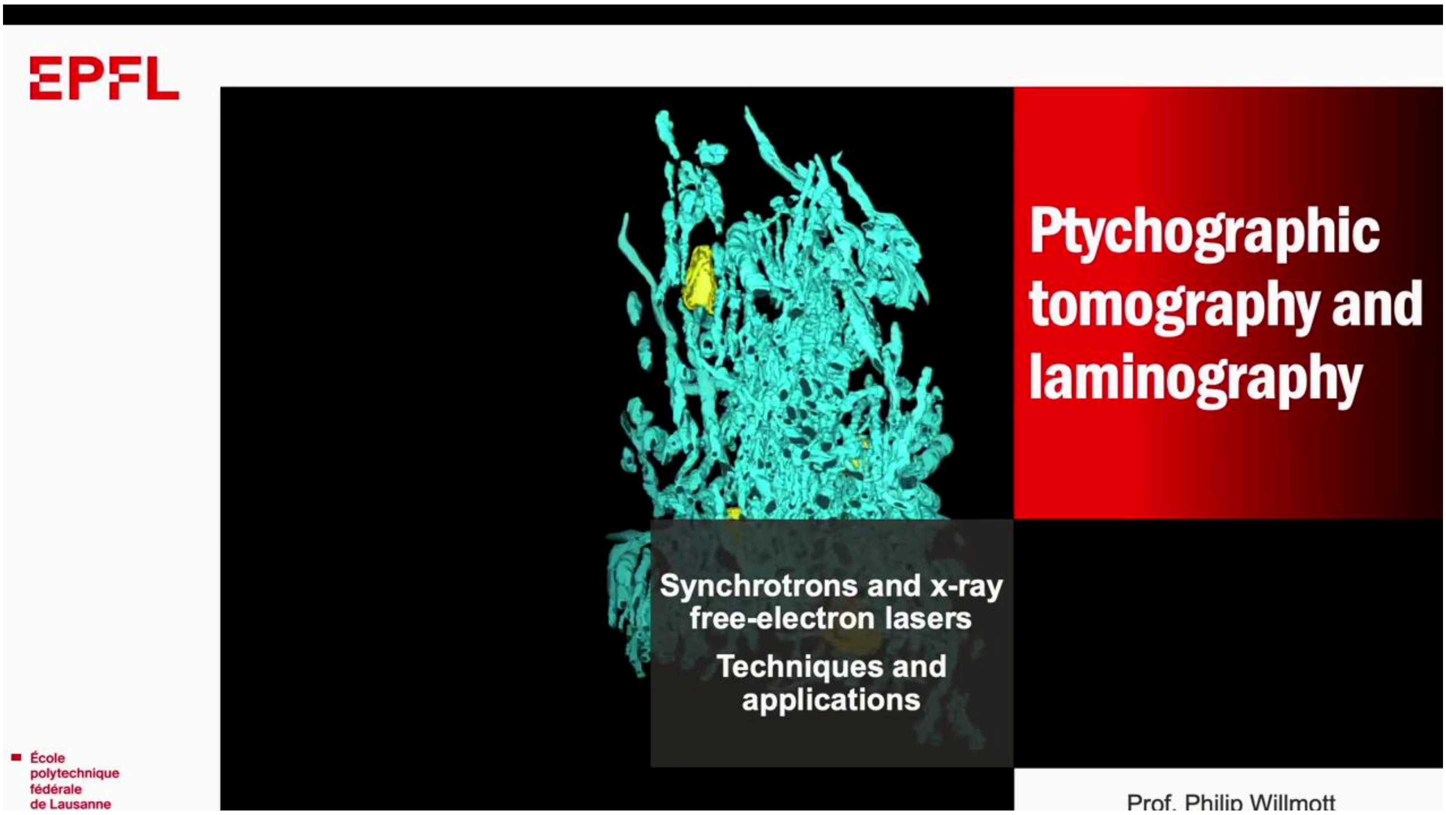

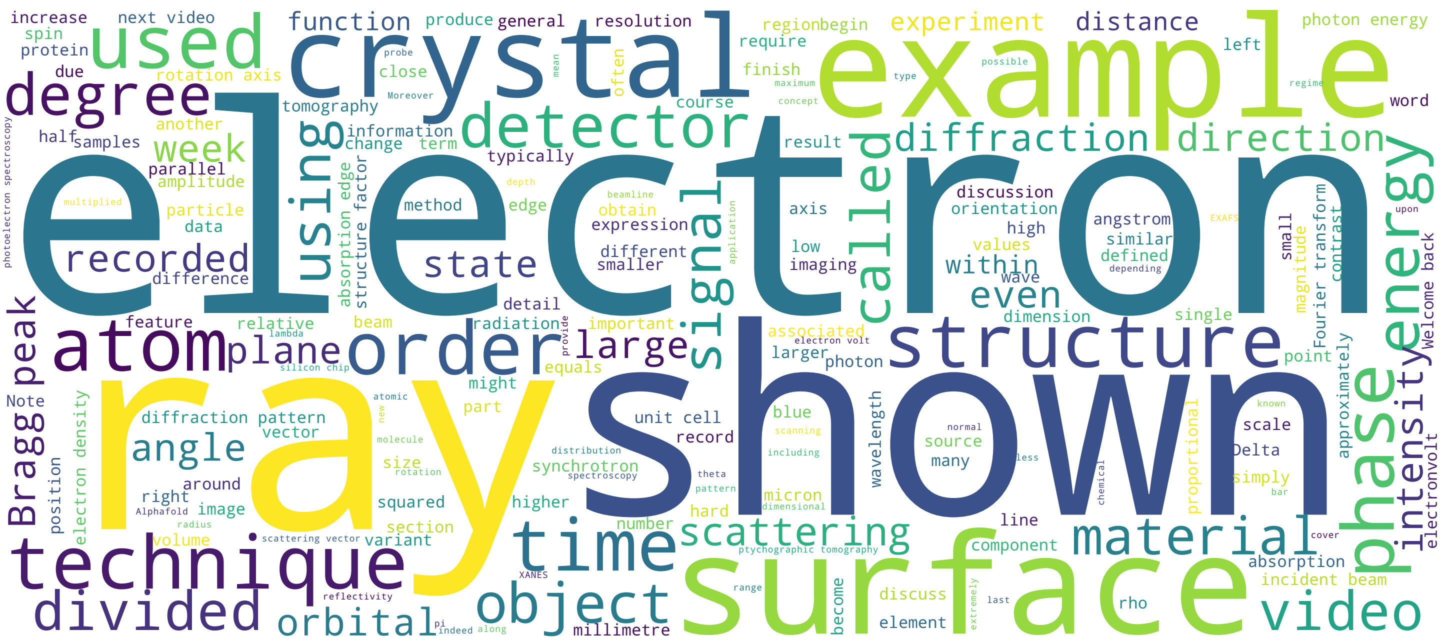

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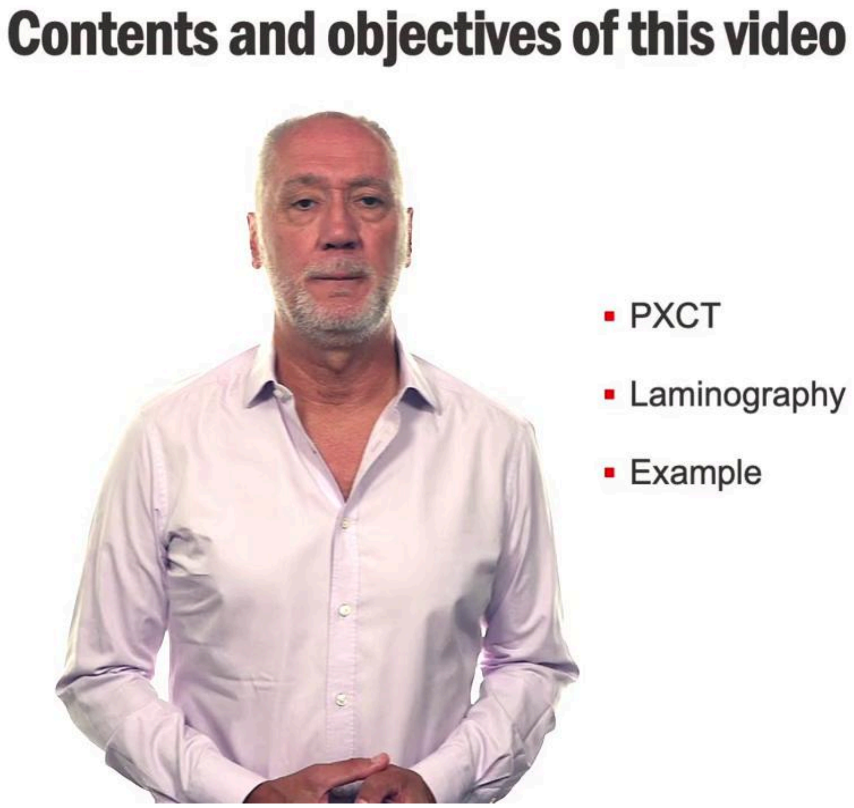


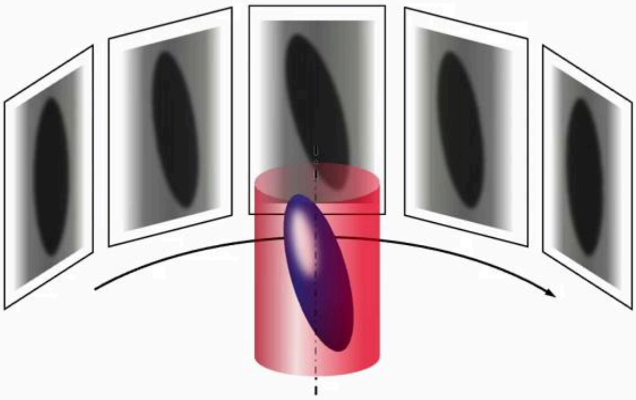
In this short video, we introduce ptychographic tomography and laminography, and finish with a recent example.

Notes

Summary

0m 04s

Ptychographic tomography



- PXCT combines
  - Ptychography
  - Tomography
- 3D reconstruction with ~ few 10s nm resolution
  - Ptychographic 2D reconstructions at different projection angles
  - Tomographic 3D reconstruction from ptychographic reconstructions
- Density variations < 1% possible

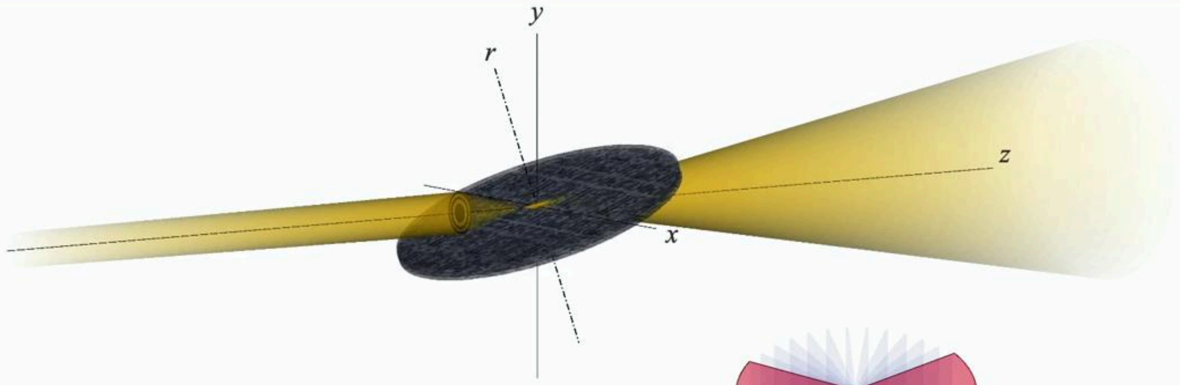
Ptychographic tomography or PXCT, combines ptychography, which produces projections of a three-dimensional object from different observation angles, with tomographic reconstruction techniques. This results in reconstructions with resolutions down to as small as around 10 nanometres. Density variations as low as 1% can be readily distinguished.

Notes

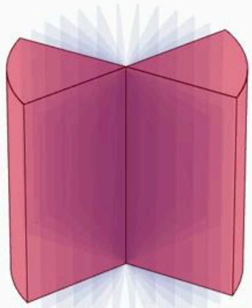
Summary

0m 12s

Ptychographic laminography



- Ptychographic x-ray laminography "PyXL"
- Used for extended samples in two dimensions (flat objects)
  - Sample rotation axis r tilted relative to x-y plane perpendicular to incident radiation (tomography)
  - Also scan sample laterally (ptychography)
  - Offset angle means some of reciprocal space cannot be accessed



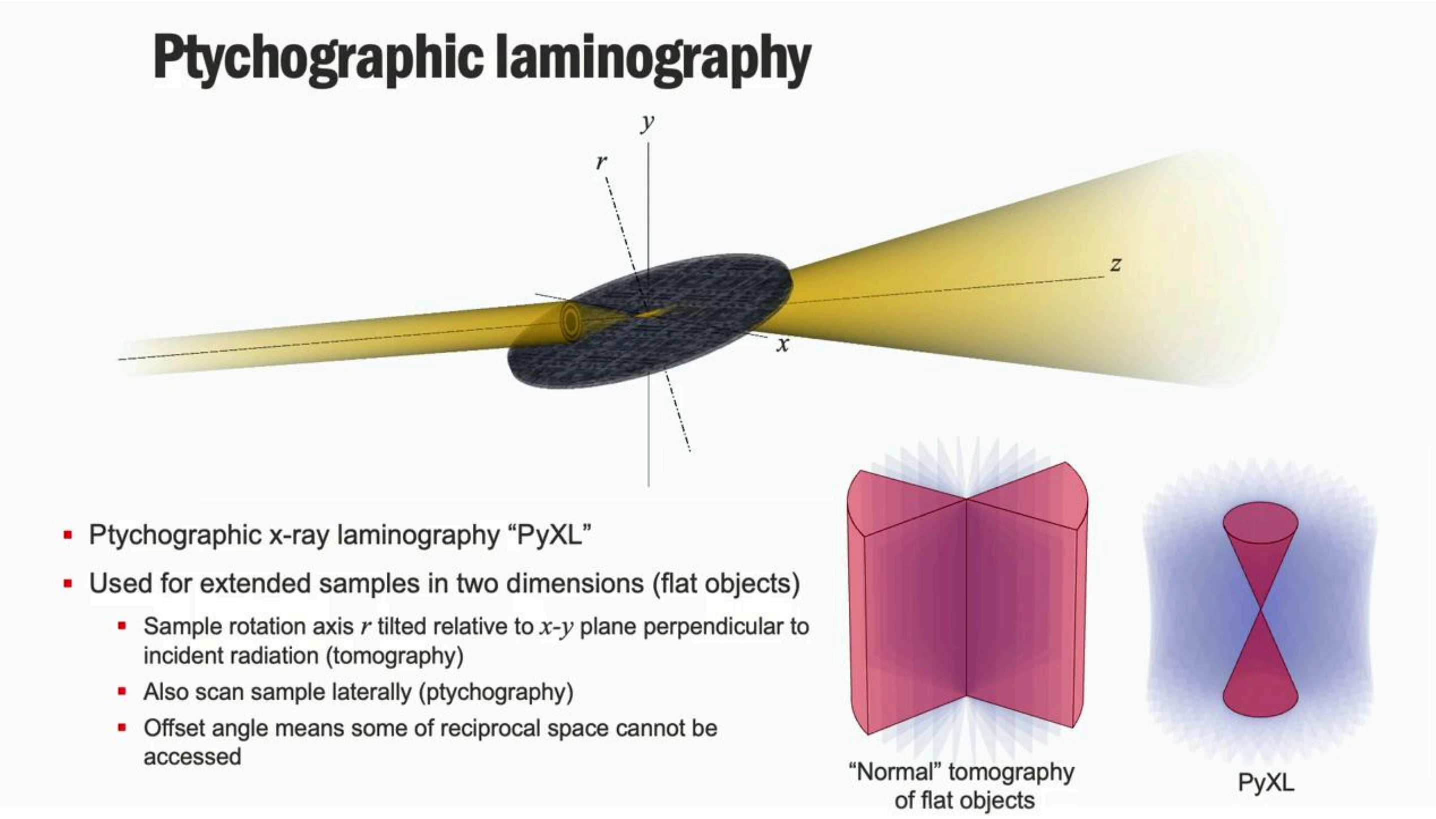
"Normal" tomography of flat objects

What geometric configurations should one use if the object being imaged is flat, that is, if one dimension is much smaller than the other two, such as in a leaf or in a silicon chip wafer? If the rotation axis is, as is usually the case in tomographic methods, perpendicular to the incident beam, then no matter what the sample orientation is, except when the normal to the flat is coincident with the rotation axis, the object will present at some point during the rotation, a depth of material through which the x-rays must pass that is much greater than at other angles. Imagine, for example, a silicon wafer with a diameter of 100 millimetres and a thickness of half a millimetre positioned so that the normal to the wafer flat surface is in the same plane as the incident beam and the rotation axis is parallel to the same wafer surface. The difference in thickness seen by the x-rays between the minimum and maximum is a factor of 200. It would be nigh impossible to choose an X-ray energy that would deliver reasonable transmission results for both extremes. Thus, if one chooses the x-ray energy to be best suited for the short penetration length, reasonable results can be expected for only a certain range of rotation angles and a certain subset will be excluded from the analysis.

Notes

Summary

0m 35s



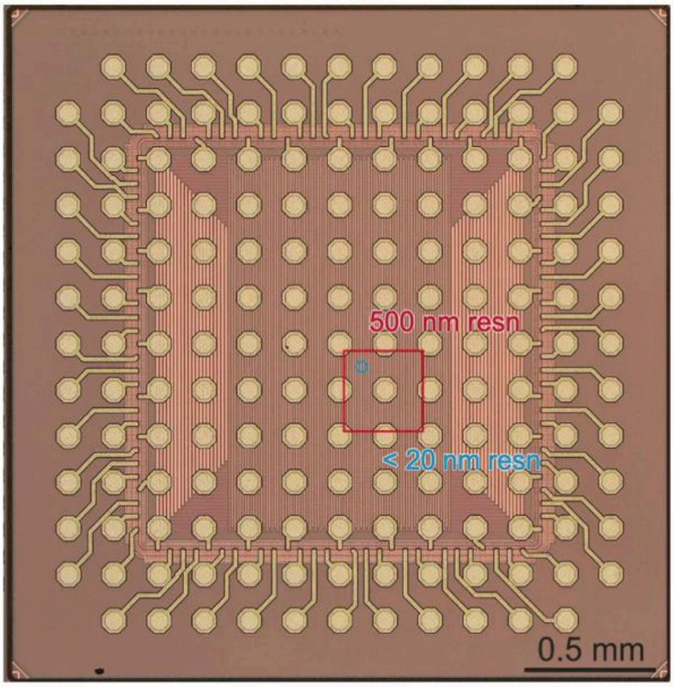
If, however, as shown in the cartoon here, the rotation axis R is tilted relative to the normal plane of the incident beam, the projections cover most of the sample space and have, all other things being equal, the same degree of absorption, resulting in a much smaller volume of data going missing. The offset angle should be chosen to minimise the volume of these exclusion cones. This variant of ptychographic tomography is called ptychographic x-ray laminography or PyXL, less of a mouthful and a wry nod to the detectors used to record the data.

Notes

Summary

2m 11s

Example – nondestructive study of chip architecture



- PyXL @ 6.2 keV
- Tilt angle off vertical $\theta = 61^\circ$
- Integrated circuit chip with 16-nm fin field-effect transistor technology
- Size of radiation on sample T = 4 μm
- Number N of angular projections between 0 and 360° = 2872
- Theoretical resolution

$$\Delta r = \pi \frac{T}{N} \tan\theta = 7.6 \text{ nm}$$

- Actual resolution 19 nm

M. Holler *et al.* Nature Electronics
https://doi.org/10.1038/s41928-019-0309-z

My choice of a silicon chip as an example of a system that lends itself to PyXL wasn't random. A groundbreaking PyXL study of a CMOS integrated circuit silicon chip with 16-nanometre architecture was reported in 2019. The tilt angle off vertical was 61 degrees and the coherent radiation had a diameter of 4 microns at the sample. For each position on the sample, a full rotation was recorded with nearly 2,900 projections. The theoretical resolution of such an experimental setup is pi times T divided by N tan theta equaling 7.6 nanometres. Small experimental errors, mainly associated with extremely small drifts and vibrations of the sample manipulator and x-ray optics, meant that the actual resolution was 19 nanometres, still a breathtaking accomplishment. Now, in the following clip, a region of around 300 by 300 microns is shown with half-micron resolution. This is given by the red box here within which a small region of around 40 microns diameter is zoomed in on, shown here in blue, in which the 19-nanometer resolution data is presented.

Notes

Summary

2m 55s

In the next video...

We begin with the overview square region and zoom directly into the high-resolution volume. All device layers and connections between them are resolved. One can distinguish, for example, a highlighted inverter circuit, which itself is no larger than half a micron. Note that the high-resolution data required 60 hours of recording. It's hoped that with the new generation of diffraction-limited storage rings, this will be reduced to minutes. In the next video, we discuss the technique of scanning SAXS tensor tomography. This actually doesn't provide real space images through speckle information but rather information in three dimensions on preferential orientations and degrees of anisotropy directly from the SAXS data.

Notes

Summary

4m 24s