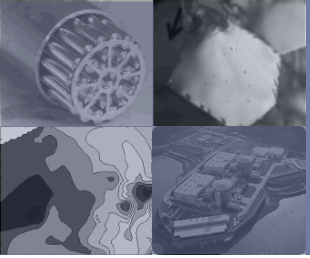


Texture

Levente Balogh

Department of Mechanical and Materials Engineering, Queen's University, Kingston, ON, Canada

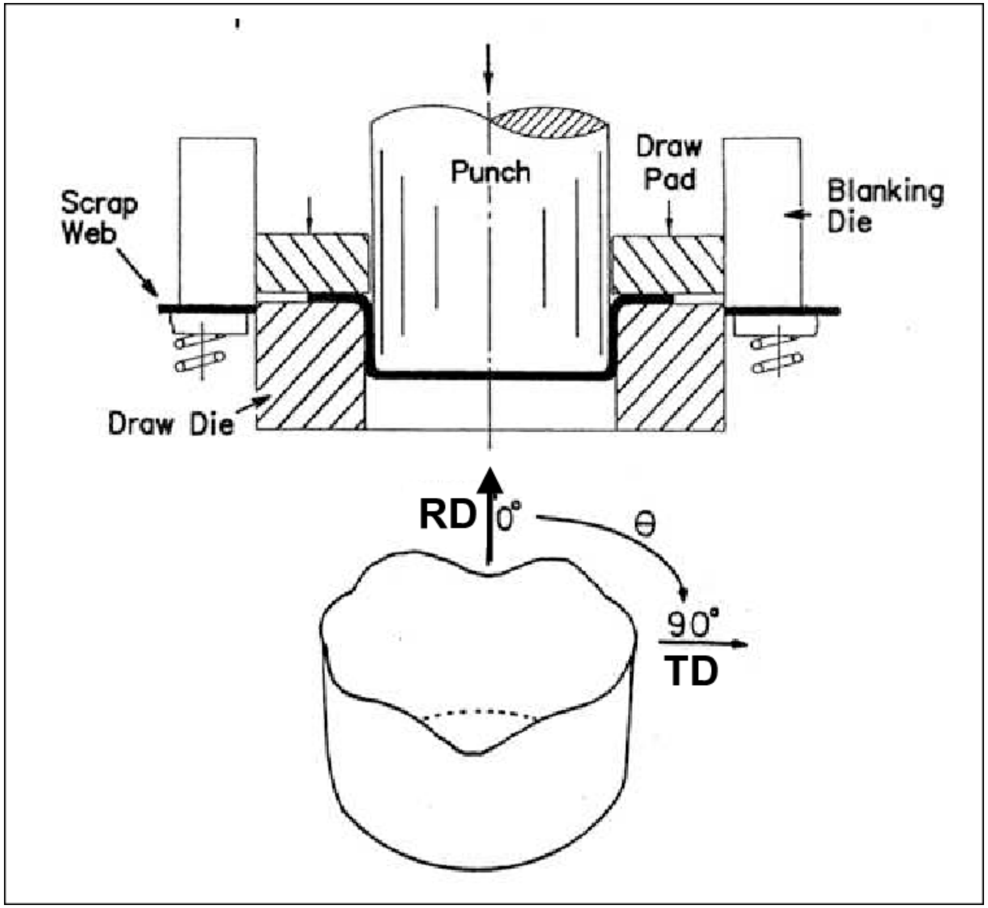
18th Canadian Powder Diffraction Workshop
28 – 31 Jul 2025

Outline

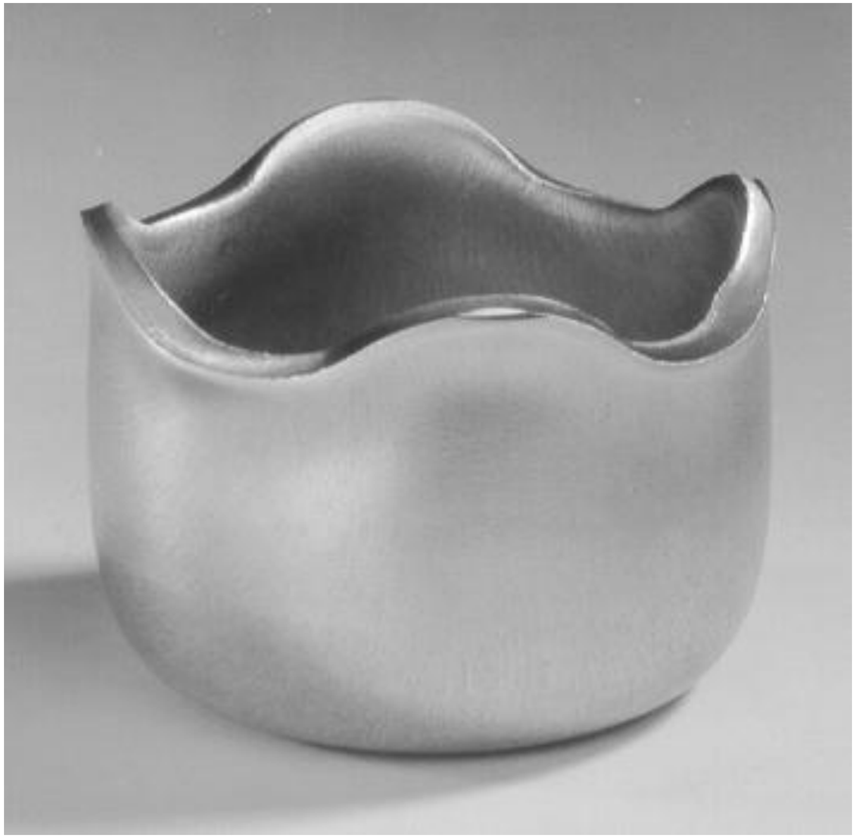
- Introduction
- What is Crystallographic Texture?
  - Examples
- Visualise Texture: Pole Figures
- Quantifying texture:
  - Euler angles
  - ODF: Orientation Distribution Function
- How can one measure crystallographic texture?
  - Electron Backscatter Diffraction (EBSD)
  - X-ray Diffraction (XRD)
  - Neutron Diffraction (ND)
  - High-Energy Synchrotron X-ray Diffraction
  - Other ND methods

Crystallographic texture: makes materials anisotropic

Earing formation during the deep drawing of cups made from circular blanks which were cut from a rolled Al plate

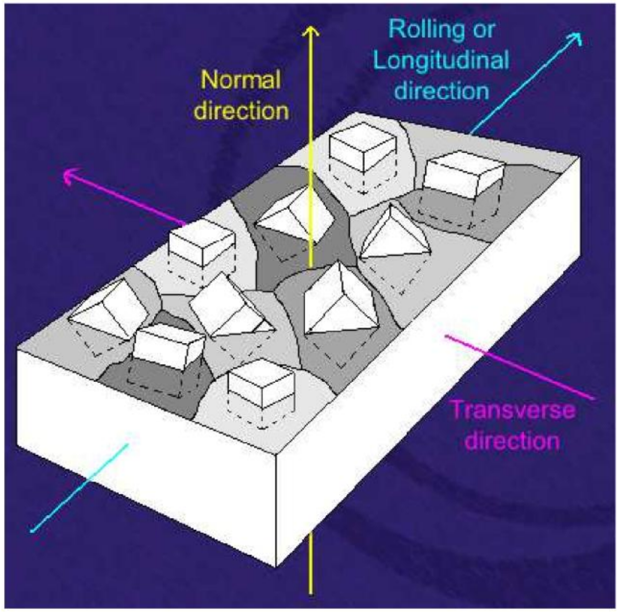


J. Hirsch, *TMS Light Metals., (2008)*

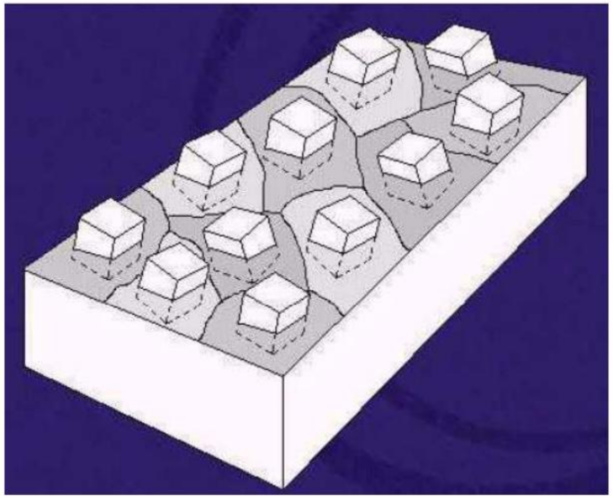


E. Olaf, J. Hirsch, *Virtual Fabrication of Aluminium Products, (2006), 189-198*

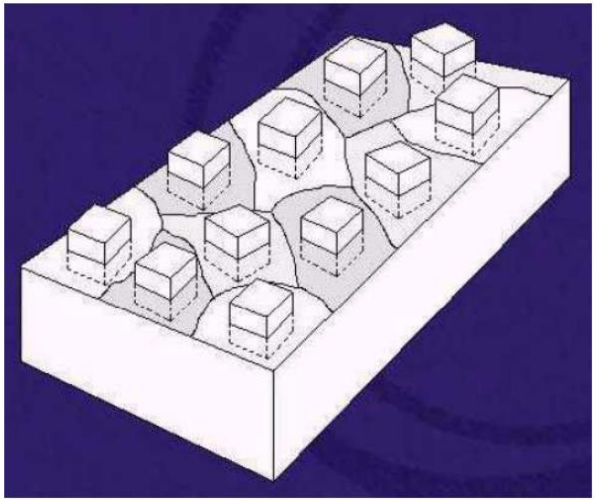
Crystallographic texture: preferred orientation of crystallites with respect to the sample coordinate system



Random orientation



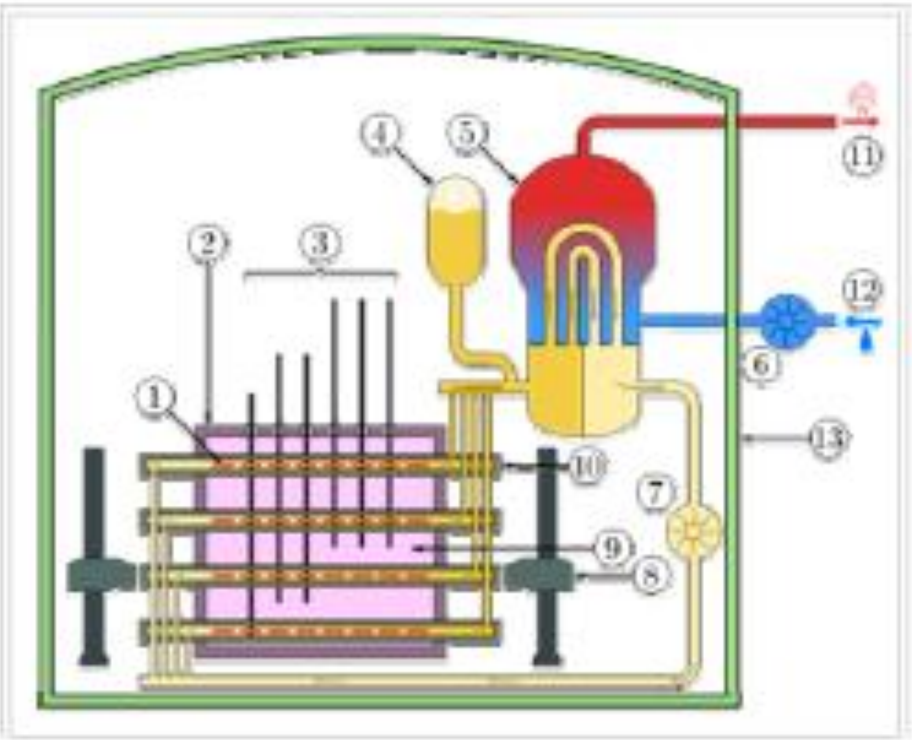
Preferred orientation

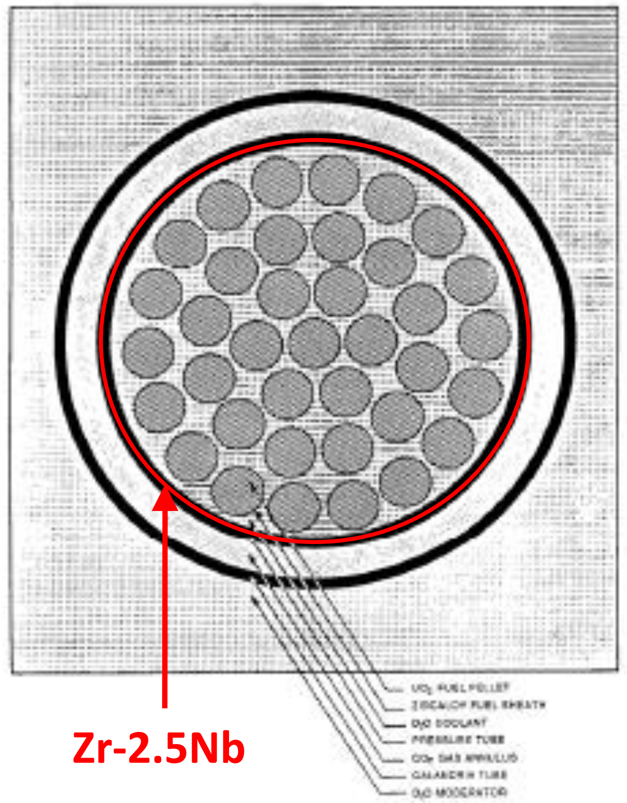


Highly oriented - close to a single crystal

OXFORD INSTRUMENTS

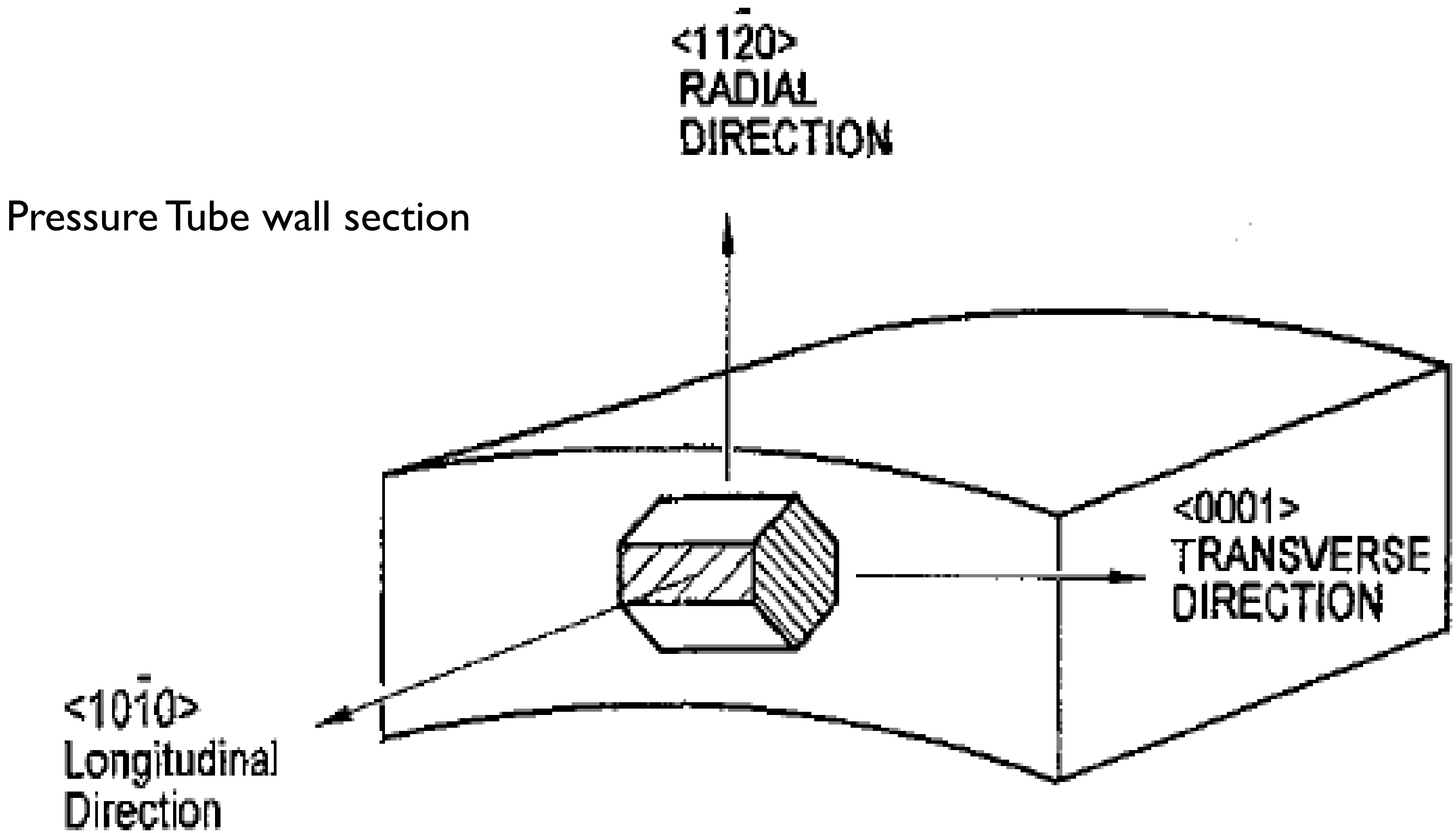
Zr-2.5Nb alloy Pressure Tubes in CANDU





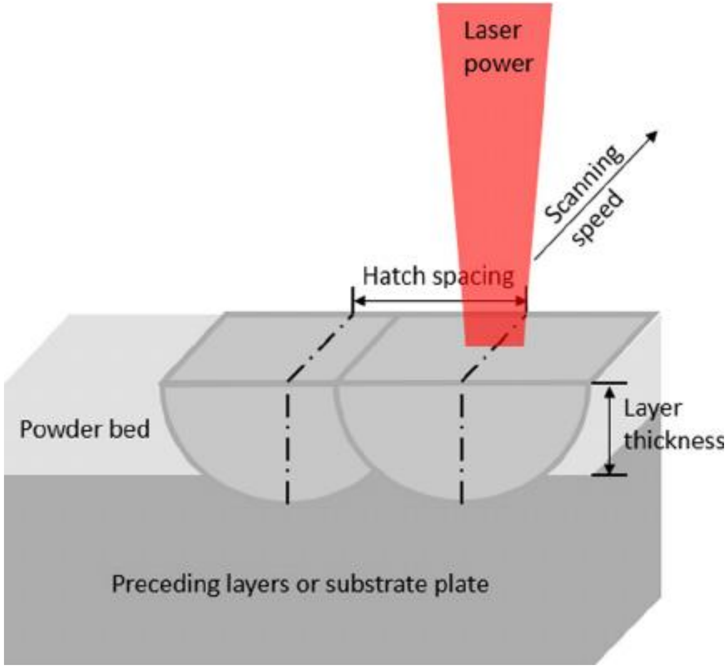
CANDU Basic Lattice Cell for 37-Element Fuel (Not to Scale)

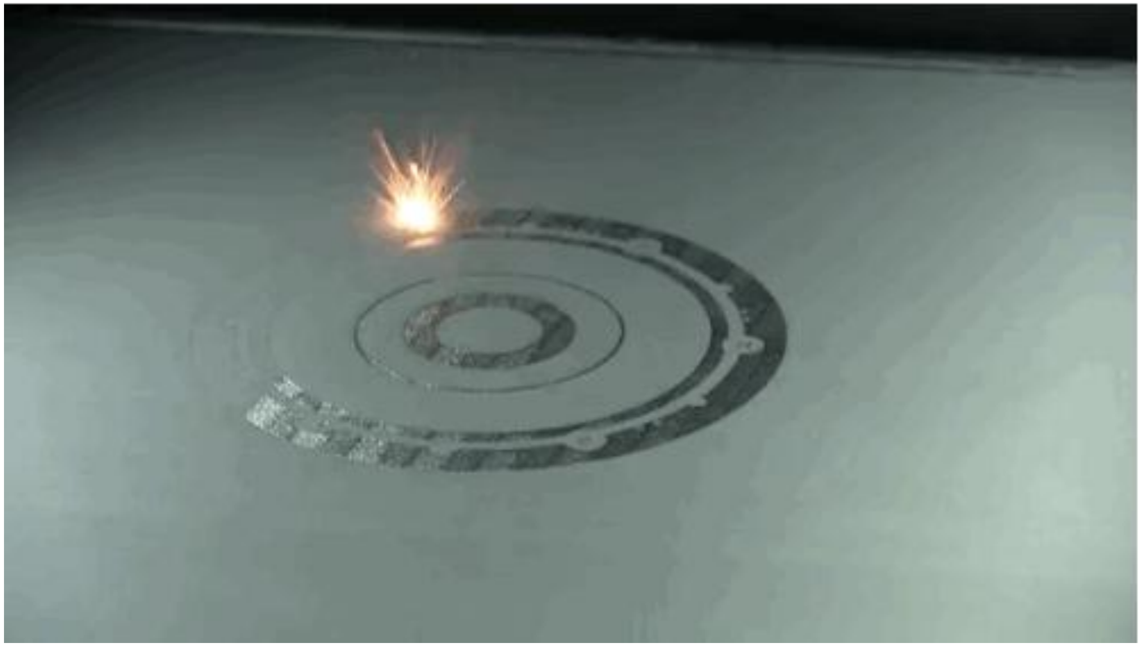
CANDU Zr-2.5Nb alloy Pressure Tubes have a very specific texture created by the manufacturing process



D.D. Radford and M.J. Worswick,
J. Phys. IV France 10 (2000)

Metals made by Additive Manufacturing (3D printing) typically develop strong crystallographic textures





T. Debroy et al., *J. Mater. Sci. Technol., 92, (2018) 112–224.*

https://giphy.com/explore/laser-sintering

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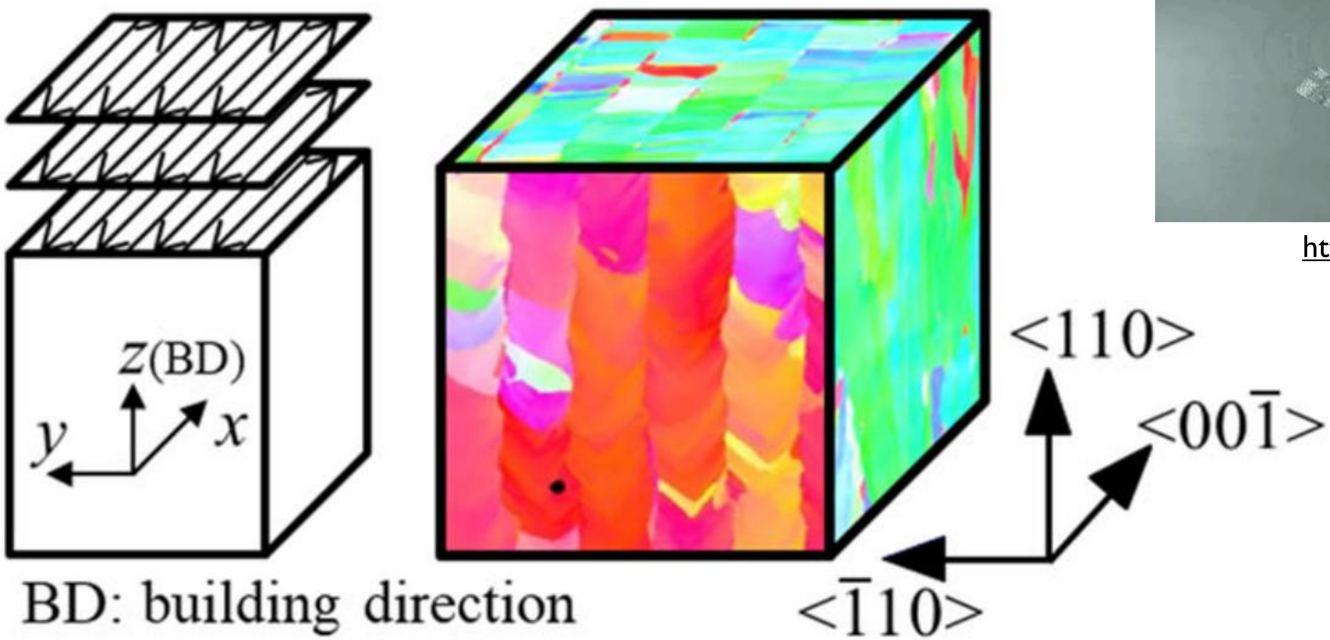

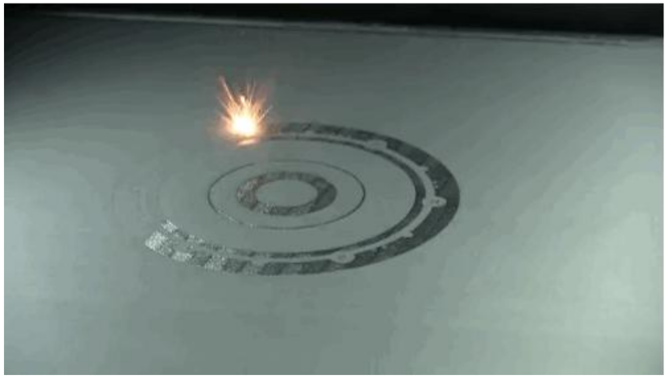

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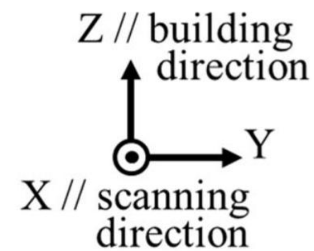


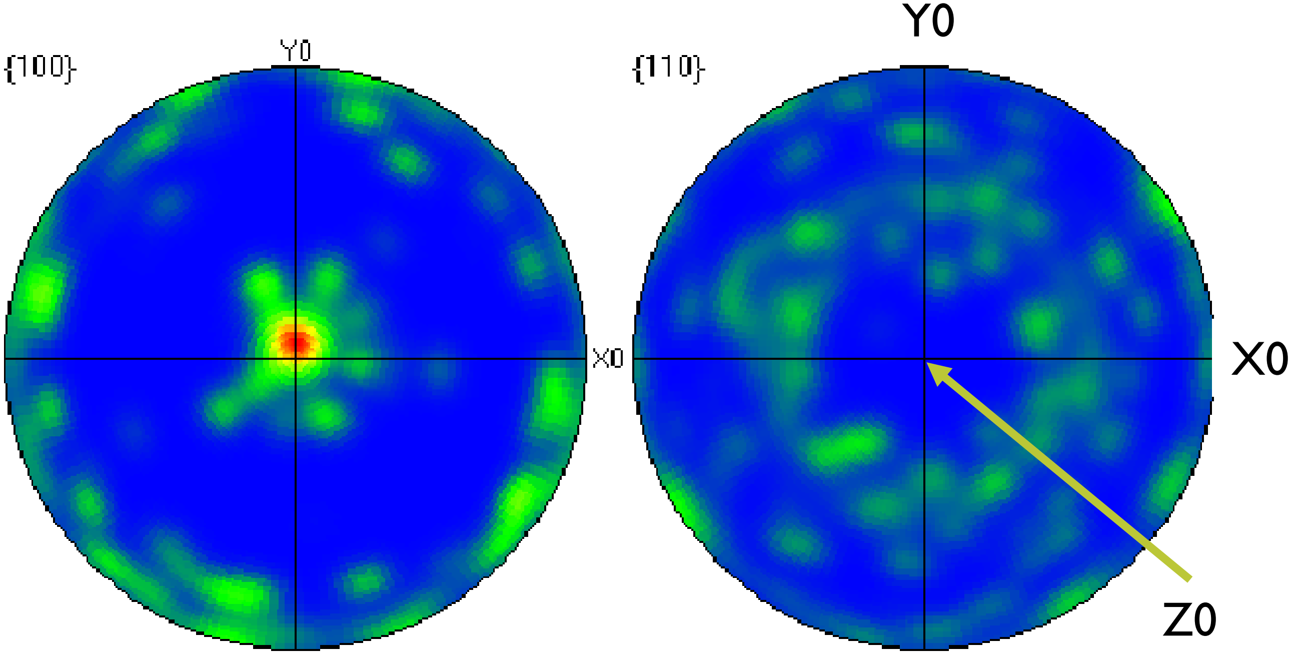
Texture of Additively Manufactured Ti-15Mo-5Zr-3Al alloy (bcc structure)

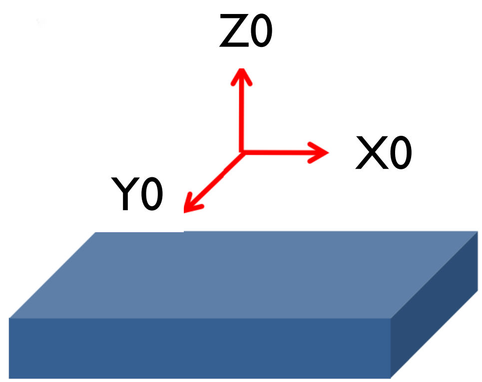
Hagihara, K., and Nakano, T., *JOM*, **74** (2022) 1760-1773.

Pole Figures: a method (from many) to visualize the crystallographic texture of polycrystals

A **Pole Figure** plots the distribution of crystallographic directions/planes in the sample coordinate system.

Pole Figures typically use **Stereographic Projection** to represent vector directions on a plane





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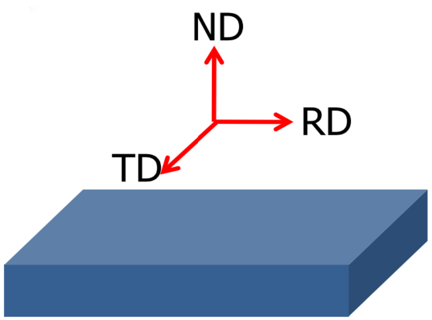
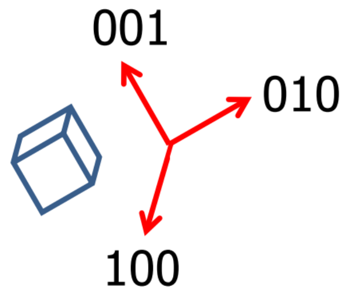
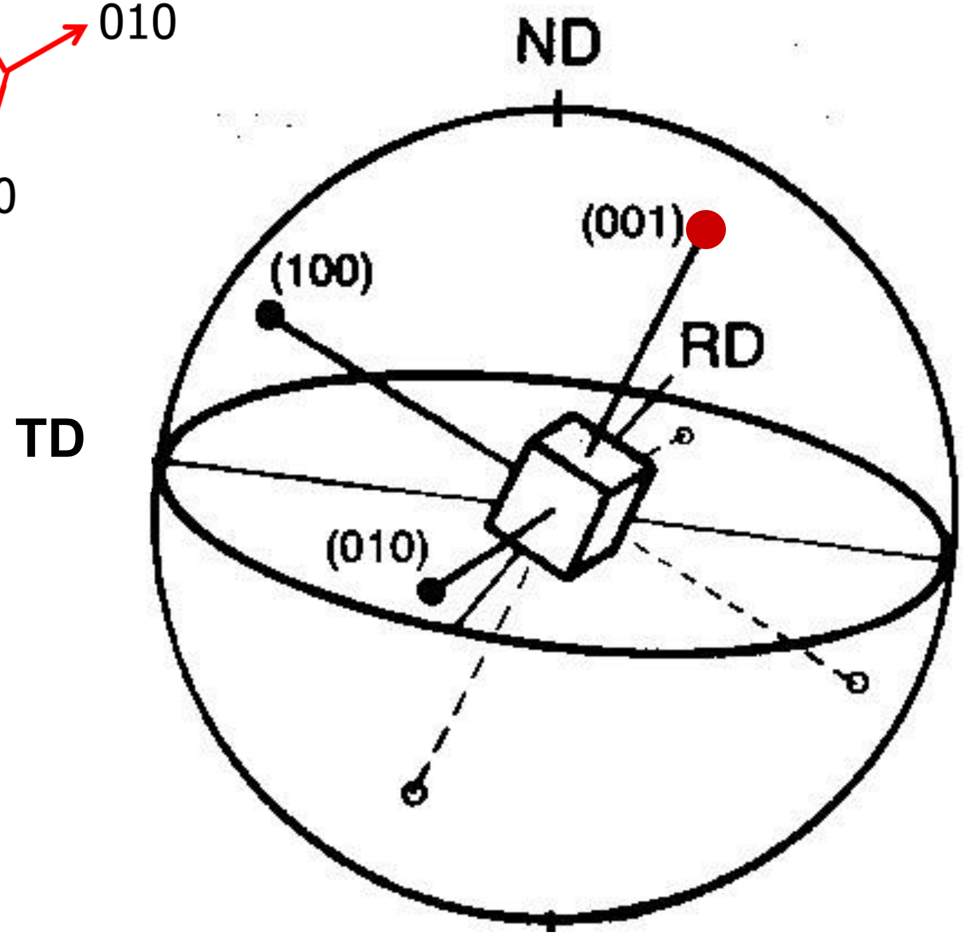
Constructing a Stereographic Projection







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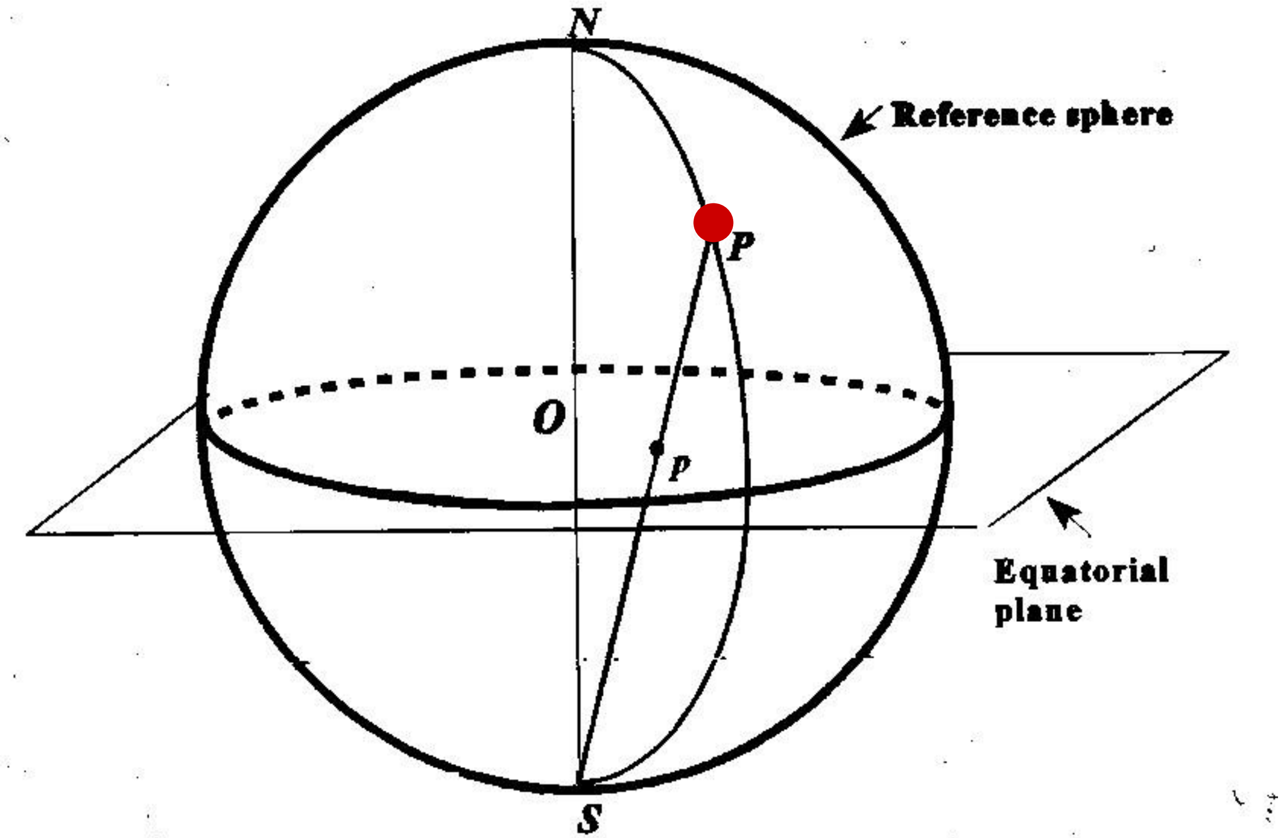
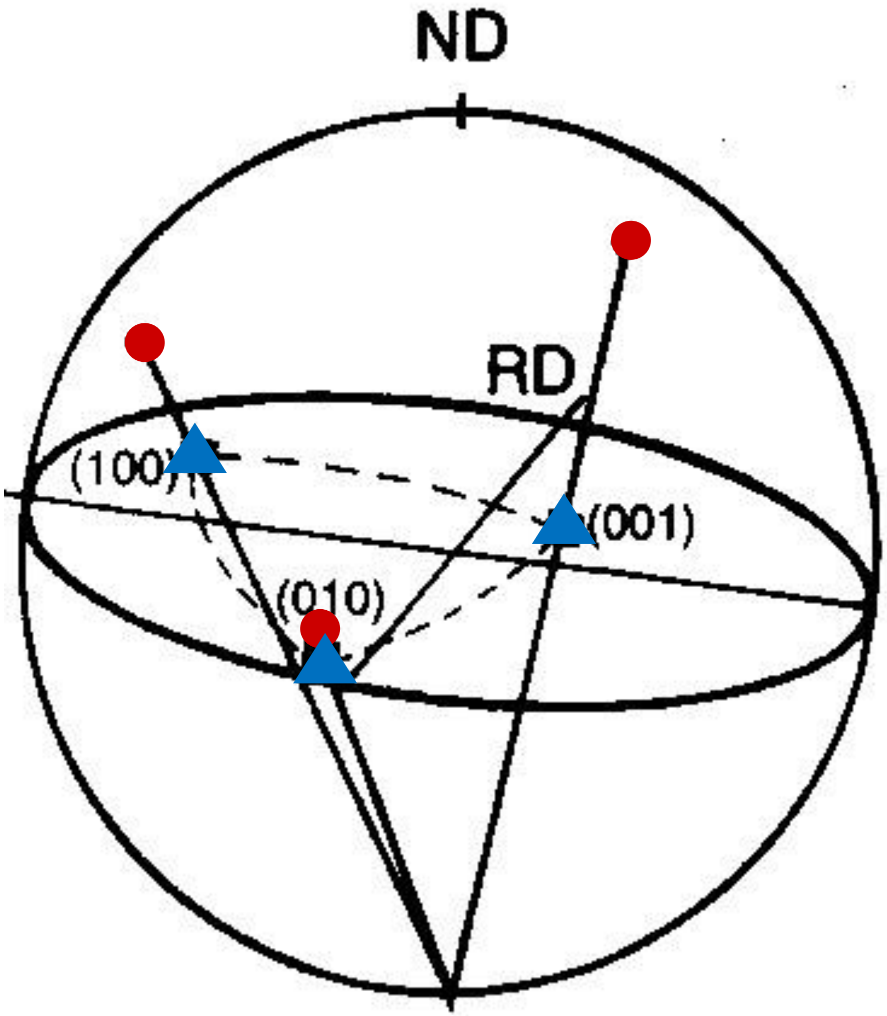


Stereographic Projection- Plane normal P is projected towards the south pole onto the equatorial plane at p. Angular relations are preserved in the projection and traditionally measured by a Wulff net.

Constructing a Stereographic Projection



Projection of all the {100} poles onto the equatorial plane using the stereographic projection.

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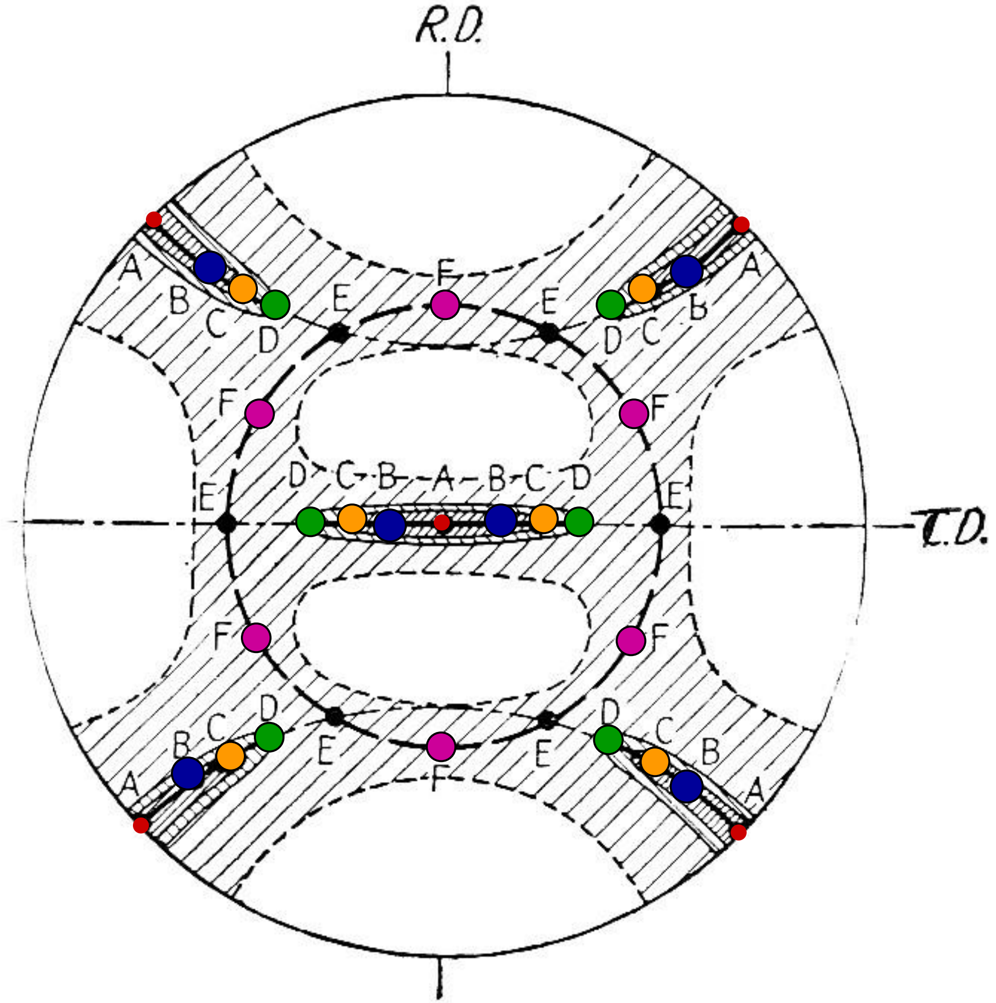
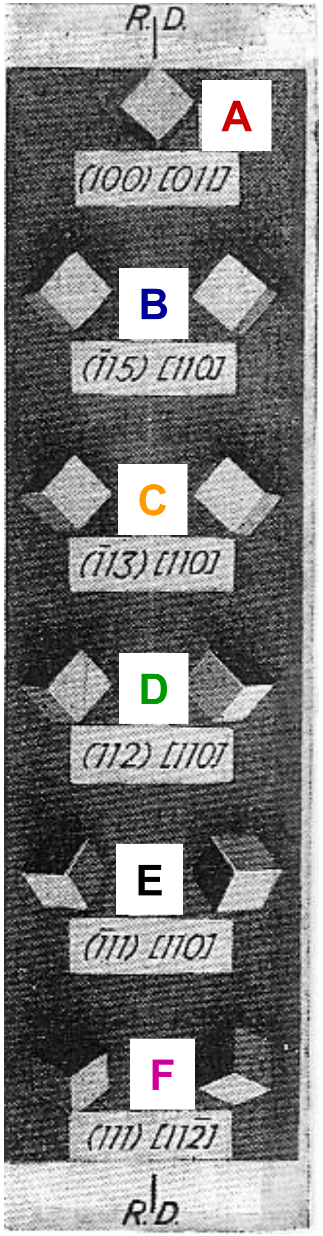
Queen's University

Pole Figures constructed with Stereographic Projection





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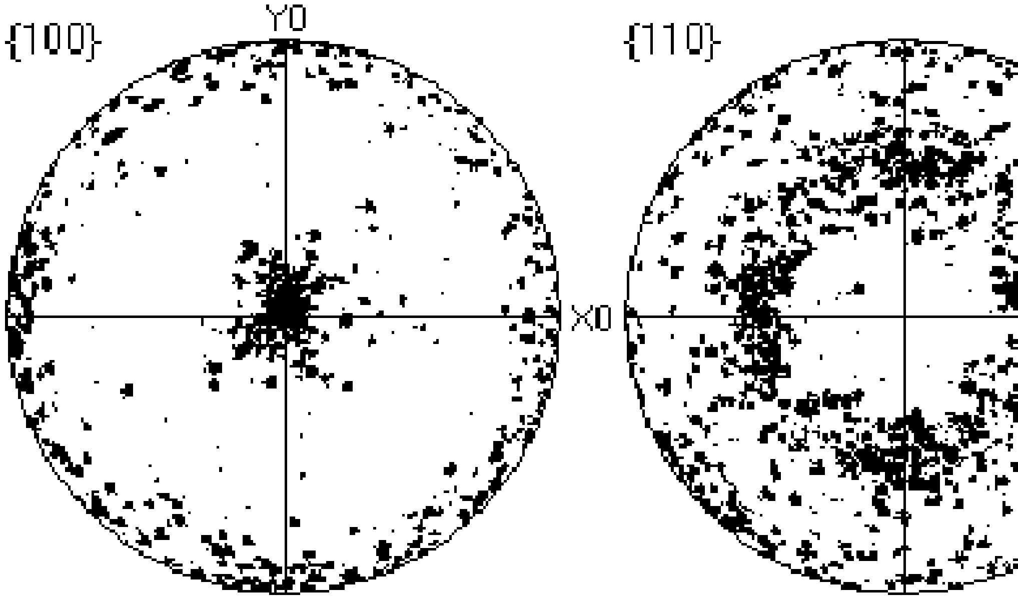
Pole Figures:
visualize the crystallographic texture of polycrystals



Stereographic projections of {100}, {110} and {111} discrete pole figures for Al.

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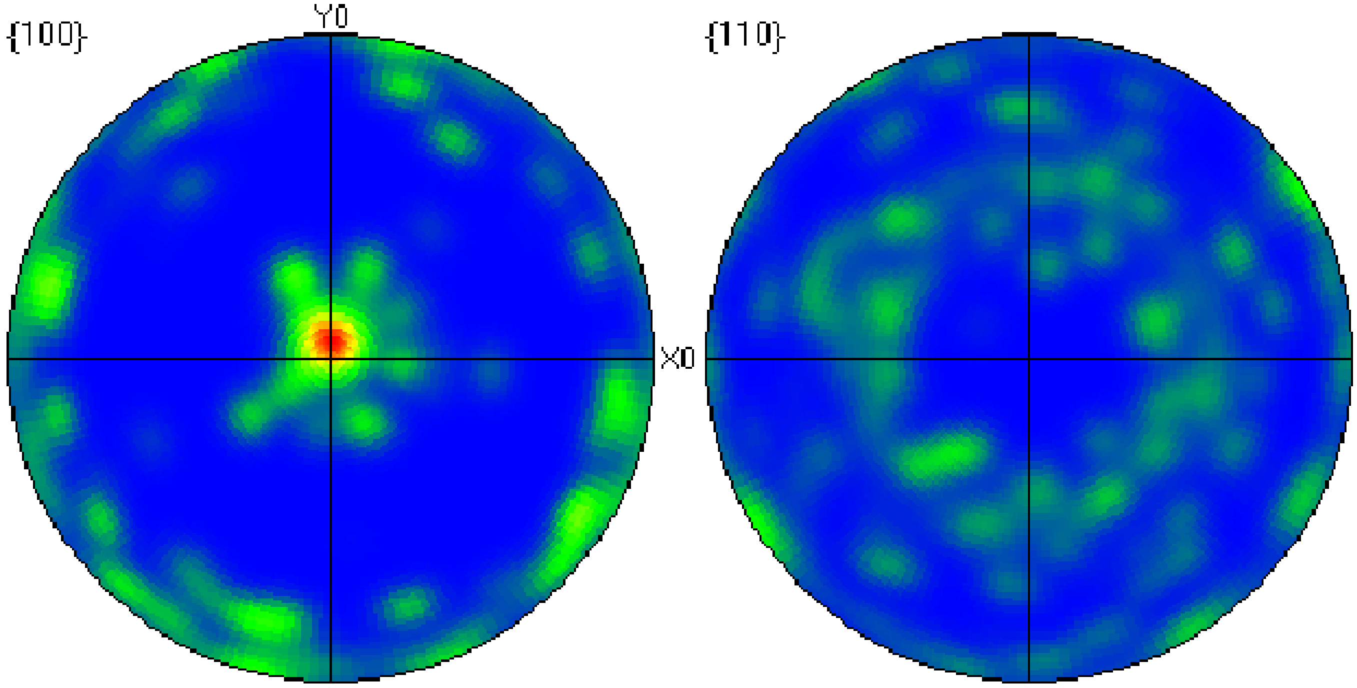
Pole Figures:
visualize the crystallographic texture of polycrystals



Stereographic projections of {100} and {110} contoured pole figures for Al
Compare to the discrete ones on previous slide.

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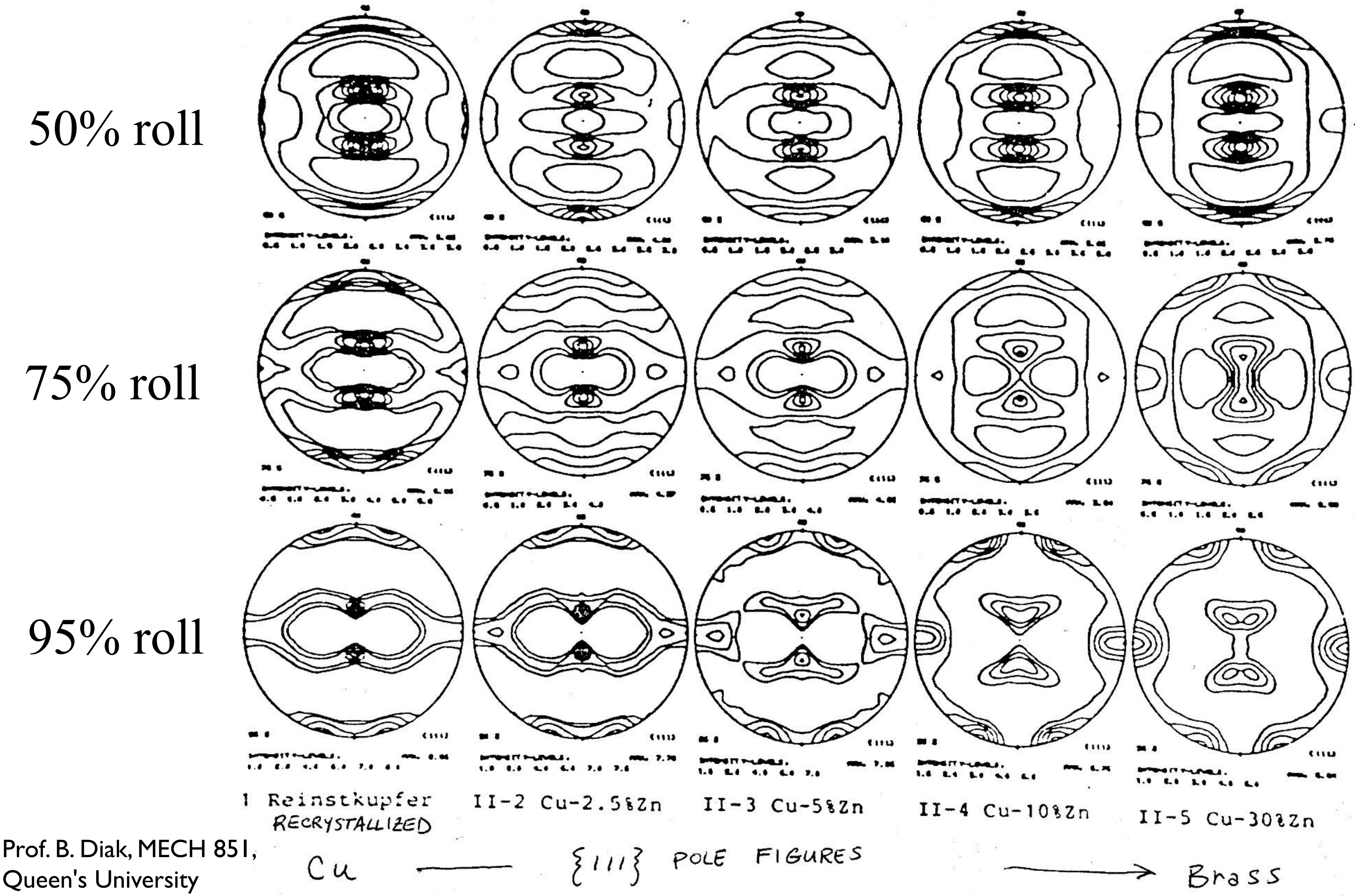
Pole Figures: visualize the crystallographic texture of polycrystals



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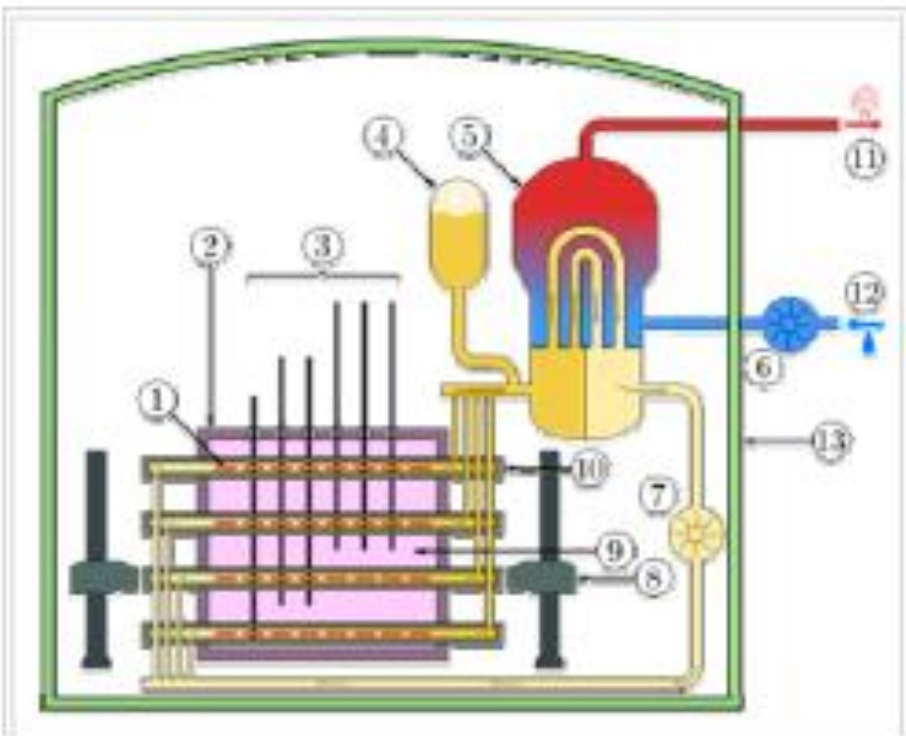
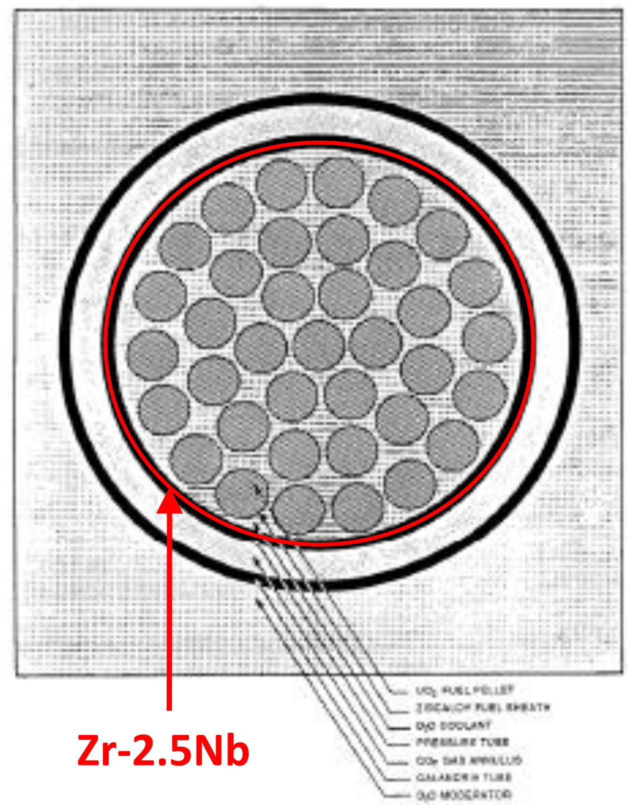
Zr-2.5Nb alloy Pressure Tubes in CANDU





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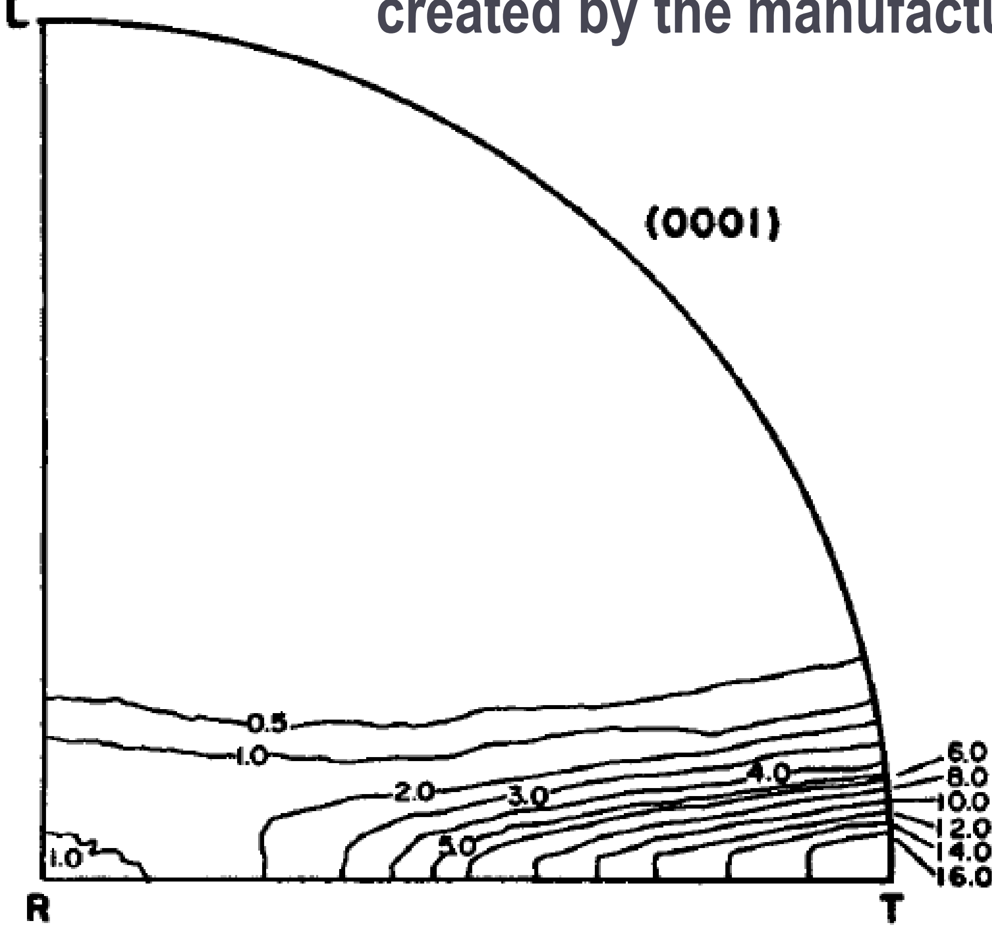
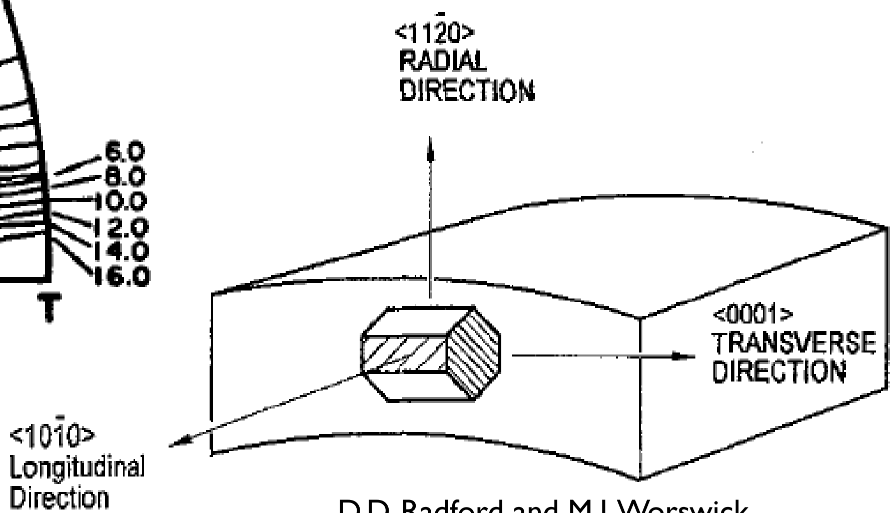


D.D. Himbeault, C.K. Chow, and M.P. Puls, Met. Mat. Trans. A, (1994) 25A 135-145.



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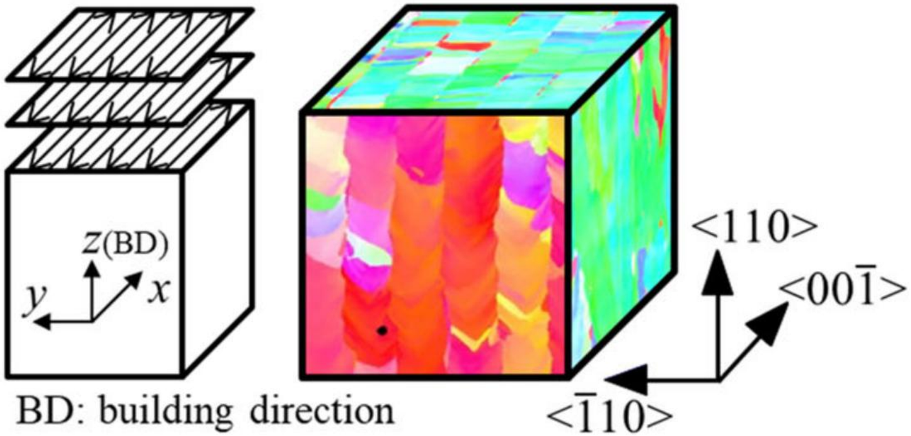

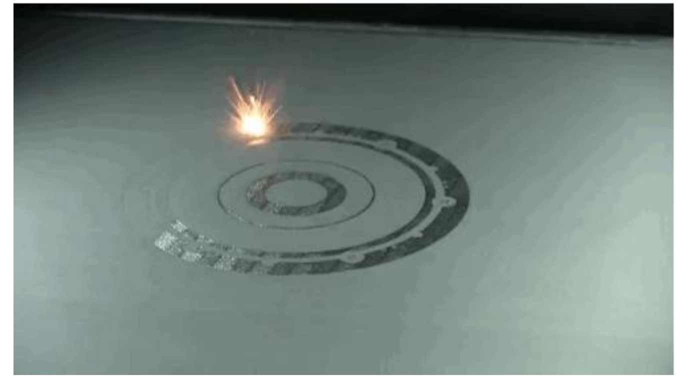

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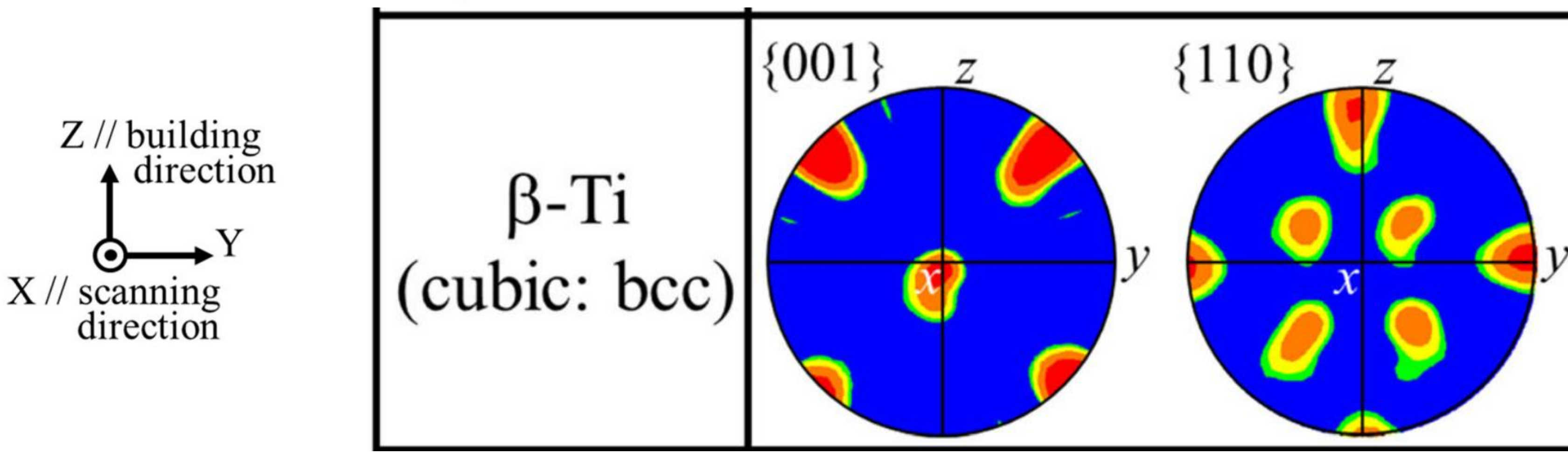


Texture of Additively Manufactured Ti-15Mo-5Zr-3Al alloy (bcc structure)

Hagihara, K., and Nakano, T., *JOM*, **74** (2022) 1760-1773.

Describe the orientation of one grain/crystallite mathematically

The orientation of a crystal, i.e., a 3D object, can be described by the same mathematical framework as 3D rotations. Such a description needs 3 parameters:

- Euler angles (ϕ_1, ϕ_2, Φ) – most popular
- Quaternions

Describe the orientation of one grain/crystallite mathematically: Quaternions

- In mathematics, **the quaternion number system extends the complex numbers.**
- **Quaternions** are used in pure mathematics, but also have practical uses in applied mathematics, particularly for calculations involving **three-dimensional rotations**, such as in three-dimensional computer graphics, computer vision, robotics, magnetic resonance imaging and **crystallographic texture analysis**.

$$a + b\,\mathbf{i} + c\,\mathbf{j} + d\,\mathbf{k}$$

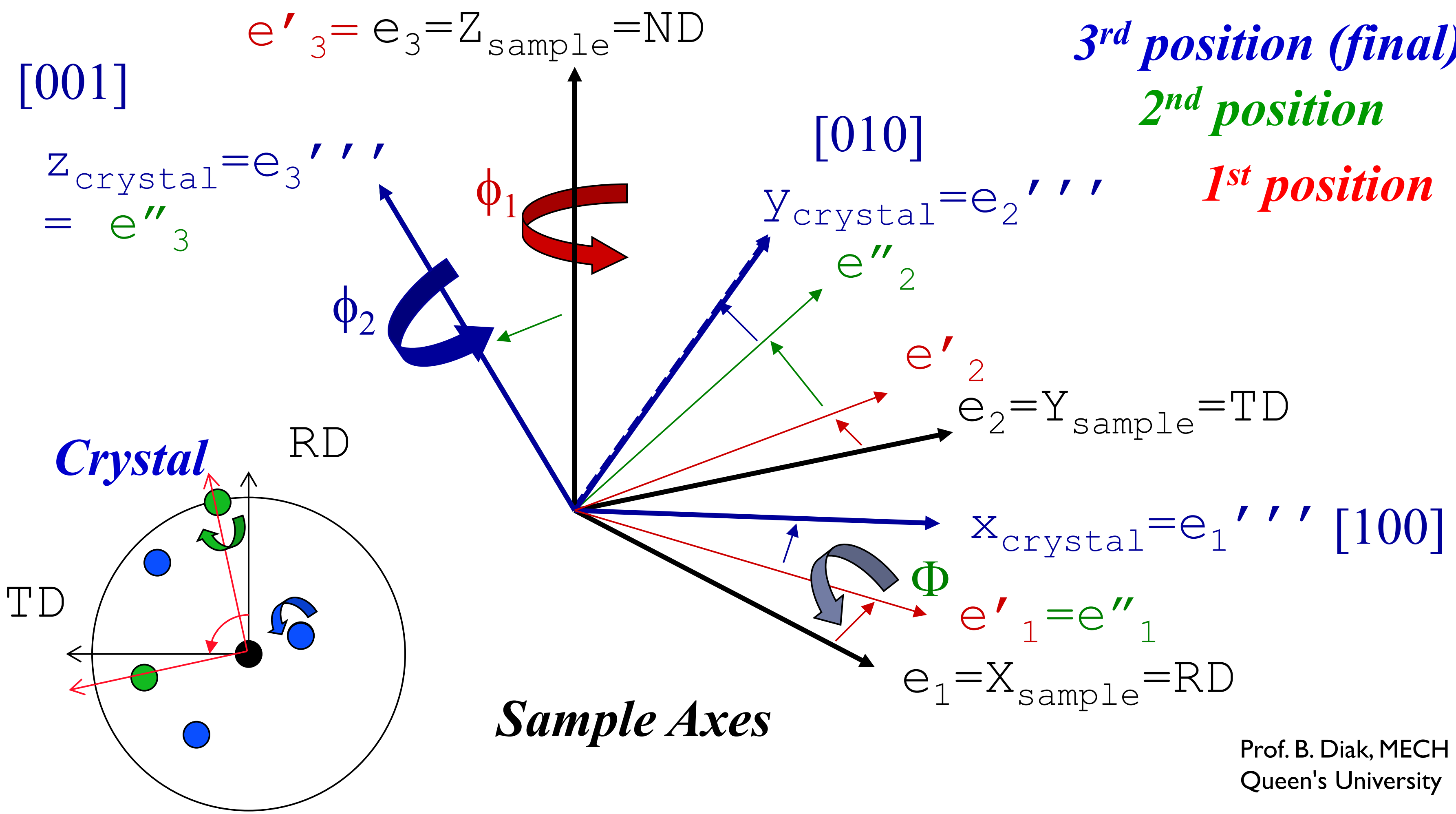
https://en.wikipedia.org/wiki/Quaternion

Multiplication table

Non commutativity is emphasized by colored squares

×	1	i	j	k
1	1	i	j	k
i	i	−1	k	−j
j	j	−k	−1	i
k	k	j	−i	−1

Describe the orientation of one grain/crystallite mathematically: Euler angles (ϕ_1, ϕ_2, Φ)



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Describe the orientation of one grain/crystallite mathematically: Euler angles (ϕ_1, ϕ_2, Φ) Bunge notation

Rotation 1 (ϕ_1): rotate axes (anticlockwise) about the (sample) 3 [ND] axis; $\mathbf{Z}_1$.

Rotation 2 (Φ): rotate axes (anticlockwise) about the (rotated) 1 axis [100] axis; **X**.

Rotation 3 (ϕ_2): rotate axes (anticlockwise) about the (crystal) 3 [001] axis; $\mathbf{Z}_2$.

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Describe the crystallographic texture of a large population of grains the Orientation Distribution Function (ODF)

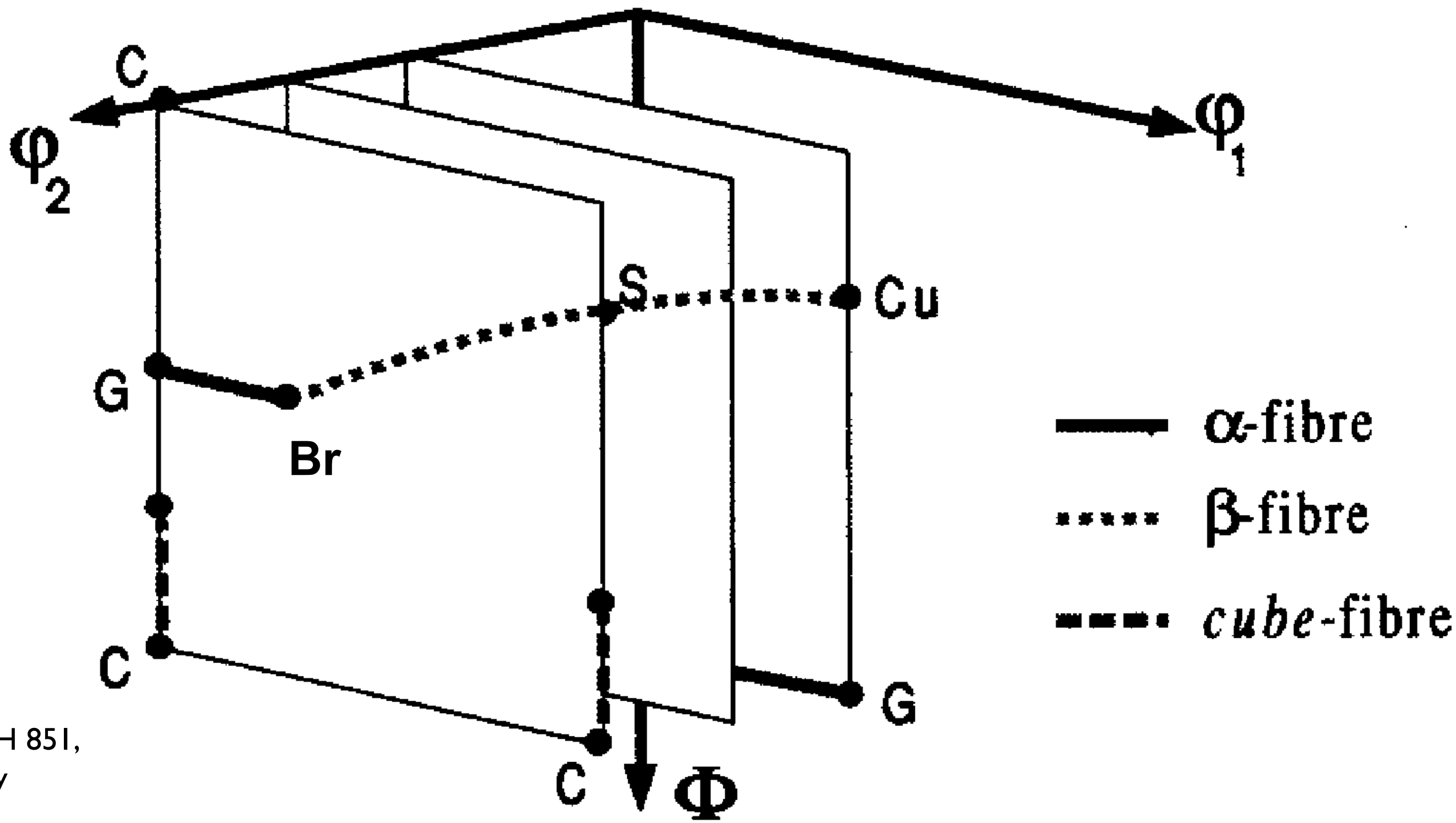
ODF:

- Assigns to every possible orientation represented by a set of Euler angles (ϕ_1, ϕ_2, Φ) a probability density (e.g., the volume fraction of grains with a certain orientation)
- A statistical distribution, which gives volume fraction *dV/V* of crystallites having the orientation *g* (i.e., (ϕ_1, ϕ_2, Φ)) within the orientation element *dg*:

$$dV / V = f(g)\, dg$$

- The ODF fully/statistically describes the texture of the given polycrystal
  - If the ODF is known a pole figure for any *(hkl)* can be derived from it

Describe the crystallographic texture of a large population of grains the Orientation Distribution Function (ODF)



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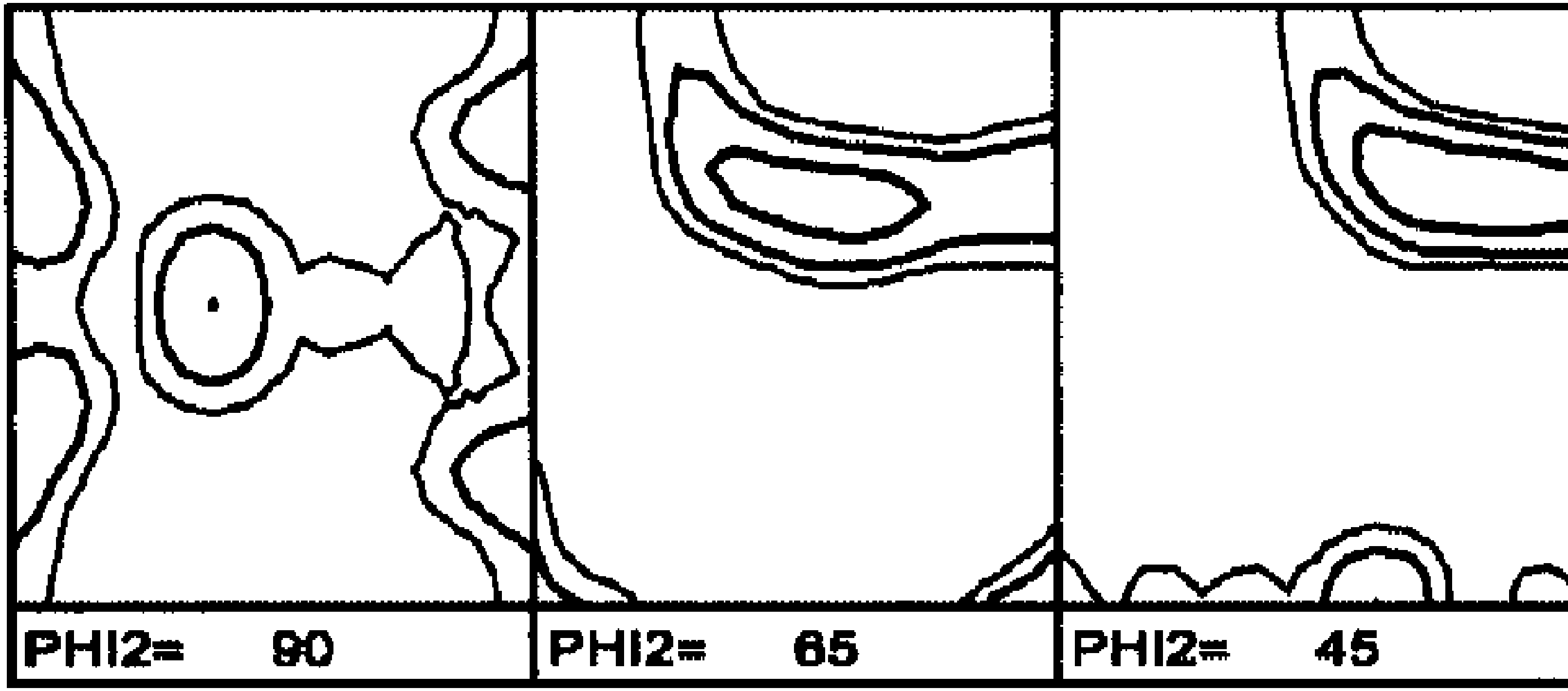
Identification of some common fcc texture components and fibres in Euler space.

Describe the crystallographic texture of a large population of grains the Orientation Distribution Function (ODF)

AA1050 Cold Rolled 60% ODF [from Delannay et al. (2002)]



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Measuring the Crystallographic Texture experimentally

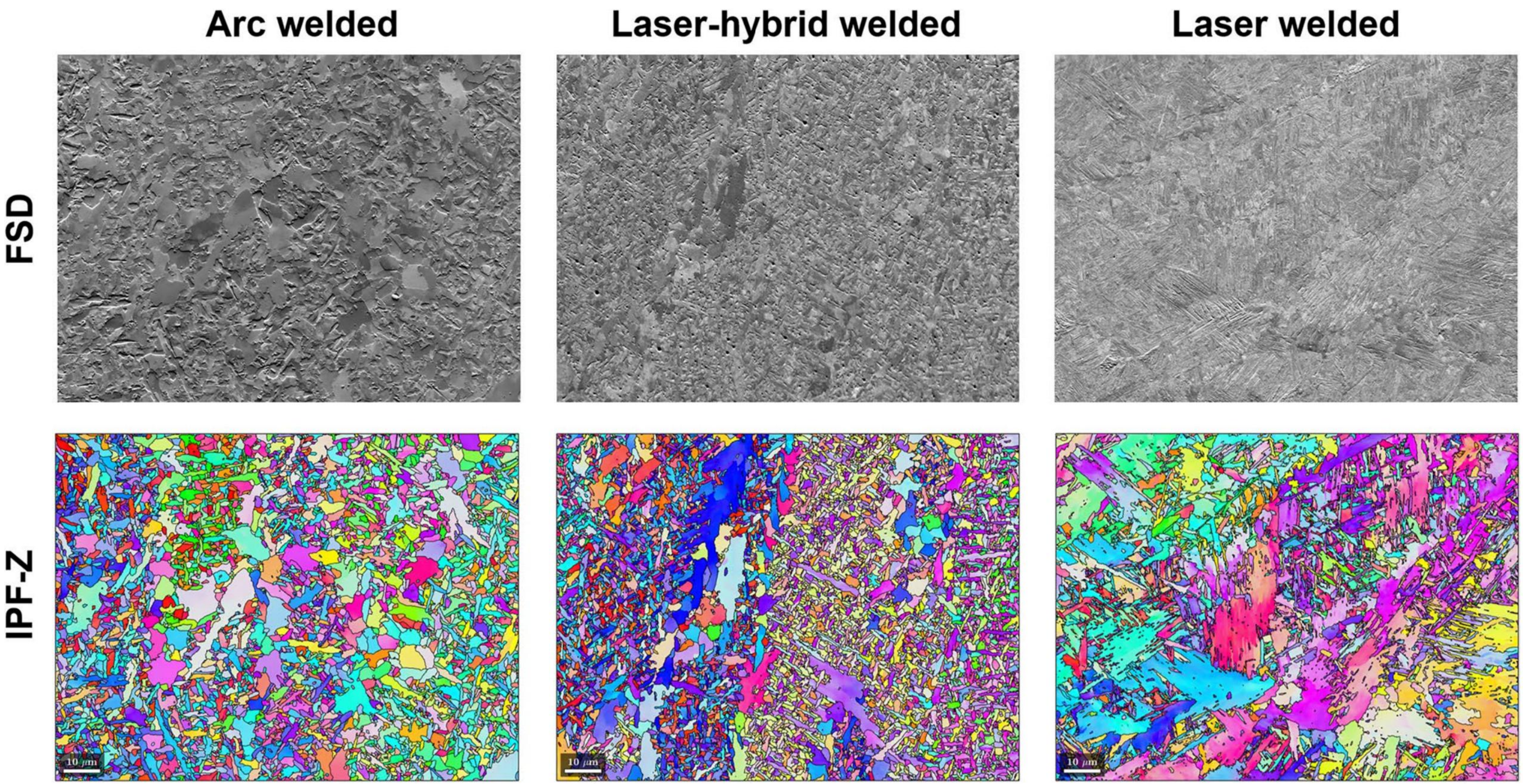
One way to approach Texture Measurements:

Measure a sufficient number of **pole figures** experimentally: *XRD, Neutron Diffraction, EBSD*

↓

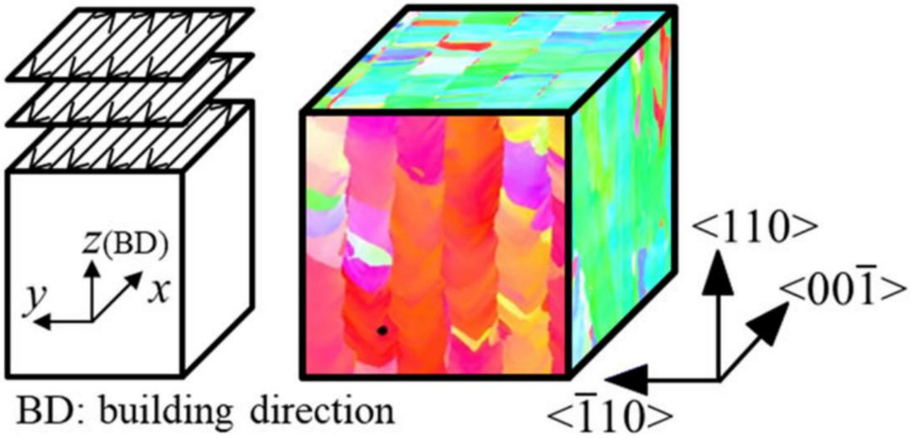
Calculate the **Orientation Distribution Function (ODF)**

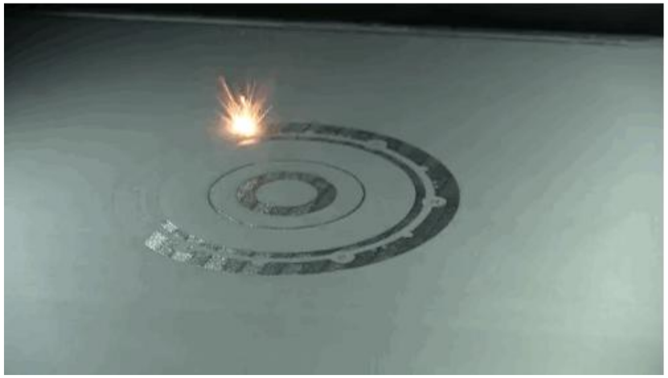
Measuring the Crystallographic Texture experimentally
Electron Backscatter Diffraction (EBSD)



Lehto et al., *Welding in the World, 66, (2022) 363–377.*

Measuring the Crystallographic Texture experimentally
Electron Backscatter Diffraction (EBSD)





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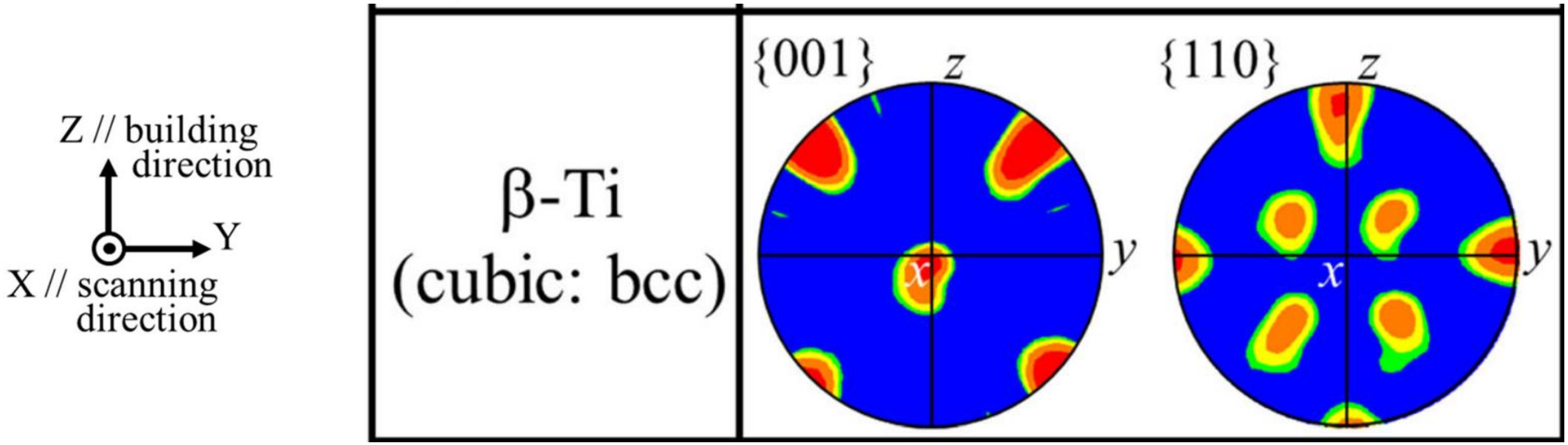

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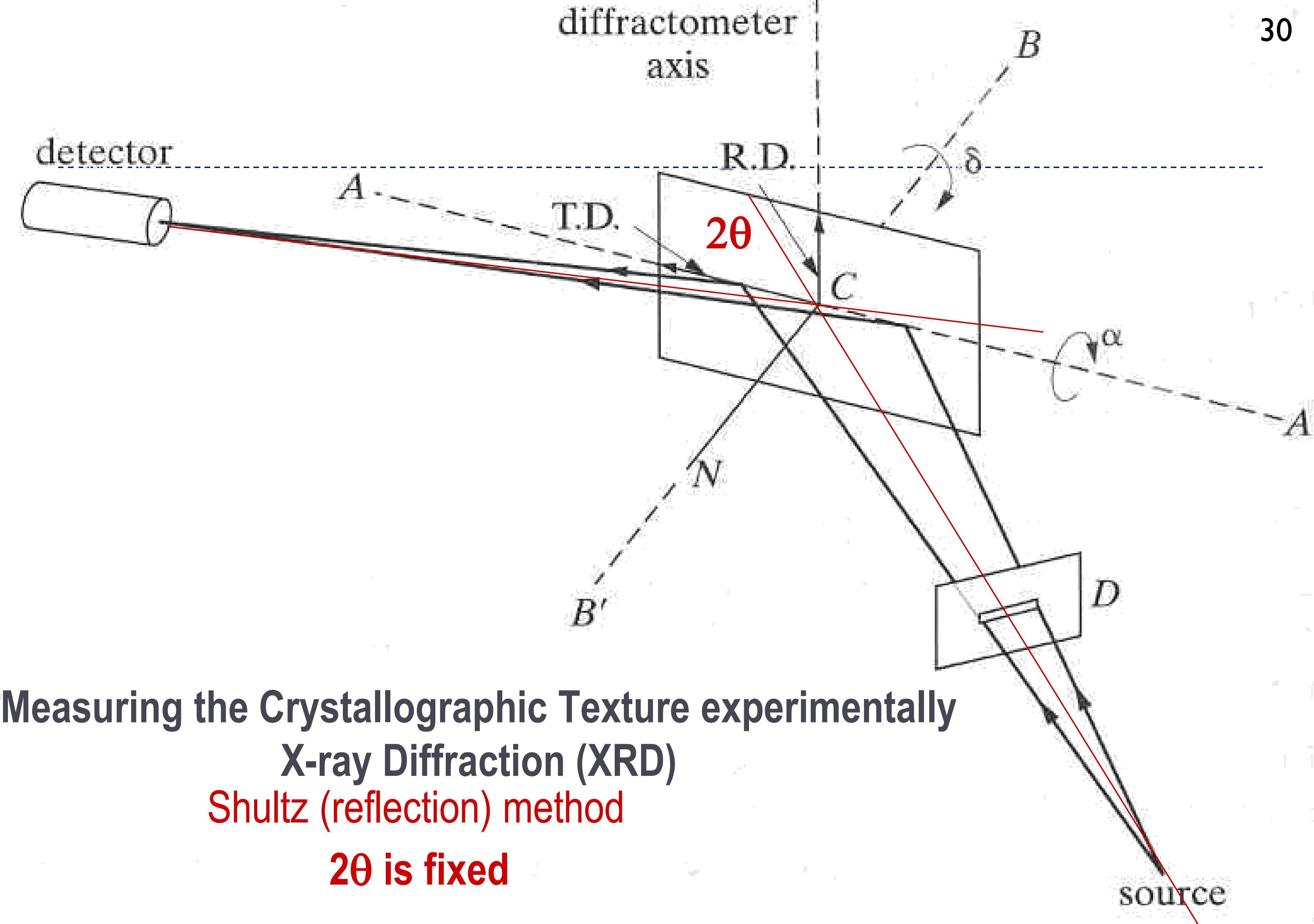


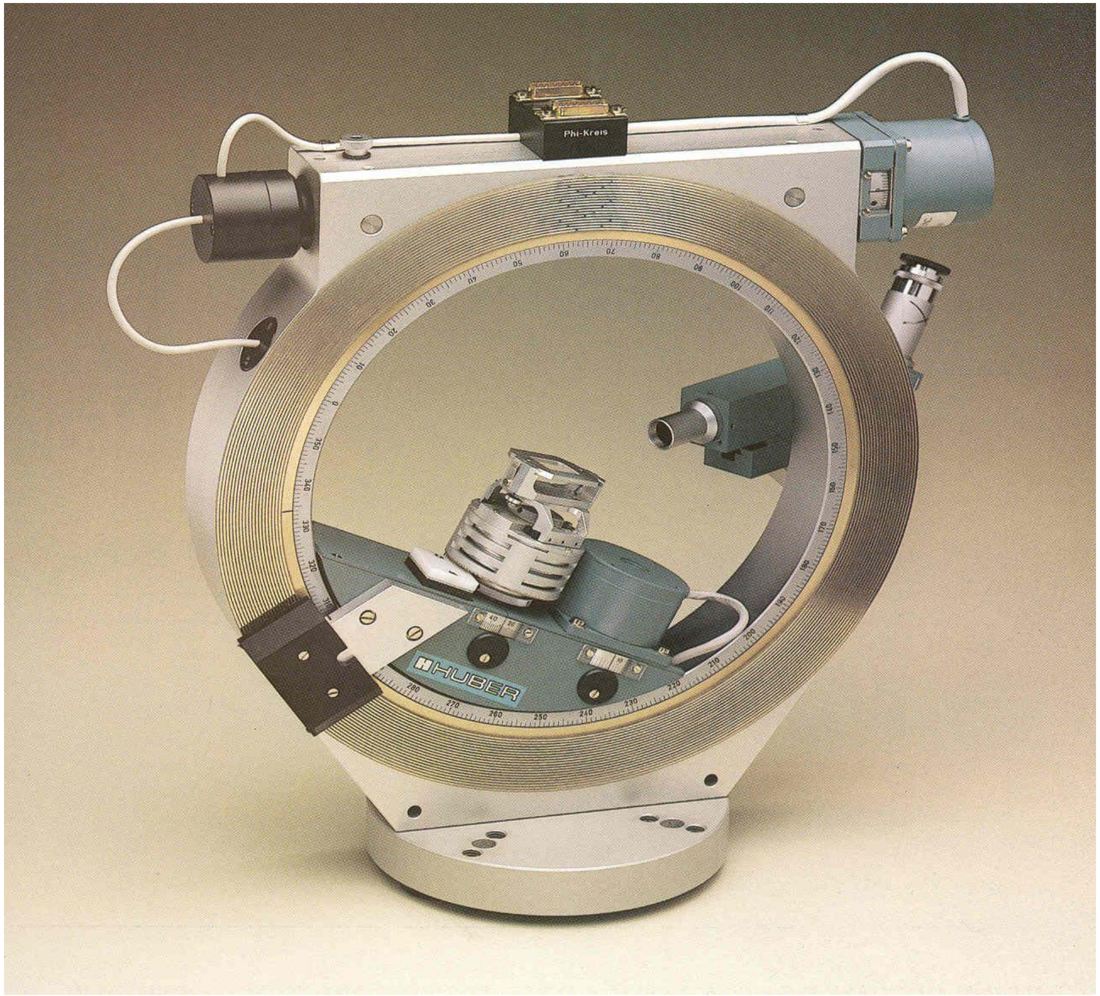
Measuring the Crystallographic Texture experimentally
X-ray Diffraction (XRD)

Shultz (reflection) method

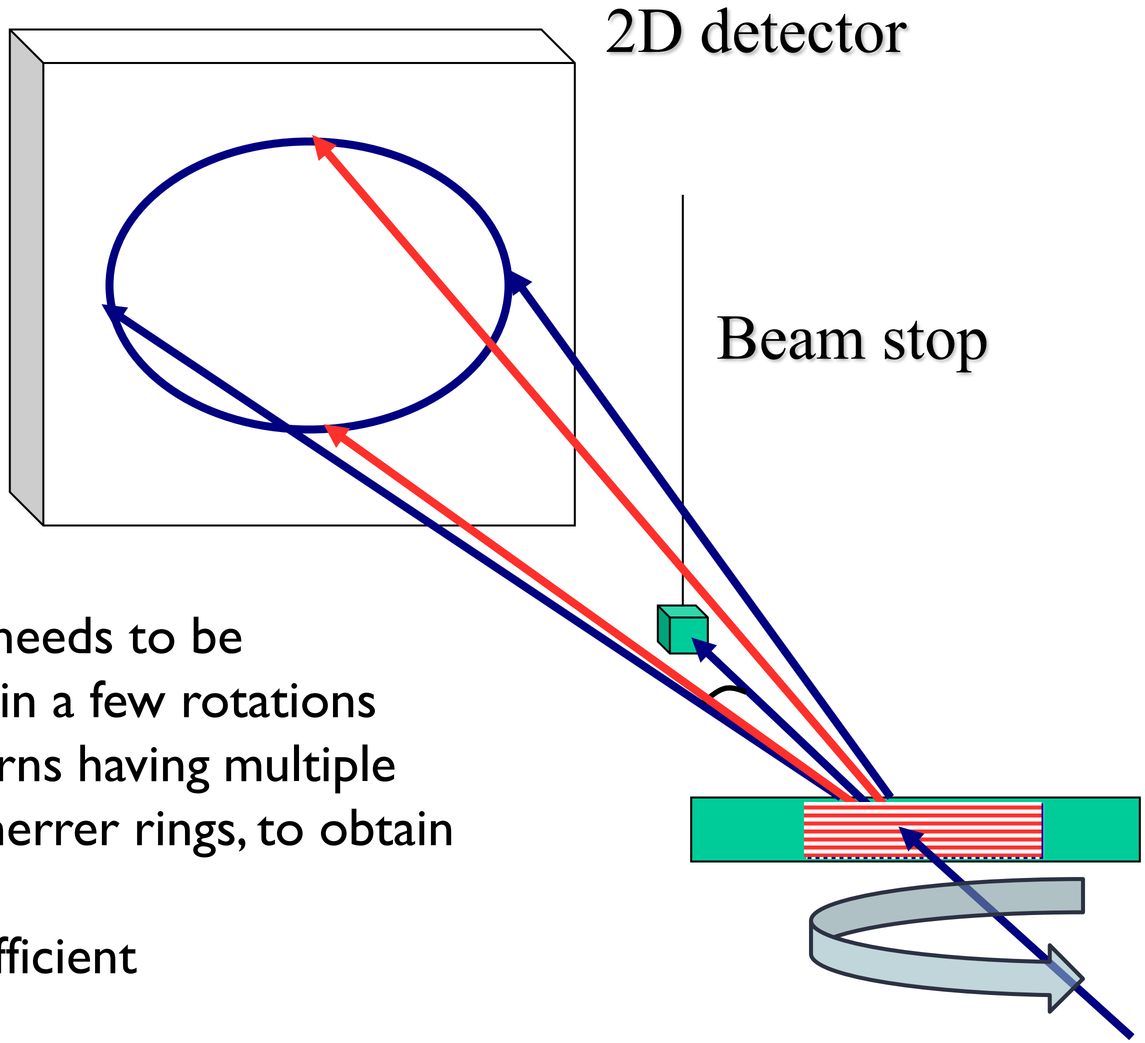
2θ is fixed

Measuring the Crystallographic Texture experimentally
Neutron Diffraction (ND)

- Transmission method used
- Specimen typically 1cm^3
- Entire PFs from one specimen >> ODF
- Bulk texture measured directly



Measuring the Crystallographic Texture experimentally
High Energy Synchrotron XRD
(no direct measurement of Pole Figures)



$\lambda = 2d\sin\theta$

$E = hc/\lambda$

e.g. E=80keV

$\boldsymbol{\lambda = 0.15}$ **Å**

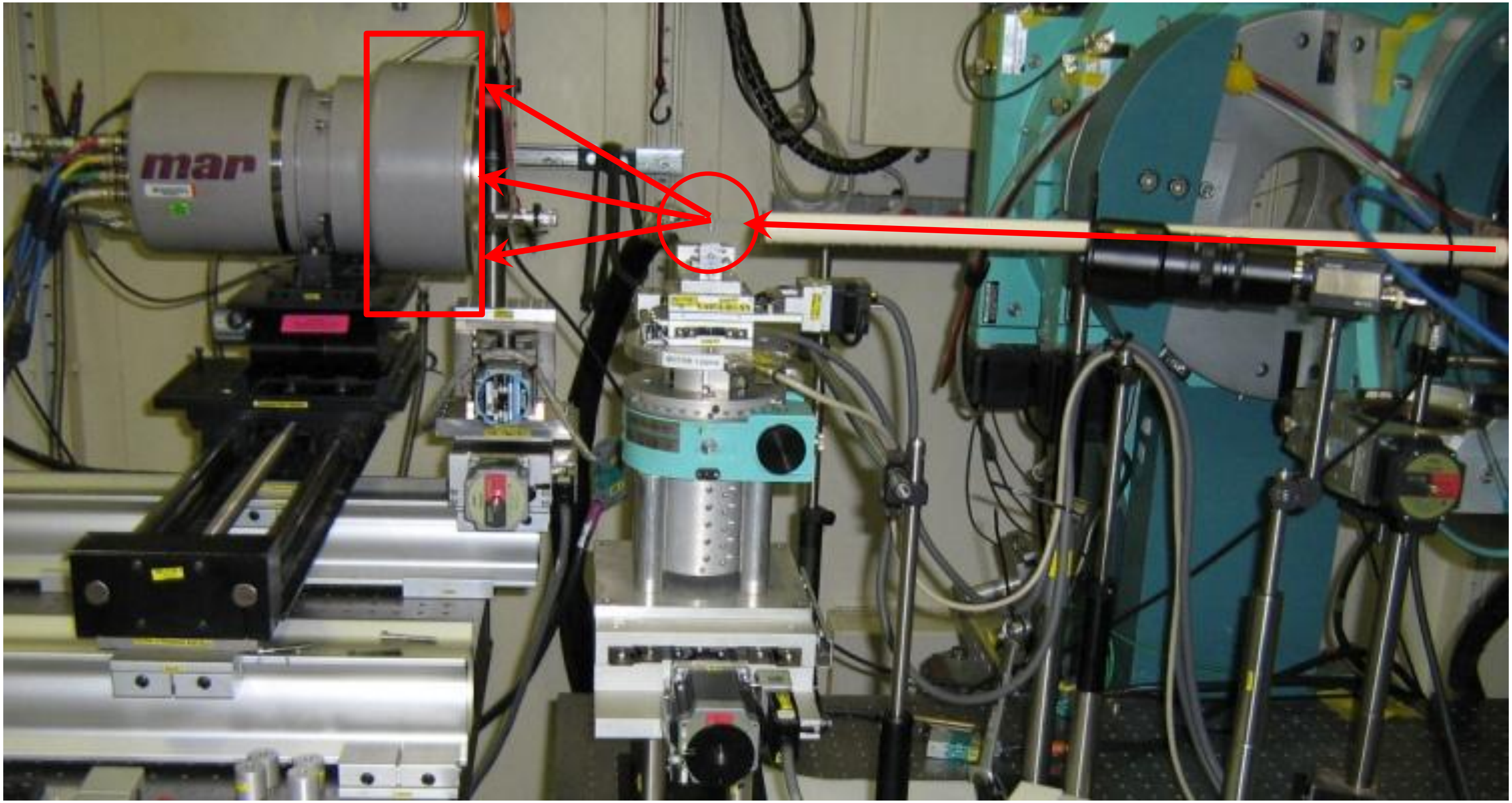
d = 1Å

$\boldsymbol{\theta \approx 4°}$

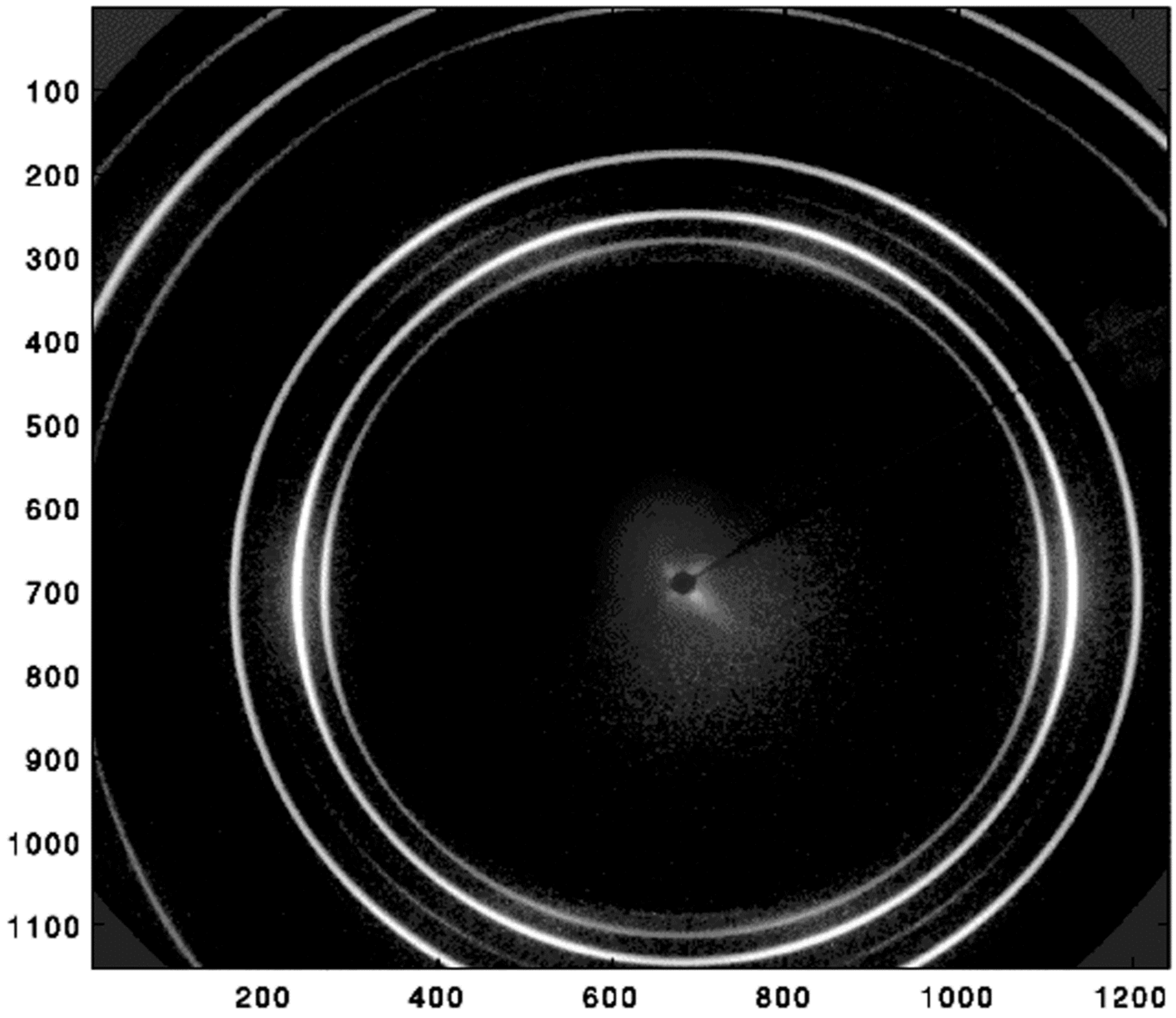
- A sample needs to be measured in a few rotations with patterns having multiple Debye-Scherrer rings, to obtain the ODF.
- Fast and efficient

High energy X-ray diffraction: wavelength much shorter than atomic spacing

1-ID beamline, APS ANL



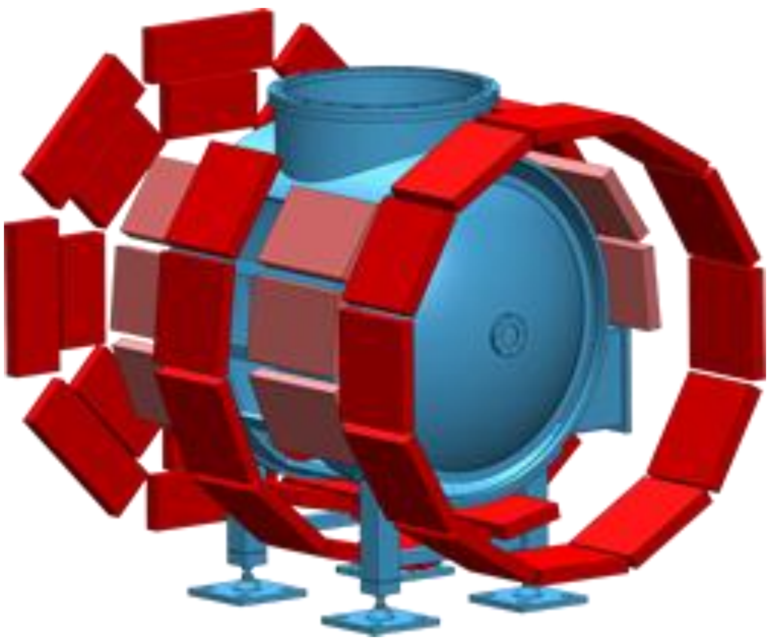
Example CCD image



Note the effect of texture: the intensity along the Debye-Scherrer rings varies

Measuring the Crystallographic Texture experimentally Neutron Diffraction (ND) (no direct measurement of Pole Figures)

HIPPO - High-Pressure-Preferred Orientation instrument at the Los Alamos Neutron Science Center (LANSCE)



- Using time-of-flight ND, each detector panel records a full, individual diffraction pattern
- A sample needs to be measured only in 3-4 rotations to obtain the ODF.
- Fast and efficient

https://lansce.lanl.gov/facilities/lujan/instruments/hippo/index.php

Thank you for your attention!