on an imaging a fluorescent screen coupled to a high resolution CCD camera.

Spatial resolution and dynamic range are important because of high intensity distribution across the image especially during diffraction experiments. The ability to adapt speed of acquisition and dynamic range from 12 to 16 bit is required.

Very high resolution is usually required in order to get as close as possible to the film resolution. Fibre optic coupling combined with proprietary scintillator deposition allows optimum detective quantum efficiency and optimum resolution to be achieved up to >200 kV operation.



Transmission Electron Microscope Imaging

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Plasma Diagnostic.

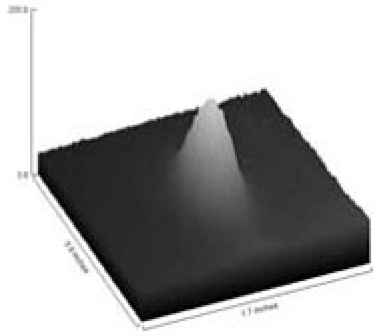
EUV / VUV detectors are used for calculating the fractional abundance of ions for hot plasmas with different electron temperatures and electron densities. They are used to characterize wavelengths and emissivity versus temperature of the brightest spectral lines emitted by the ions wavelengths longer than 45 Å.

ITER plasmas will be analyzed in selected EUV lines, similar to the space-based instruments routinely used to study temperatures, emission measures and motions of 0.1–2 keV solar coronal plasmas.

It is important to mach the detector yield over the entire spectral range whilst maintaining good spatial as well as temporal resolution. It is possible to use direct and indirect detection.

Direct detection is achieved by selecting back thinned CCDs in order to optimize quantum efficiency in the range of 100 eV and above. With a band gap of 3.5 eV on average, each photon is well discriminated, however coping with bright signals can be issue.

Indirect detection can be used with either a MCP or phosphor screen assembly read out by a CCD detector with better compromise on dynamic range.



Plasma Diagnostic

Streak Camera read out.

Streak Cameras are used for characterization of fast temporal events down to femtosecond range, and routinely down to picosecond range. A temporal profile of a light pulse is converted into a spatial profile, by time-varying deflection of the light across the width of camera.

National Ignition Facilities, Synchrotrons, telecom industry as well as well the plasma physics and ultras fast spectroscopy community are using streak cameras with direct fibre optic coupling CCDs in order to record streak patterns directly from the streak tube.

Excellent spatial resolution, must be delivered by the CCD read out in order to exceed traditional film performance. Streak tubes usually have 1,000:1 dynamic range, therefore cameras must also have good dynamic range. With MCP image intensification, the low light levels may be amplified few 100 to 1000 fold, hence the requirements to cope with overexposure in case of saturation artefacts.

In the absence of MCP, the camera must have good sensitivity. Fibre optic coupling with no demagnification is then the best possible option for collecting the light emitted of the streak tube phosphor screen.

Streak Camera read out