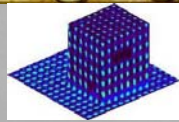
µrad diffraction with refractive x-ray optics for colloidal and photonic crystals



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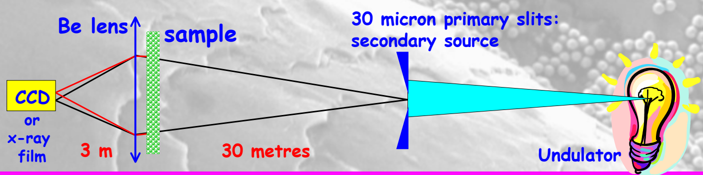
Abstract

We report the application of microradian x-ray diffraction (µradXRD) to colloidal and photonic crystals with *d*-spacing of order 10^3-10^4 Å. Using x-ray refractive optics we achieve resolution of the order of a few microradian, which allows not only for diffraction measurements at extremely small angles, but also the determination of long-range order parameters from the width of the Bragg peaks.

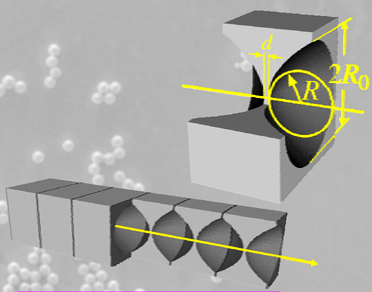
Optical scheme



- Be lens makes an image of the 30 µm primary slits on the detector
- Zoom factor 1:10
  - => theoretically one can expect 3 µm spots
  - => @ 3 m sample detector distance = 1 µrad resolution

in practice - we got to 7 µrad in digital data and 2 µrad on films (see Part IV).

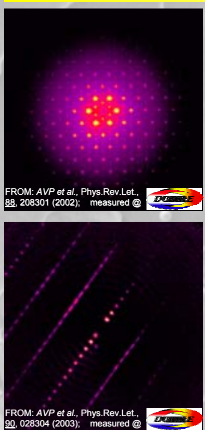
Refractive optics: Be lenses



sketch of a single Be lens & a stack of lenses

Photo of the stack used in the experiment

Part I: from milli- to micro-radian



Self-organised silica hard-sphere crystals

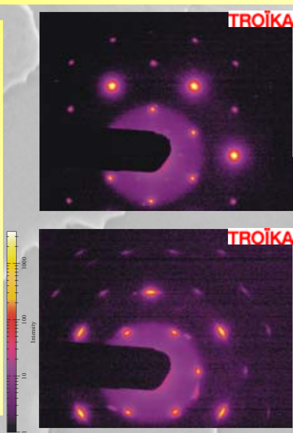
LEFT:
how it was (2001):

XRD patterns from a randomly stacked hexagonal close-packed (rhcp) colloidal crystal with (sub)milliradian resolution:

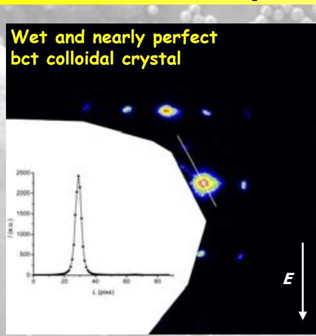
(resolution~150 µrad)

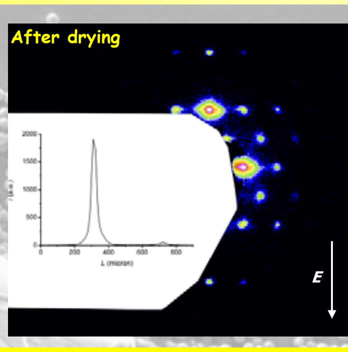
RIGHT:
how it is now (2004):

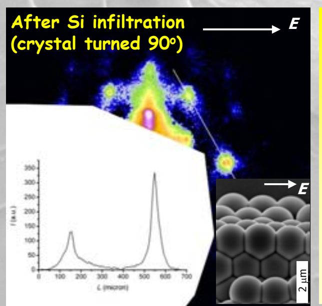
µradXRD patterns from a well-ordered and strained rhcp with crystal in the same system. The distinction was not possible before.



Part II: Infrared photonics







Body-centred tetragonal (bct) crystal

Silica (diameter 1.4 µm) spheres form bct crystals in an external electric field. To make a photonic crystal from such a template several steps are needed:

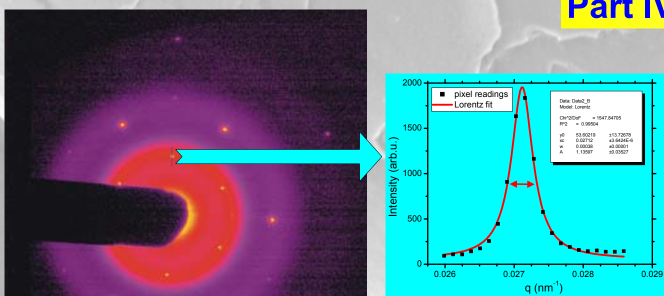
(1) Fixing spheres by a polymer network
(2) Drying the solvent out
(3) Silicon infiltration
(4) Etching the spheres away

Unfortunately, the structure degrades. We use µradXRD to verify the structure at different steps in order to improve the fabrication process.

Part III: Wall crystallisation

Latex hard-sphere colloid

µradXRD pattern of an rhcp crystal at the capillary wall coexisting with colloidal fluid in the bulk

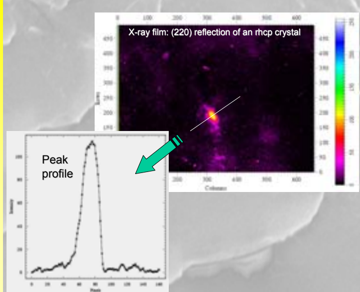


Part IV: How far did we get?

Peak profiles

LEFT: Profile through a Bragg peak: Lorentz fit yields full-width-at-half-maximum (FWHM) of about 3 pixels corresponding to **0.00038 nm^{-1}** or less than **7 µrad !**

Yet, this was limited by the detector resolution. Optics can do even better! We have also used high-resolution x-ray films (RIGHT) to record diffraction patterns. They show 5.5 µm spot @ 3 metres distance, or about **2 µrad !**



See also

(for our x-ray studies):

A.V. Petukhov et al., Phys.Rev.Lett., 88, 208301 (2002); ESRF Highlights 2002, 19-20; Phys.Rev.Lett., 90, 028304 (2003); ESRF Newsletter, v. 38, 19-20 (2003); Phys. Rev. E, 69, 031405 (2004).

(for photonic crystals):

A. Yethiraj & A. van Blaaderen, Nature, 421, 513 (2003).

Acknowledgements

It is our pleasure to thank the staff of the TROIKA beamline: Anders Madsen, Federico Zontone, Andrei Fluerasu, Henri Gleyzolle & Patrick Feder for excellent support; Marc Diot & Cyril Ponchut for the detector; ESRF for granting us the beamtime.