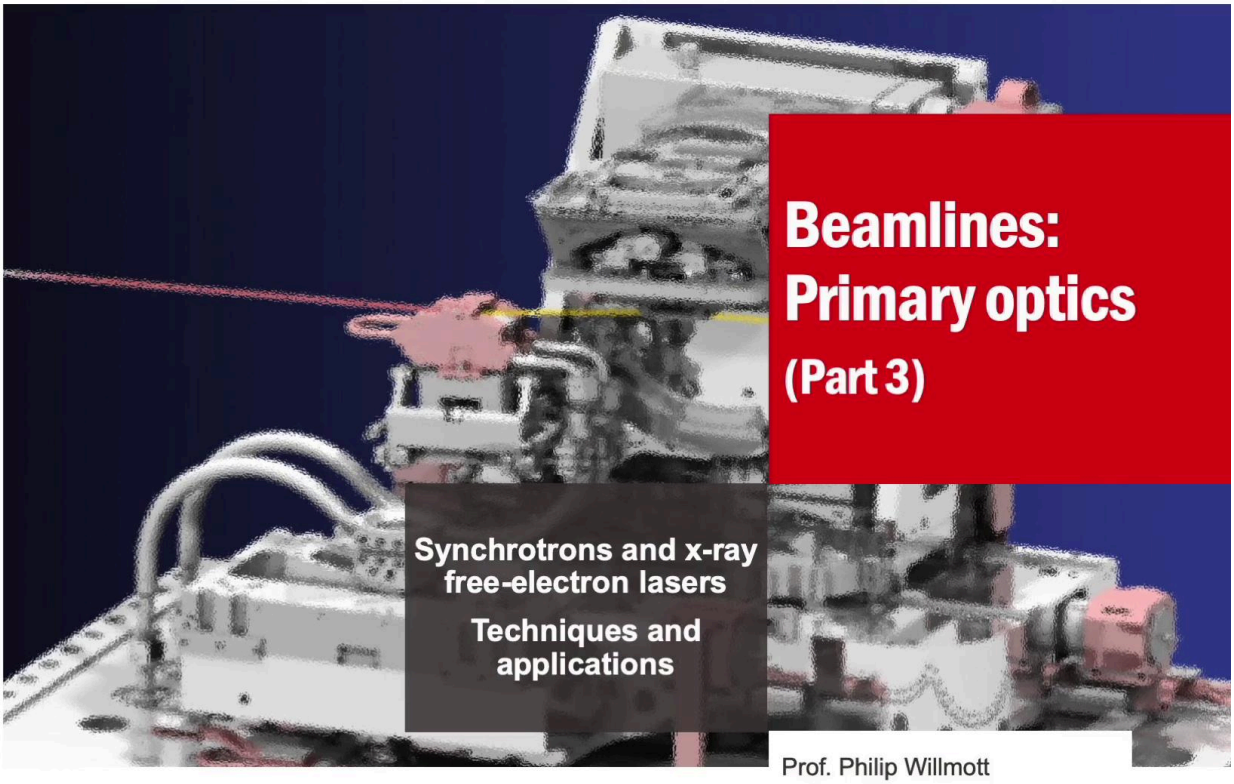
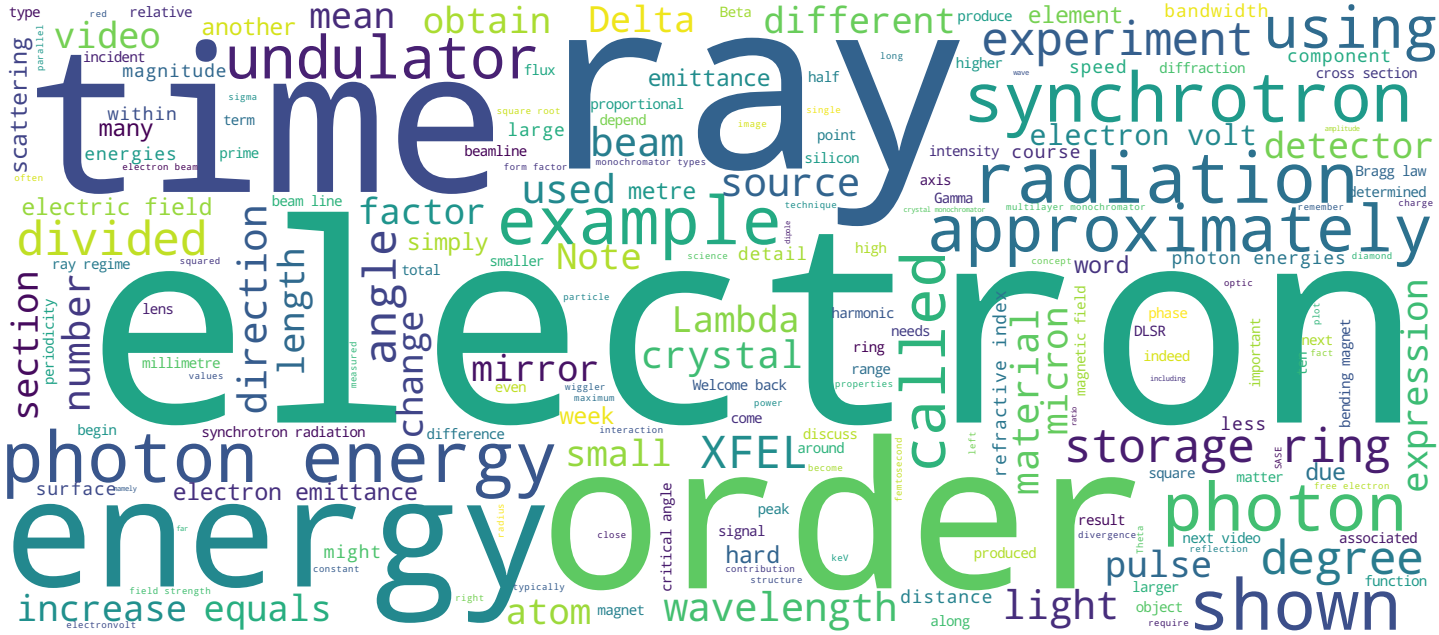


École polytechnique fédérale de Lausanne



Contents and objectives of this video

- Monochromators
  - Need for monochromators
  - Overview of mono types
    - Wavelength ranges
    - Magnitudes of periodicity

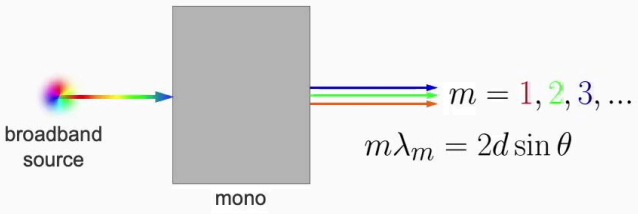
Welcome back. In this short video, we will familiarise ourselves with the general features of monochromators.

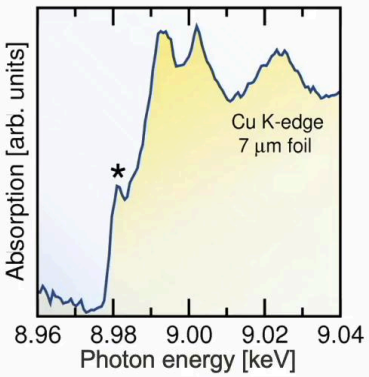
Notes

Summary

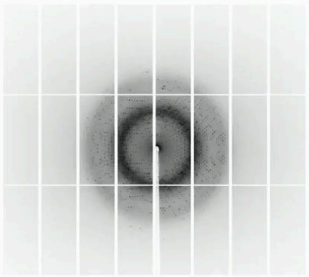
0m 05s

Need for monochromators





- Spectral width from SR-sources
  - Bending magnets $\Delta\nu/\nu \sim 1$
  - Undulators $\Delta\nu/\nu \sim 1/100$
- Spectral resolution required by experiments
  - Diffraction ~ 10^{-3} – 10^{-4}
  - Spectroscopy ~ 10^{-4} – 10^{-5}
- Harmonic suppression



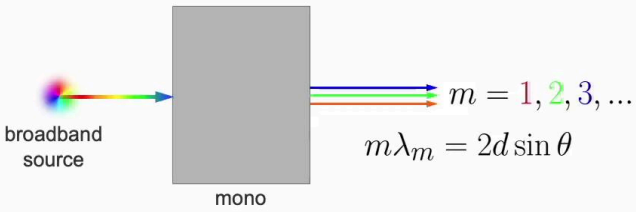
So what are monochromators, and why do we need them? Monochromators, often just called monos, for short, select a certain bandwidth or set of bandwidth of frequencies from synchrotron radiation sources. The relationship between the transmitted wavelengths follow Bragg's law or variants thereof, whereby the energies are integer multiples m of the lowest energy transmitted signal. Bending magnets and wigglers provide varied broadband radiation, and for the large majority of experiments, only a small fraction of this in the form of a narrow range of energies is used. Even the bandwidth of undulator spectral peaks as they emerge is more often than not insufficient for many types of experiments and require further monochromatisation. For example, X-ray absorption spectra contains subtle features that can provide invaluable chemical and orientational information. The pre-peak in the Zane's spectrum of copper at its K absorption edge highlighted here with an Asterix, provides information on the oxidation state. The width of this peak is approximately 1.7 eV. In other words, about one-five hundredth of its energy. In order to resolve such features, the spectral bandwidth Delta Mu upon Mu must be better than this.

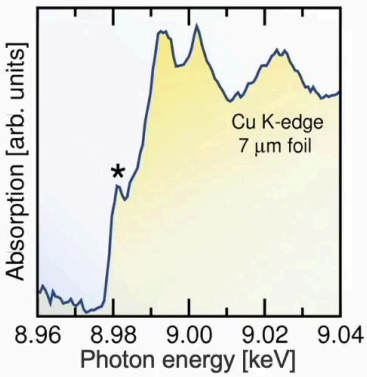
Notes

Summary

0m 13s

Need for monochromators





- Spectral width from SR-sources
  - Bending magnets $\Delta\nu/\nu \sim 1$
  - Undulators $\Delta\nu/\nu \sim 1/100$
- Spectral resolution required by experiments
  - Diffraction ~ 10^{-3} – 10^{-4}
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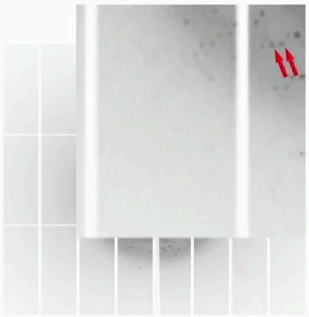


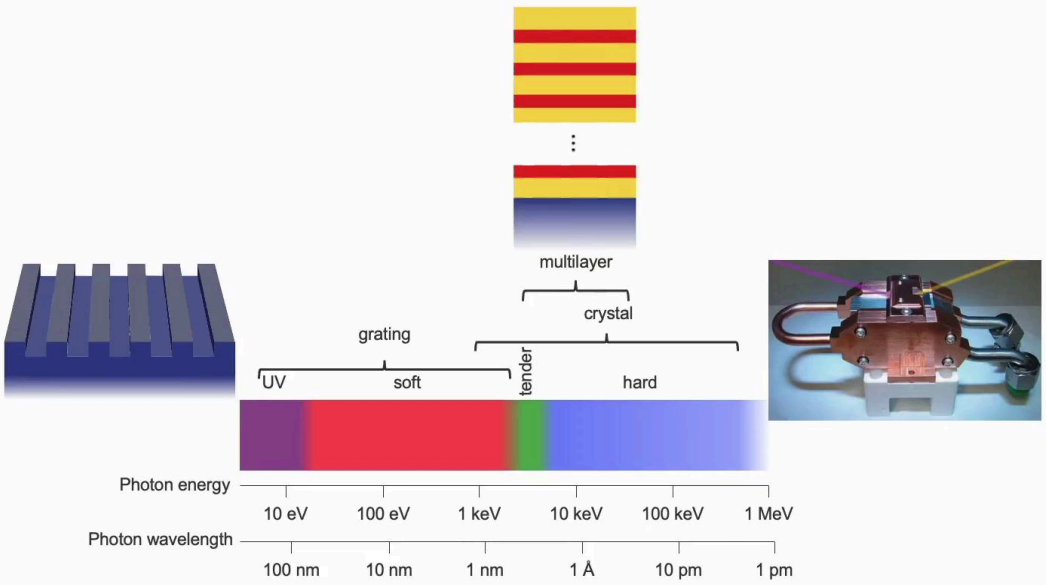
Below the copper absorption spectrum, a typical macromolecular diffraction pattern is shown. If we blow up a portion of this, we see that diffraction spots are only very slightly angularly separated, and would overlap if the degree of monochromacity were an order of magnitude worse.

Notes

Summary

1m 41s

Types of monochromator



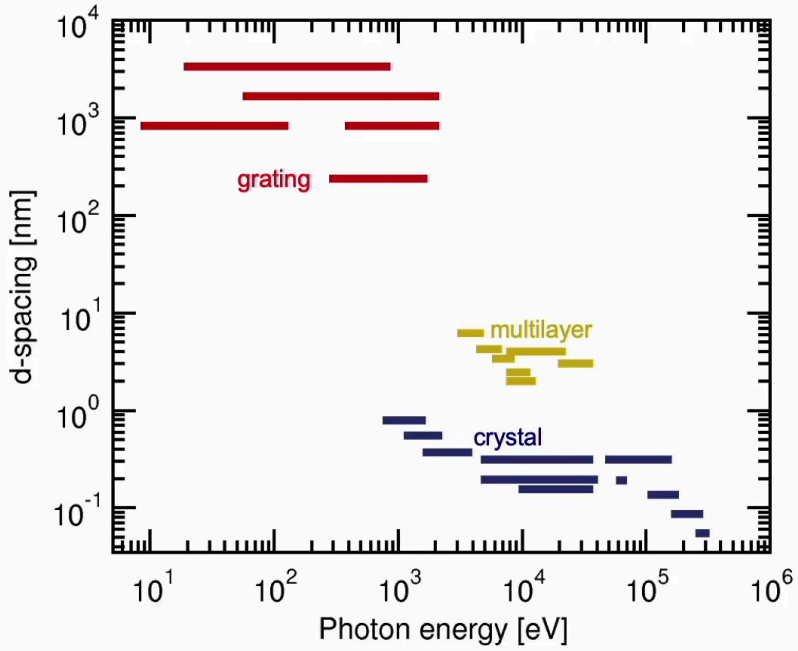
Depending on the photon energy range of the beam line and their demands for flux, different monochromator types are used. Soft X-ray beam lines use gratings, while most hard X-ray beam lines employ monochromators based on crystal diffraction. The tender X-ray regime between approximately two and four eV is also mostly served by crystal monochromators, though can use so called multilayer monochromators as well. Multilayer monos are also employed fairly extensively in the medium hard X-ray regime as a means to obtain more flux through their intrinsically larger bandwidths.

Notes

Summary

2m 01s

Types of monochromator



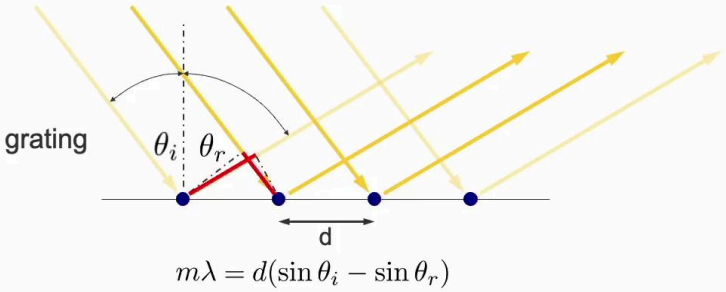
A selection of different but representative monochromator types from synchrotrons around the world is shown here as a function of photon energy in periodic spacing d. Notice immediately the strong correlation between photon energy and d-spacing. This should come as no surprise. A high photon energy is associated with short wavelengths, for which one needs a diffraction element of similar periodic dimensions. The range of suitable photon energies served by multilayer monochromators is fairly narrow and determined by two physical limitations. The lower limit is set by the absorption coefficient of the material used to fabricate the multilayers. The heavy component of the multilayer becomes too absorbing below a few keV photon energy. For example, rhodium has an attenuation length of only 400 nm at three keV. The upper limit is determined by the geometry in Bragg's Law. The incident angle to satisfy the Bragg condition for 40 keV photons using a five nm period multilayer is 0.178 degrees. And the footprint on the multilayer, assuming a beam height of 0.5 millimetres, would have a length of over 320 millimetres. Fabricating high quality multilayers with such large dimensions becomes extremely challenging.

Notes

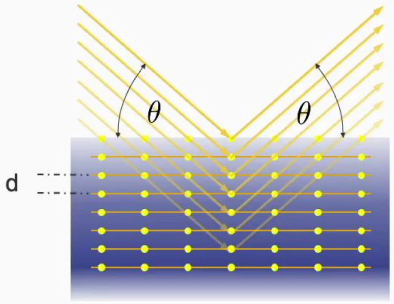
Summary

2m 42s

Types of monochromator

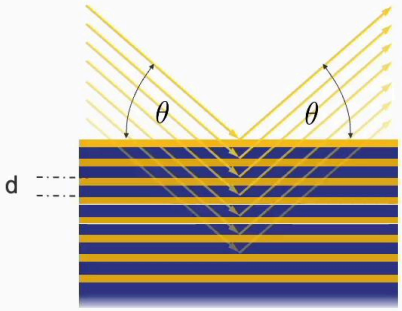


$$m\lambda = d(\sin\theta_i - \sin\theta_r)$$



Crystal
3-D periodicity

$$m\lambda = 2d\sin\theta$$



Multilayer
1-D periodicity

$$m\lambda = 2d\sin\theta$$

How do grating monochromators on the one hand and crystal and multilayer monos on the other differ from each other? Gratings can come in various flavours regarding their groove profiles. They are in general, typically fabricated via advanced lithographic and etching techniques on glass substrates. Scattering of grating features leads, at certain angles, to constructive interference, when the difference in the optical path difference d sine Theta_i minus sine Theta_r is equal to an integer number of wavelengths. As we saw in the previous slide, typical grating periodicities are anywhere between a couple of hundred nanometres to a few microns. In the case of a crystal for which d is a few angstroms, interference of hard X-rays is between specularly reflected radiation from successive layers of atomic planes, which therefore follows the famous Bragg Law. Multilayer monochromators followed the same principle and can thus be thought as one dimensional artificial crystals. Because their periodicity is approximately one order of magnitude larger than those normally associated with crystal monochromators, the angle of incidence is correspondingly smaller compared to Bragg angles associated with crystal monos, normally only a couple of degrees, or sometimes even less.

Notes

Summary

4m 11s

In the next video, we will look in more detail at the main three different monochromator types, their most salient features and how they operate.

Notes

Summary

5m 43s