EM Lab EBSD Configuration

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The geometry configuration for the electron backscatter diffraction (EBSD) detectors in SEMs at the EM Lab is using at 20mm SEM working distance with 70-degree sample tilted angles. The specified directions with respect to the sample coordinates are named as **ND** (normal direction), **TD** (transverse direction) and **RD** (rolling/reference direction) as shown in below left geometry schematic illustration of Fig.1. One representative set of Kikuchi band from the sample (hkl) lattice planes is shown in the below right schematic (Fig. 2).

NB, the 70-degree tilted angle setting increases the backscatter yield tremendously, but the resolution perpendicular to the tilt angle is roughly three times poorer than that of parallel to the tilt axis due to the asymmetric EBSD emission along the beam longitudinal direction. After tilt compensation correction, the EBSD absolute angle resolution is typically obtained with an accuracy of 2 degrees as using a FEG-SEM.

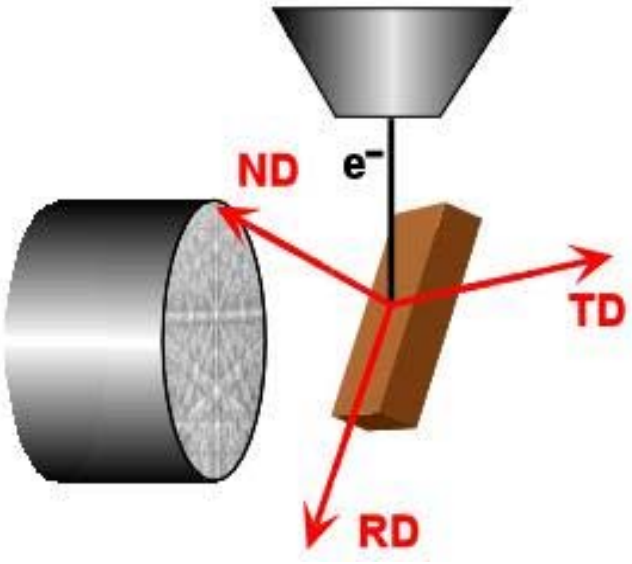

Fig. 1

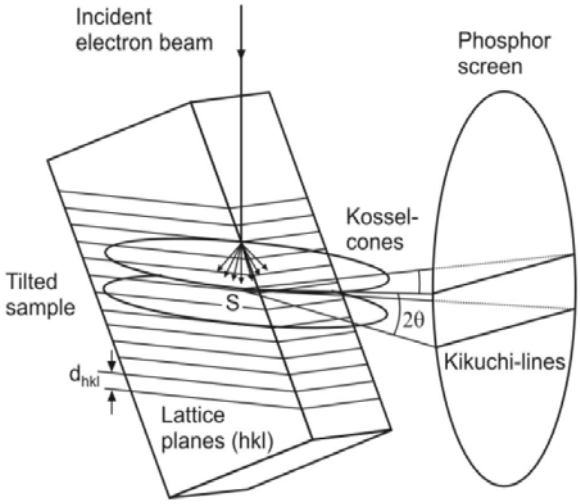

Fig. 2

For EBSD quantitative analysis, 3 parameters are needed to describe the orientation of a crystal grain relative to the sample reference frame. Mainly, TWO systems are used for this quantitative description for visualization of the grain microstructures, i.e. Euler angles (3 rotations) and pole figures, and both systems are adopted in the EM Lab EBSD analysis programme-Orientation Imaging Microscopy (OIM) Analysis version 4.5.

Pole figures (PF) are most common source of texture information in material X-ray analysis. Each PF, i.e. **Stereographic Projections** (SP), is equivalent to a geographic map of a hemisphere (North pole in the centre) as shown below Fig. 3, which formed to connect a line from the South pole to the point on the surface of the north hemisphere sphere. The intersection of the line with the equatorial plane defines the project point. The equatorial plane is the projection plane. The PF of Fig. 3 is also could be characterized by the angles α and β, where α ranges (radial ranges) are from 0 at the centre to 90 degree at the edge, and β ranges (azimuthal ranges) are from 0 to 360 degree, where

$$OP = R \tan(\alpha/2)$$

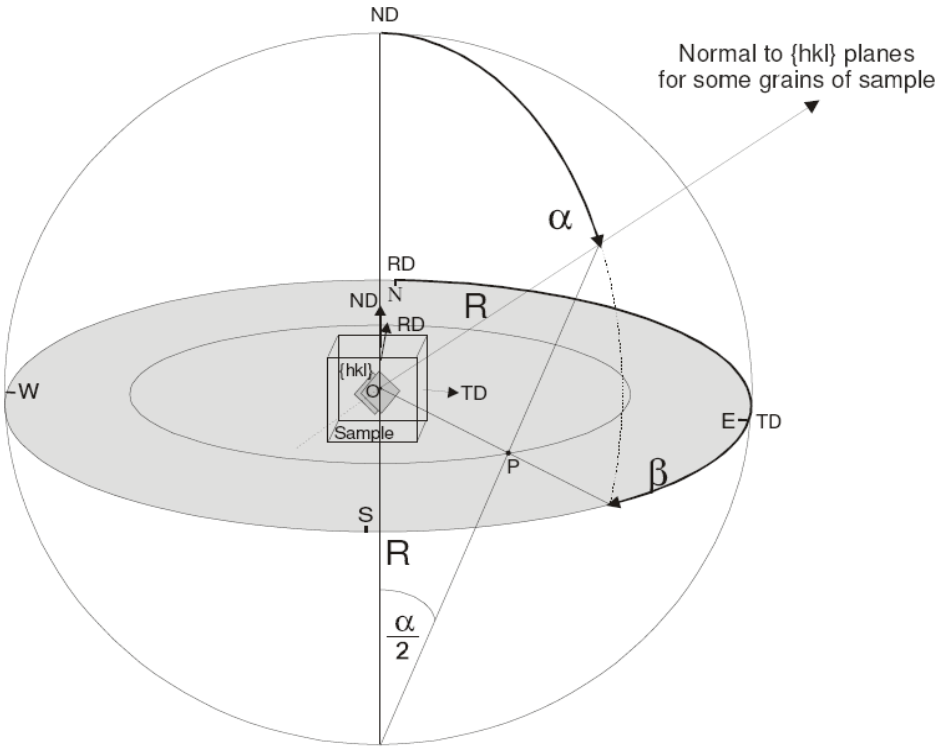

Fig.3

While, the **Standard Stereographic projections** (SSP, e.g. shown in Fig. 5 of a cubic SSP) provide maps of **low index** directions and planes. Miller indices are a convenient way to represent a direction or a plane normal in a crystal, based on integer multiples of the repeat distance parallel to each axis of the unit cell of the crystal lattice. Consider a cubic until cell system (hereafter, will use the same cubic system as example), the schematic representation of the Miller indices of a pole is given in below Fig. 4.

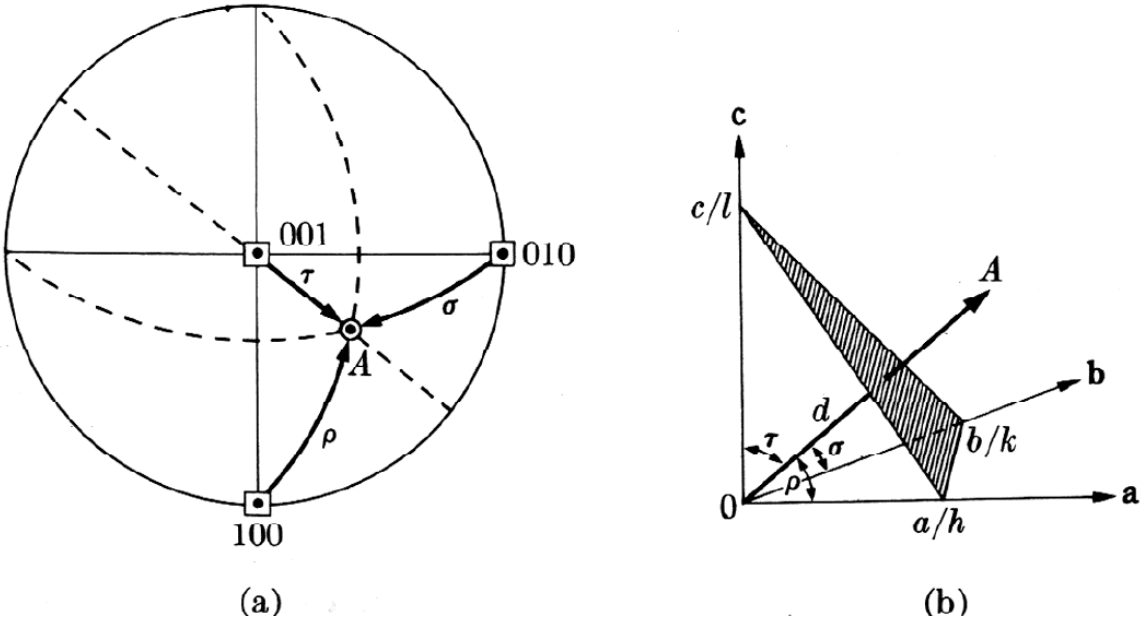

Fig. 4

When a plane is written with parentheses, (hkl), this indicates a particular plane. By contrast when it is written with curly braces, {hkl}, this denotes the family of planes related by the crystal symmetry. Similarly a direction written as [uvw] with square brackets indicates a

particular direction whereas writing within angle brackets, <uvw> indicates the family of directions related by the crystal symmetry.

The pole figures of a cubic **single crystal** can be derived from the standard stereographic projections by deleting all others of non-equivalent Miller indexes as shown in below Fig. 5, where with constructed three basic PFs of {100}, {110} and {111}.

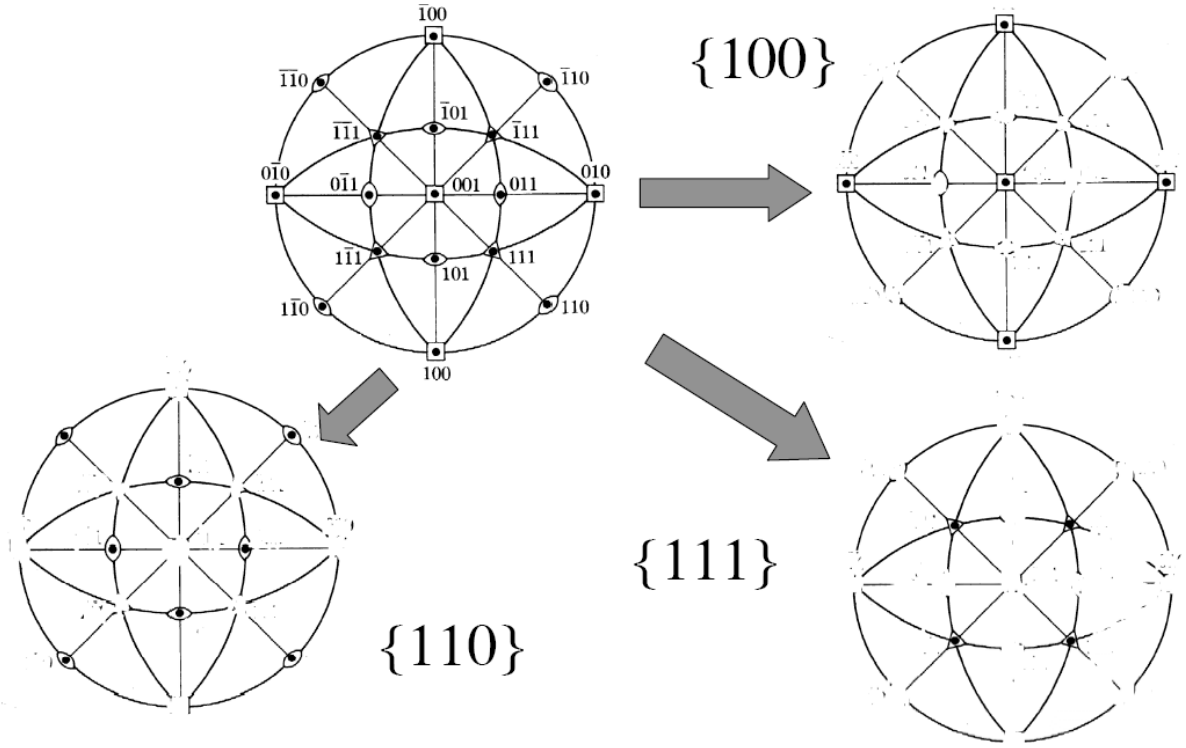

Fig.5

For **polycrystalline** materials, a set of poles can be plotted for each individual grain to produce a composite pole figure. If the grains are randomly oriented, then we should expect to see the poles distributed evenly over the pole figure. More often the grains are not randomly oriented, but tend towards particular orientations depending on the material composition and process history. This is so-called the **"preferred" orientation**, or **crystallographic texture** of the sample. In such a case, the poles will be concentrated within certain areas of the pole figure.

In pole figure, the 3D grain orientations could be plotted as two-dimensional projections, which would be useful for simplifying the analysis of sample orientation distribution. A pole figure shows the position of a pole (a normal to a lattice plane) relative to the polycrystalline sample reference frame. For the Miller Index Definition of Texture Component, it needs specify the crystallographic plane normal that is parallel to the specimen normal (i.e. the ND), and a crystallographic direction that is parallel to the RD, as already defined by in above Fig.1, as,

$$(hkl) \parallel ND, [uvw] \parallel RD, \text{ or } (hkl)[uvw]$$

Consider the same cubic until cell system from a rolled sheet with RD, TD and ND axis as shown in below Fig. 6(a), and the correspond (001) pole figure is shown in Fig. 6(b).

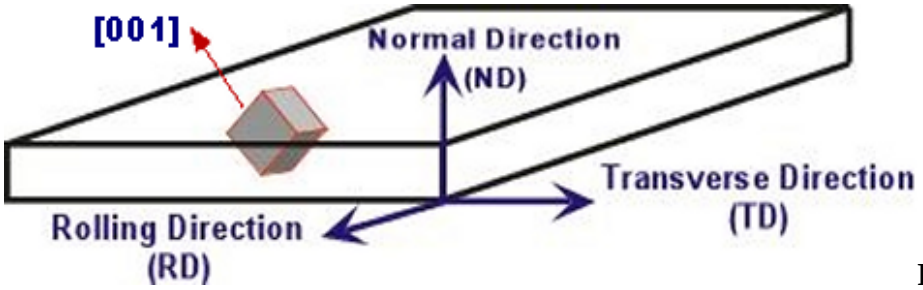

Fig.6(a)

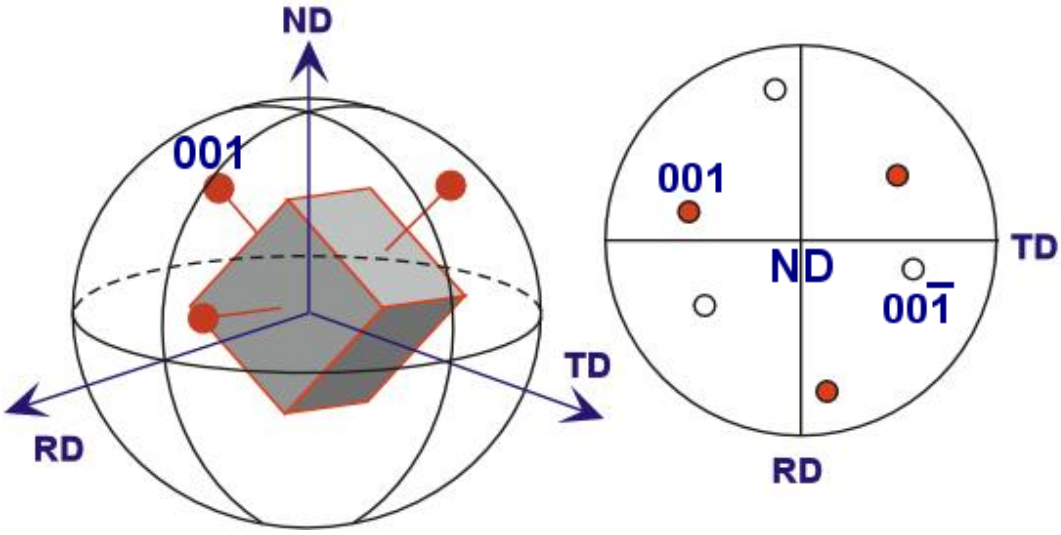

Fig. 6(b)

The representation of orientations in the pole figure becomes ambiguous if there is more than one orientation because each orientation is determined by several poles which cannot be associated to a specific orientation in a unique way. For an unambiguous representation of orientations one can take advantage of the fact that orientations can be described uniquely by a rotation (as shown in below Fig. 7). It is common to describe a rotation in terms of Euler angles, i.e. to co-orientate a unit cell with the sample reference frame, shown in an Orientation Distribution Function (ODF).

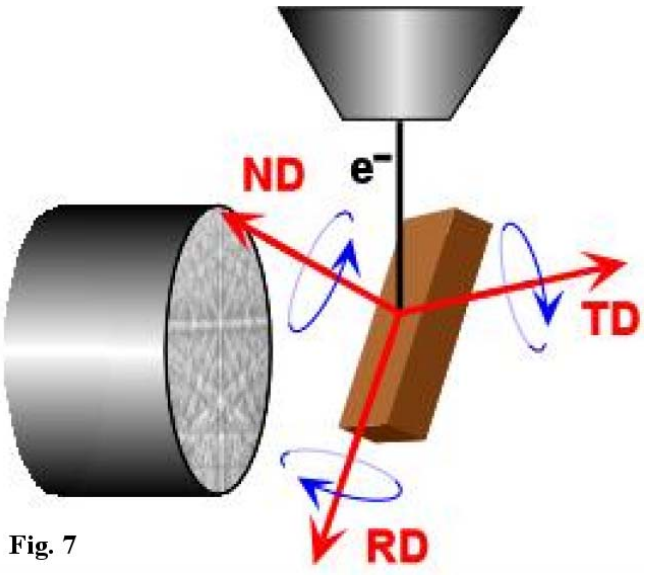

Fig. 7

Since an orientation is determined by its rotation, a set of Euler angles φ1, Φ and φ2 uniquely defines an orientation. If we define a space in which the 3 coordinates correspond to the Euler angles, each point in this space represents an orientation. In general the angles range over

$$0° \leq \phi 1 \leq 360°$$
$$0° \leq \Phi \leq 180°$$
$$0° \leq \phi 2 \leq 360°.$$

However, for the cubic crystal symmetry and because of the specimen symmetry at

rolling direction, one can reduce the angular range to,

$$0°\leq\varphi1\leq90°;\ 0°\leq\Phi\leq90°;\ 0°\leq\varphi2\leq90°$$

in which each orientation occurs at least once, as demonstrated in Fig. 8.

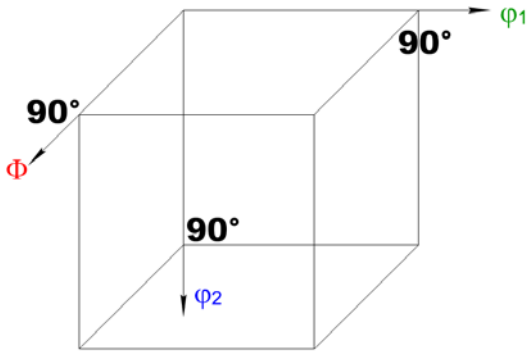

Fig. 8

Similar to the <uvw> (hkl) quantitative description, Euler description is easily related back to crystallographic directions in the material. The mathematical relationships between Euler angles and the <uvw> (hkl) orientations can be calculated from the following equations,

$$\cos\Phi = \frac{l}{\sqrt{h^2+k^2+l^2}}$$

$$\cos\varphi_2 = \frac{k}{\sqrt{h^2+k^2}} \quad \sin\varphi_2 = \frac{h}{\sqrt{h^2+k^2}}$$

$$\sin\varphi_1 = \frac{w}{\sqrt{u^2+v^2+w^2}}\sqrt{\frac{h^2+k^2+l^2}{h^2+k^2}}$$

In OIM Analysis version 4.5, the **Inverse Pole Figure Map** (IPF) is also used to show the positions and directions of individual sample grains relative to the sample reference frame. Each point in an IPF is coloured according to an automatically colour coded unit triangle of the inverse pole figure. For example, as shown in below Fig.10 of an OIM scan from a cubic material, the colour red is assigned to the [001] crystal direction, blue to [111] and green to [101]. An orientation map is generated by shading each point in the OIM scan according to some parameters reflecting the crystallographic rotation. Crystals with their 111 axis normal to the surface of the sample will be blue as shown in Fig. 9. If a point in the scan is oriented such that the crystal direction aligned with the specified sample direction is somewhere between an [001] (red) and [111] (blue) direction (i.e. [112]), then the point would be shaded in purple.

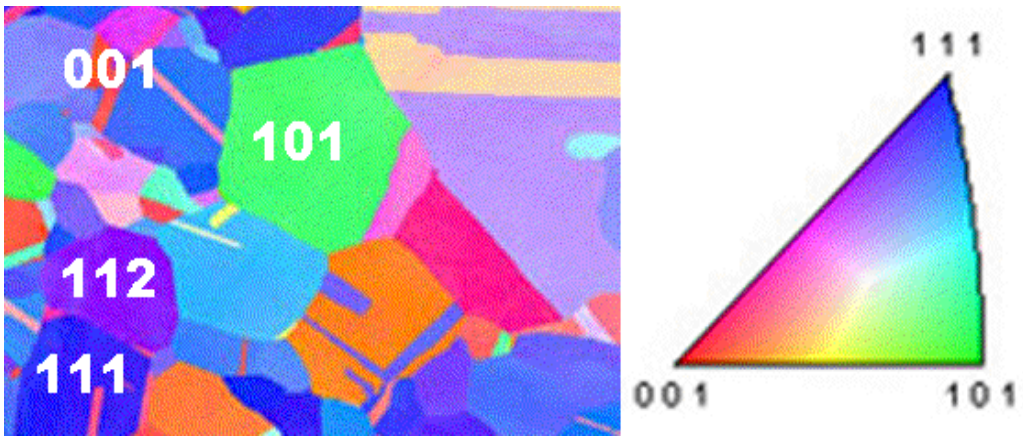

Fig. 9 http://folk.ntnu.no/yingday/NilsYD/EBSDbasic