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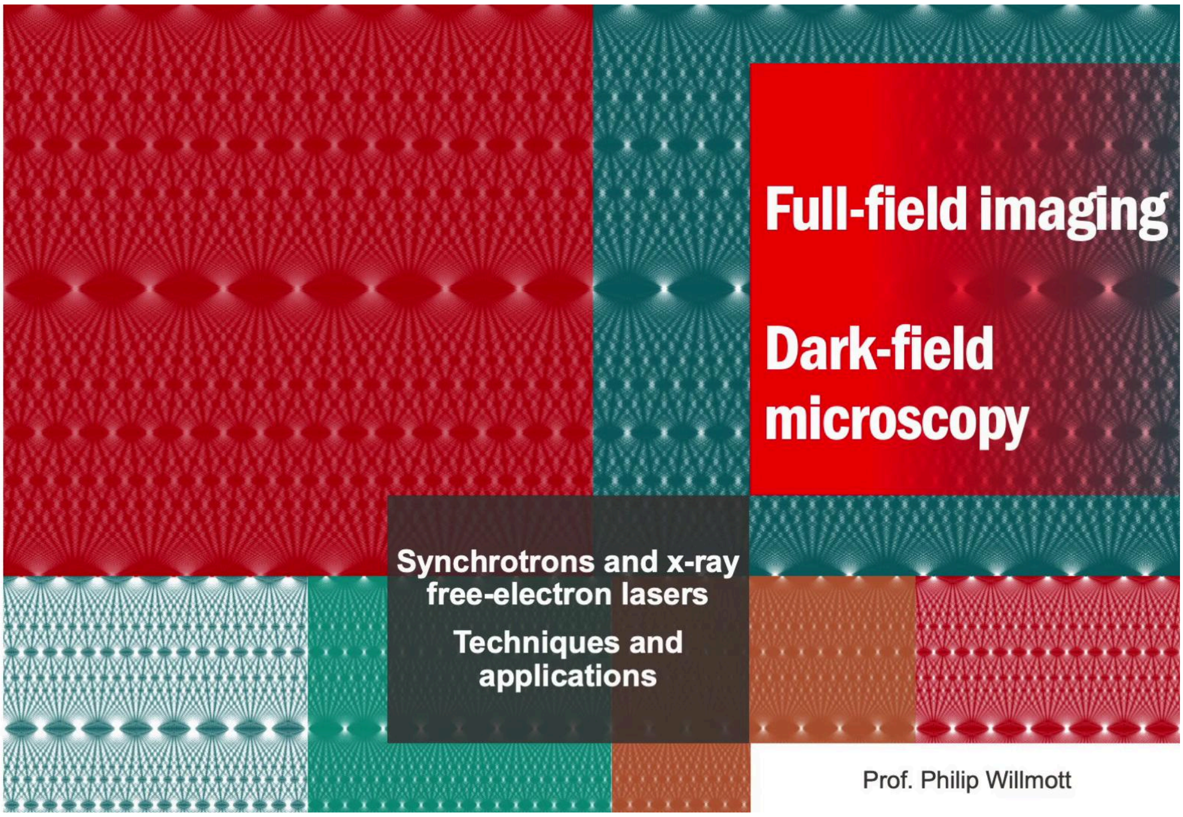
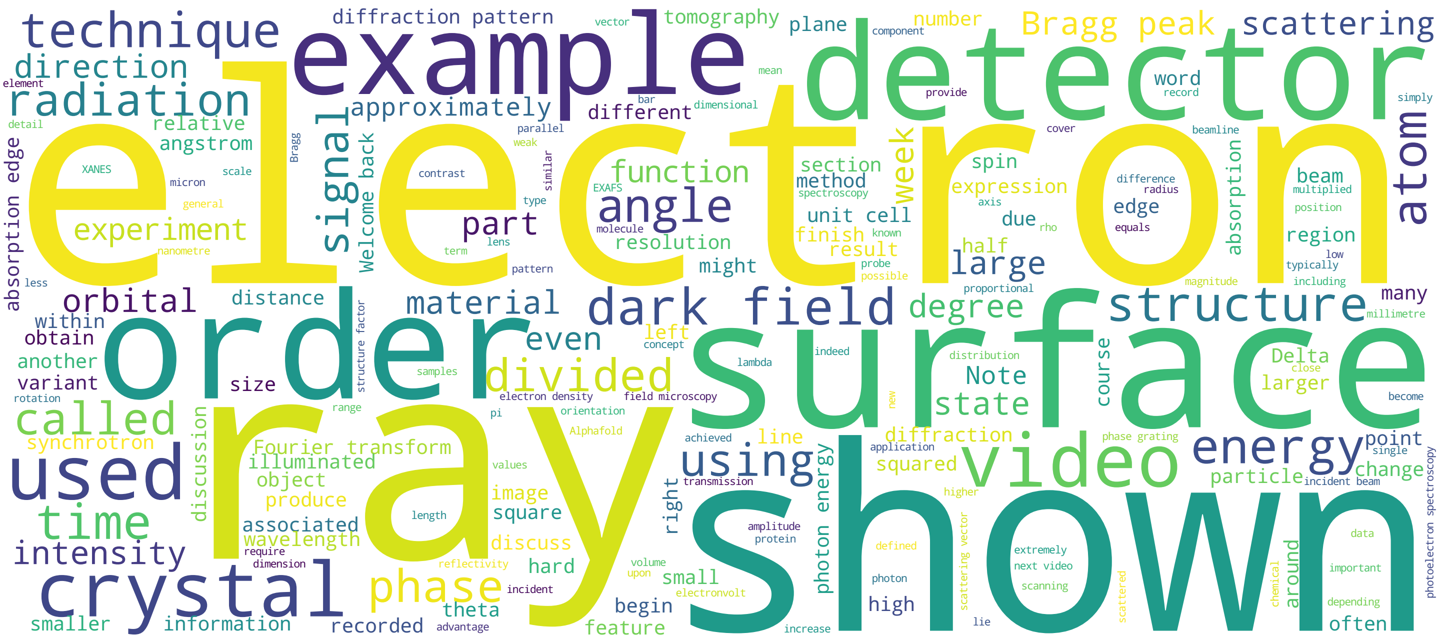
École polytechnique fédérale de Lausanne





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Video

Contents and objectives of this video

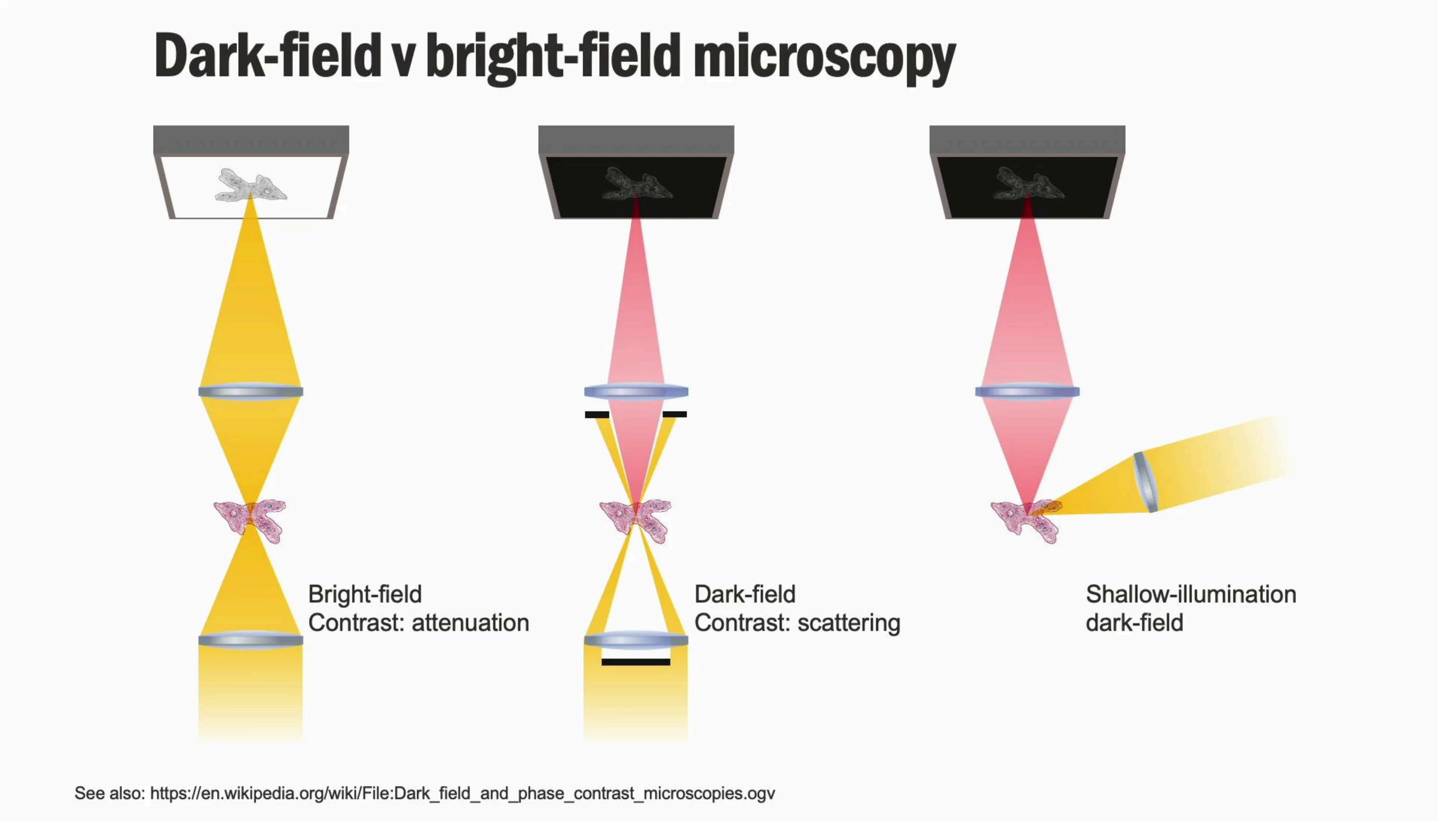
- Dark-field v bright-field microscopy
- General features
- Advantages
- Diffractive dark-field x-ray microscopy

Welcome back to this introductory course on synchrotron and XFEL radiation. Now, in this first video of the 3rd section of the 5th week, we discuss dark-field x-ray microscopies, and how these differ from bright-field techniques, highlighting their general features, and advantages. We finish with a description of a variant of dark-field microscopy in which gratings are employed and the so-called Talbot Effect exploited.

Notes

Summary

0m 05s



In understanding what is meant by dark-field microscopy, we begin with bright-field methods, which are the classical approach. Here, contrast is achieved by attenuation, which, as we've already discussed, can be very weak for soft matter irradiated by hard x-rays. In forward scattering dark-field techniques, the sample is illuminated by an annular source. That part of the radiation that is not scattered by the sample is then blocked by an opaque ring, while that part of the radiation which is scattered is allowed to pass through a second lens and is imaged on the detector, which thus only sees this scattered radiation and is otherwise dark. Hence the name. The same effect can be achieved if the radiation on the sample is incident at shallow angles.

Notes

Summary

0m 37s

Dark-field microscopy – advantages

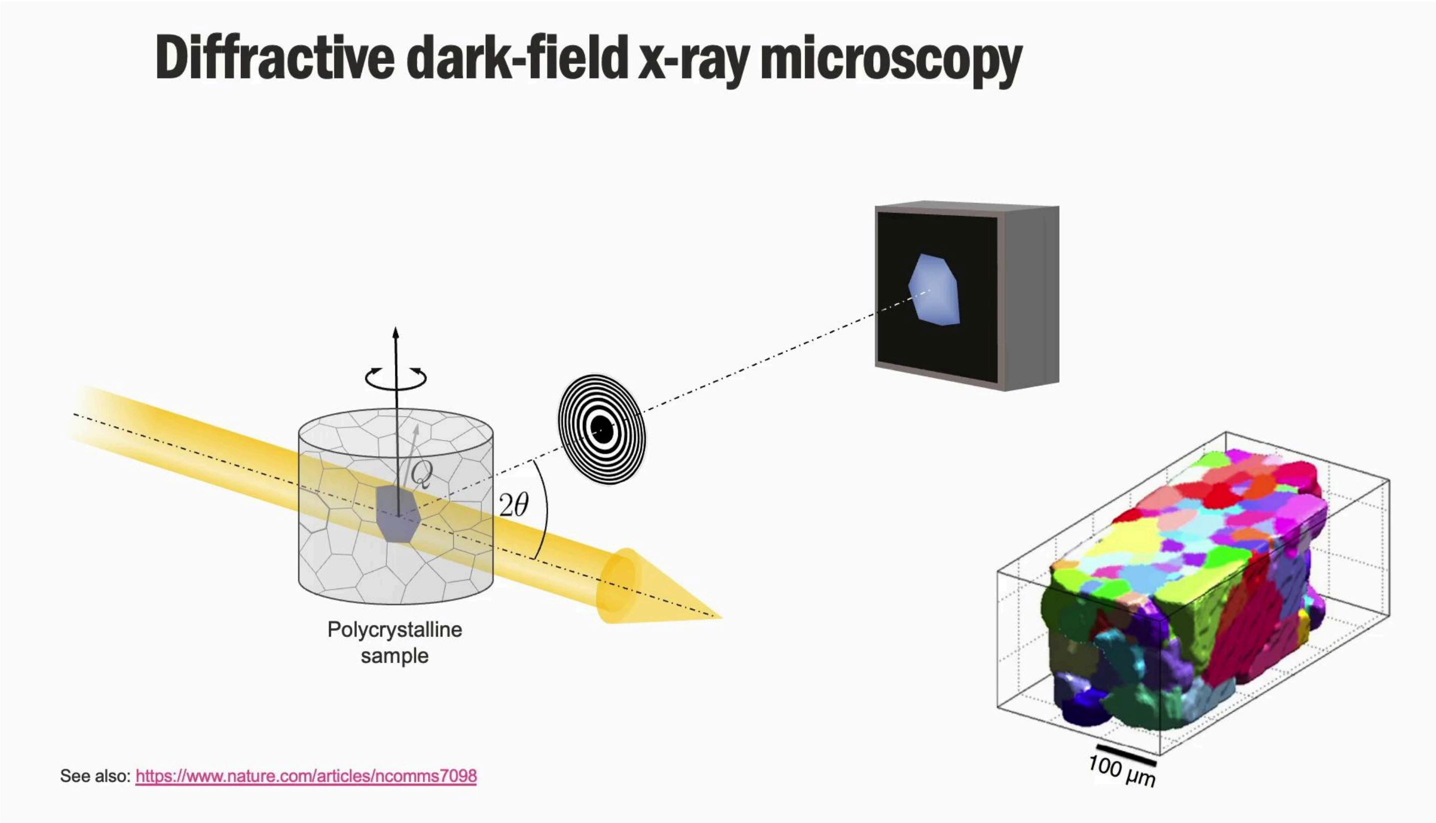
- Improved contrast: dark-field imaging produces a high contrast image with improved visibility of low-contrast features. Particularly useful for imaging materials with low electron density, e.g., soft tissues, polymers, and composites
- High sensitivity: highly sensitive to small changes in the sample's structure, making it useful for detecting subtle variations in materials, such as cracks, voids, and defects
- High resolution: x-ray dark-field imaging has the potential to produce high-resolution images, which can reveal fine details of the sample's internal structure. Very useful in materials science, biology, and other fields where the precise arrangement of structures is important.
- Can image small objects: x-ray dark field microscopy can be used to image small objects, such as nanoparticles, with high resolution and contrast. This is useful in nanotechnology and materials science research.
- Overall, x-ray dark field microscopy is a powerful imaging technique that has the potential to revolutionize many fields of science and engineering by nondestructively providing detailed images of the internal structure of materials and biological specimens.

For soft matter irradiated by hard x-rays, not only is absorption weak, but so is also the scattering strength. Dark-field microscopy is therefore a technique that profits from intense sources, notably from 4th generation DLSRs. The magnification factor provided by the downstream lens is equal to q divided by p, achieved typically using Fresnel zone plates or compound refractive lenses, and has a limit of approximately a factor of a hundred, yielding resolutions of the order of 50 nanometers. Recently, an innovation called an axicon can be fabricated which utilizes the entire beam flux by focusing it to a sharp ring and placing the scattered object upstream of this. In summary, the advantages of dark-field microscopy include higher contrast with improved visibility for poorly scattering and low-contrast objects associated with low electron densities. It's highly sensitive to small changes in the sample structure, making it very useful for detecting subtle features such as cracks, voids, and defects. It has an ultimate resolution of only a few tens of nanometers, and can thus also image small objects on the micron scale or smaller. Dark-field microscopies thus promise to be very valuable tools in future synchrotron facilities, particularly in the fields of biology and materials engineering.

Notes

Summary

1m 32s



Diffractive dark-field imaging is a relatively modern technique in which crystalline components with a certain lattice constant can be selectively highlighted. The Bragg condition is met by setting the detector at an angle two theta to the instant beam and collecting diffraction signal with a lens. The crystal orientation relative to the incident beam is adjusted by sample rotation so that q lies at an angle 90 minus theta relative to the incident beam and detector axis. In this manner, a three-dimensional image of crystallite orientations can be built up as shown here from the provided reference.

Notes

Summary

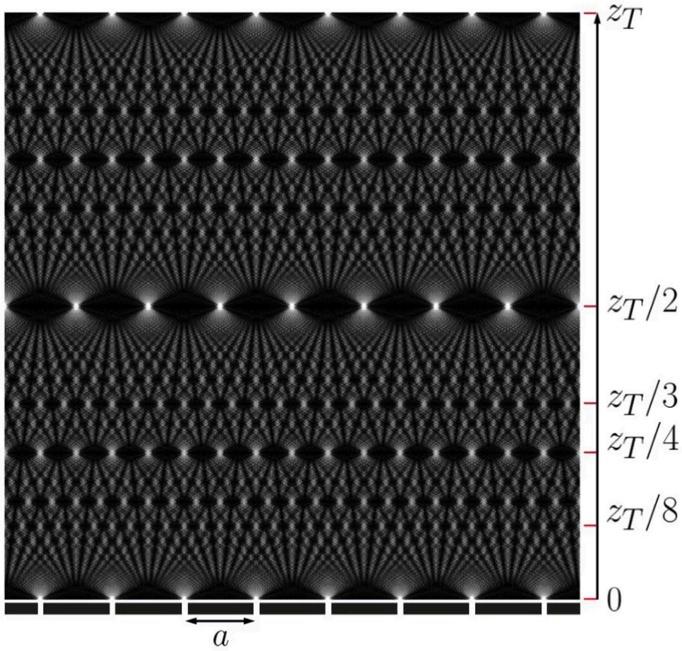
3m 11s

Dark-field x-ray microscopy using gratings

- Talbot effect
  - Self-imaging through Fresnel diffraction of periodic structures when illuminated with plane-wave coherent light
  - Forms a series of images at regular intervals behind the structure.
  - First image at the "Talbot length"

    $$z_T = 2a^2/\lambda,$$

    where a = period of the grating and λ = wavelength of the light. At z_T, the light waves recombine and form an image that is an exact replica of the original structure.
  - Subsequent images appear at regular intervals behind the first image plane
  - Talbot effect occurs because the periodic structure acts as a diffraction grating, creating a set of diffracted waves that interfere constructively at certain distances behind the grating, leading to the formation of the self-images.



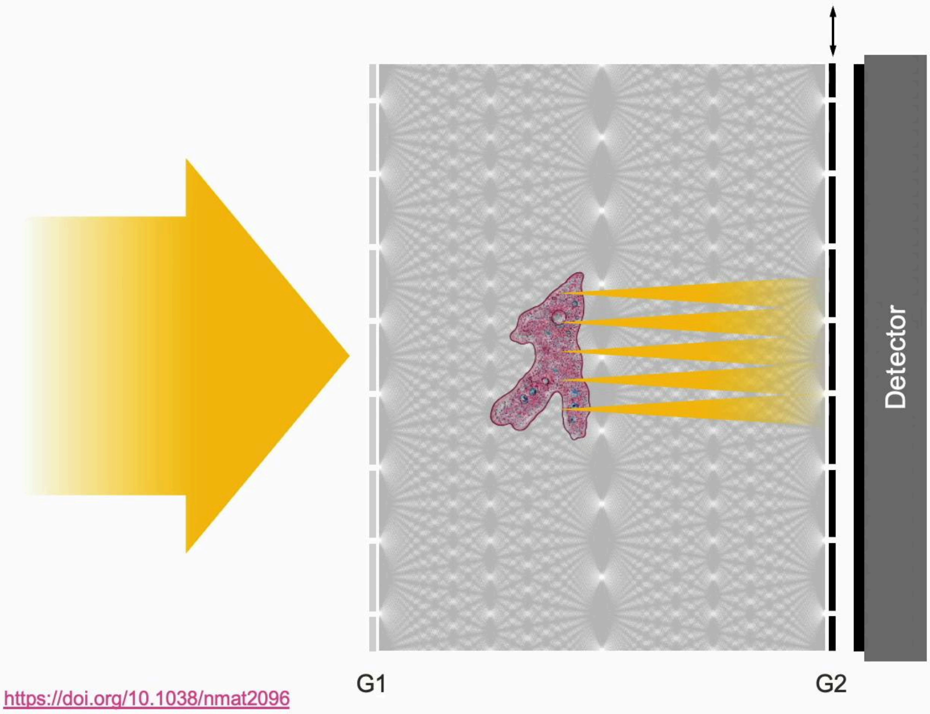
We will now complete our discussion of dark-field x-ray imaging with a variant that operates by the use of periodic gratings. In order to understand this, we need to become familiar with the so-called Talbot Effect. This is a self-imaging phenomenon in the Fresnel diffraction regime of periodic structures when illuminated by a plane-wave coherent beam of radiation. This occurs first at a distance zT equal to twice the square of the grating periodicity divided by the wavelength of light used.

Notes

Summary

3m 53s

Dark-field x-ray microscopy using gratings



F. Pfeiffer *et al.*, https://doi.org/10.1038/nmat2096

In dark-field grating interferometer imaging, a phase grating G1 is illuminated with a coherent x-ray playing wave. By phase grating, it has meant that the grating elements imprint only a periodic phase profile, but they don't significantly attenuate the beam. A second absorption grating, which does attenuate the beam, G2, with the same periodicity as G1, is placed downstream of G1 at the Talbot length. Now, if this grating is translated sideways, it can now entirely block the Talbot image of the phase grating. If, however, a sample is inserted between the gratings, scattering will still pass through the second grating producing a dark-field image. This is a very simplified explanation, and you are referred to the Nature Materials reference below for a more detailed explanation, including how this can be used with an incoherent lab-based source, if one includes an initial grating, which they labelled G0 in their publication.

Notes

Summary

4m 32s

In the next video...

In the second video of this third section, we will consider Zernike x-ray microscopy, a form of phase contrast microscopy developed by Frits Zernike in the 1930s in the visible regime.

Notes

Summary

5m 38s