12. Electron backscatter diffraction analysis technology

Contents

12.1 Overview

- Electron backscattered diffraction (EBSD) technology, started in the 1980s, is a new technology based on scanning electron microscopy.

- This technology can be used to observe the microstructure of the sample, obtain crystallographic data at the same time, and conduct data analysis.

- This technology combines the characteristics of X-ray statistical analysis and transmission electron microscopy, electron diffraction micro-area analysis and supplements X-ray diffraction and electron diffraction crystal structure and crystal orientation analysis.

- Electron backscattered diffraction technology has become an effective analytical method for studying the deformation, recovery, and recrystallization processes of materials, especially its application in micro-region texture analysis.

12.2 Fundamentals of Crystallographic

- Grain boundary type

1) Small angle grain boundary: it refers to the grain boundary where the orientation difference between adjacent grains is less than **10°**, usually **2°**. These include tilted grain boundaries, twisted grain boundaries, coincident grain boundaries, etc., as shown in Figure 1, Figure 2, and Figure 3.

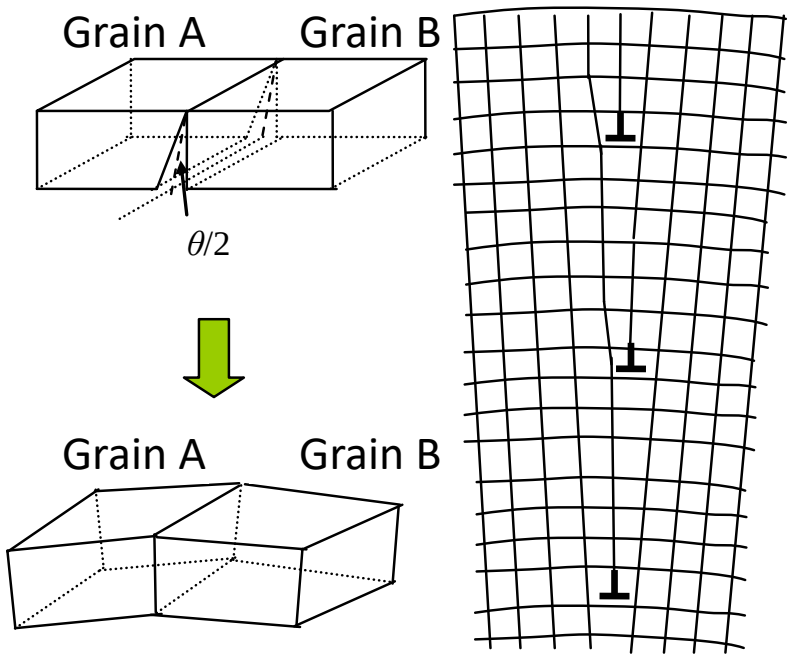


Figure 1: Symmetrically tilted grain boundaries

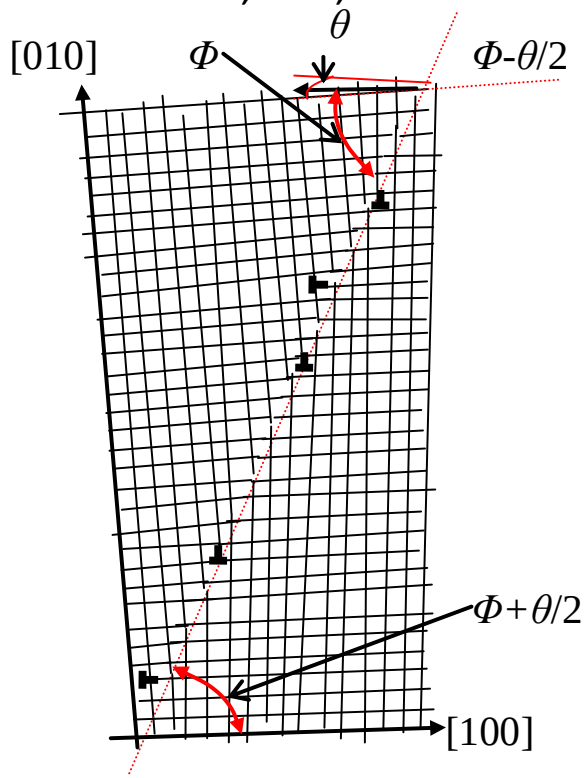


Figure 2: Asymmetrically tilted grain boundaries

12.2 Fundamentals of Crystallographic

- Grain boundary type

1) Small angle grain boundary refers to the grain boundary where the orientation difference between adjacent grains is less than **10°**, usually **2°**. These include tilted grain boundaries, twisted grain boundaries, coincident grain boundaries, etc., as shown in Figure 1, Figure 2, and Figure 3.

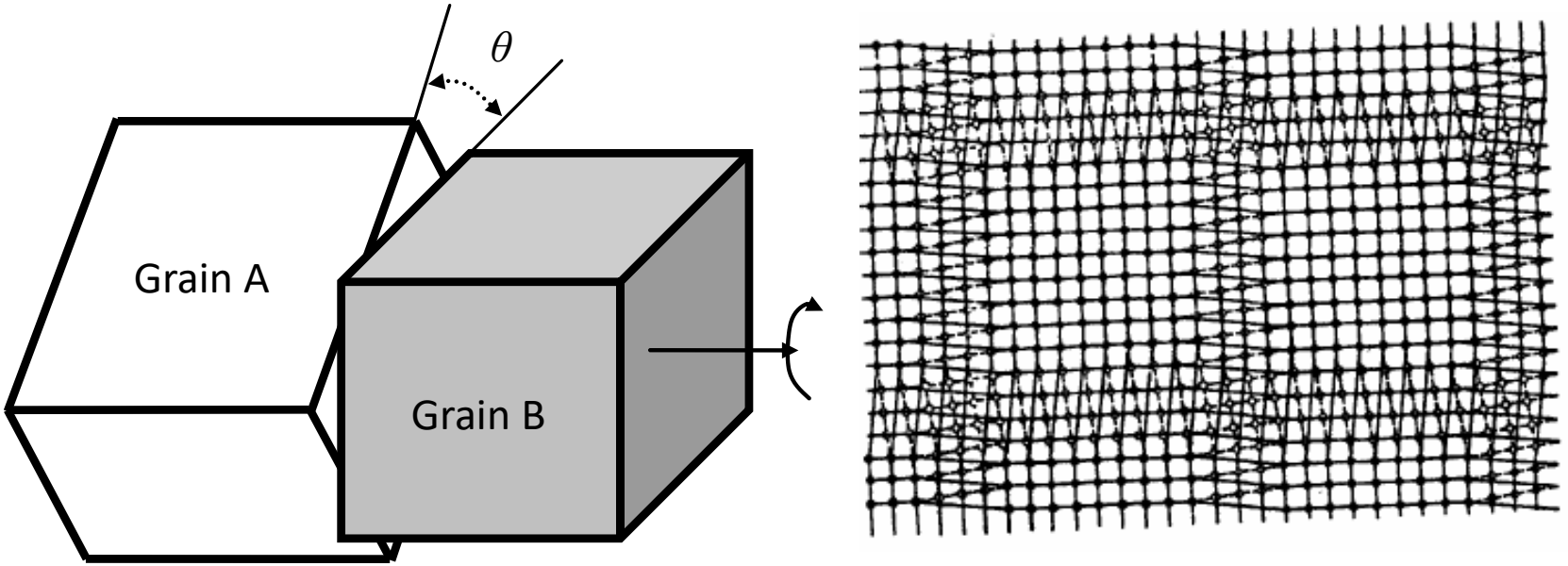


Figure 3: twisted grain boundary structure

12.2 Fundamentals of Crystallographic

- Grain boundary type

2) High-angle grain boundaries: refers to grain boundaries where the orientation difference between adjacent grains is greater than **10°**. Classic models include the soap bubble model, supercooled liquid model, island model, and coincident position lattice model. The coincident position lattice model is shown in the figure.

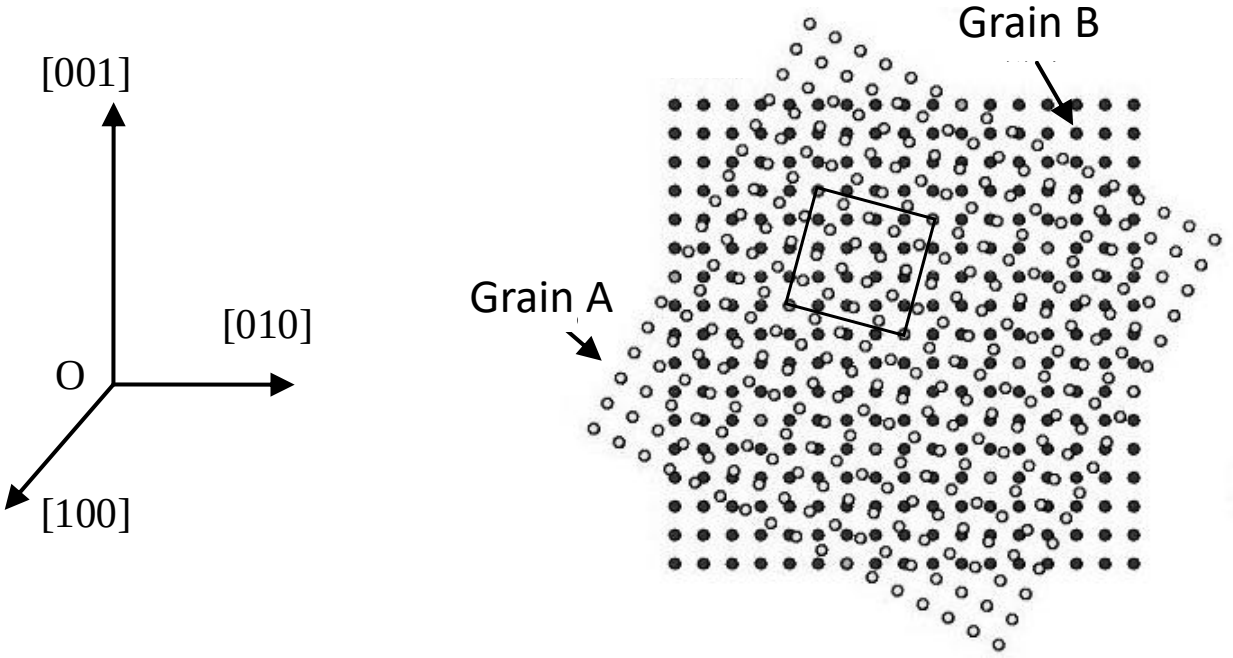


Figure: lattice structure at coincident positions

12.2 Fundamentals of Crystallographic

- Phase boundary

The interface between two materials with different structures or compositions is called a phase interface. Phase interfaces can be divided into three types:

1. Coherent phase boundary: The atoms on the interface are located at the nodes of the two-phase lattice at the same time. At this time, the two phases on both sides of the interface have an orientation relationship; there is often lattice distortion near the interface.

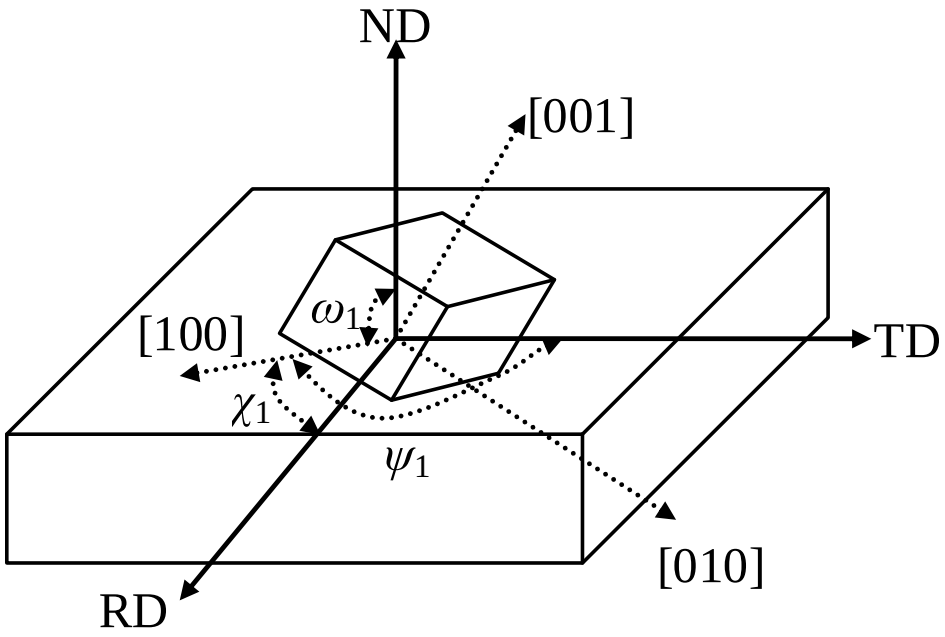
2. Incoherent phase boundary: Incoherent phase boundary is an interface that has no coherent relationship at all. When there is a large difference in the crystal structure of the two phases, or the size of the second phase is larger, there is such an interface between the two phases.

3. Partially coherent phase boundary: An interface that maintains its coherent nature with the help of dislocations. This type of interface is common in martensitic transformation and epitaxial growth crystals.

12.2 Fundamentals of Crystallographic

- Establish of the crystal orientation coordinate system

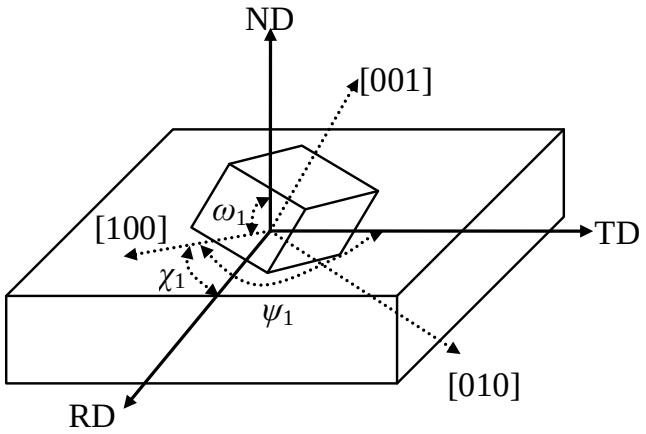
As shown in the figure, the sample coordinate system consists of three mutually perpendicular directions: rolling direction **RD**, transverse direction **TD**, and normal direction **ND**; the crystal coordinate system (taking a cubic crystal as an example) consists of three mutually perpendicular crystallographic axes [100], [010] and [001].



12.2 Fundamentals of Crystallographic

- Establish of the crystal orientation coordinate system

The relationship between the axes of the sample coordinate system and the crystal coordinate system can be expressed by the cosine of the included angle. From this, a direction cosine matrix ***g*** can be constructed.



$$g = \begin{bmatrix} \cos\chi_1 & \cos\psi_1 & \cos\omega_1 \\ \cos\chi_2 & \cos\psi_2 & \cos\omega_2 \\ \cos\chi_3 & \cos\psi_3 & \cos\omega_3 \end{bmatrix}$$

In the formula, χ_1, χ_2, and χ_3 are the angles between the sample coordinate system ***RD*** and the crystal coordinate system [100], [010] and [001] respectively; ψ_1, ψ_2 and ψ_3 are the angles between ***TD*** and [100] , the angle between [010] and [001]; ω_1, ω_2 and ω_3 are the angles between ***ND*** and [100], [010] and [001]. The matrix is an orthogonal matrix with 3 independent components. Only 3 independent components are needed to determine crystal orientation. However, it is more complicated to reflect the crystal orientation using this method.

12.2 Fundamentals of Crystallographic

- Establish of the crystal orientation coordinate system

Using the angle between the axes of the sample coordinate system and the crystal coordinate system to express the crystal orientation is cumbersome and not clear enough. For this purpose, the crystal rotation angle can be used to construct crystal orientation characteristics.

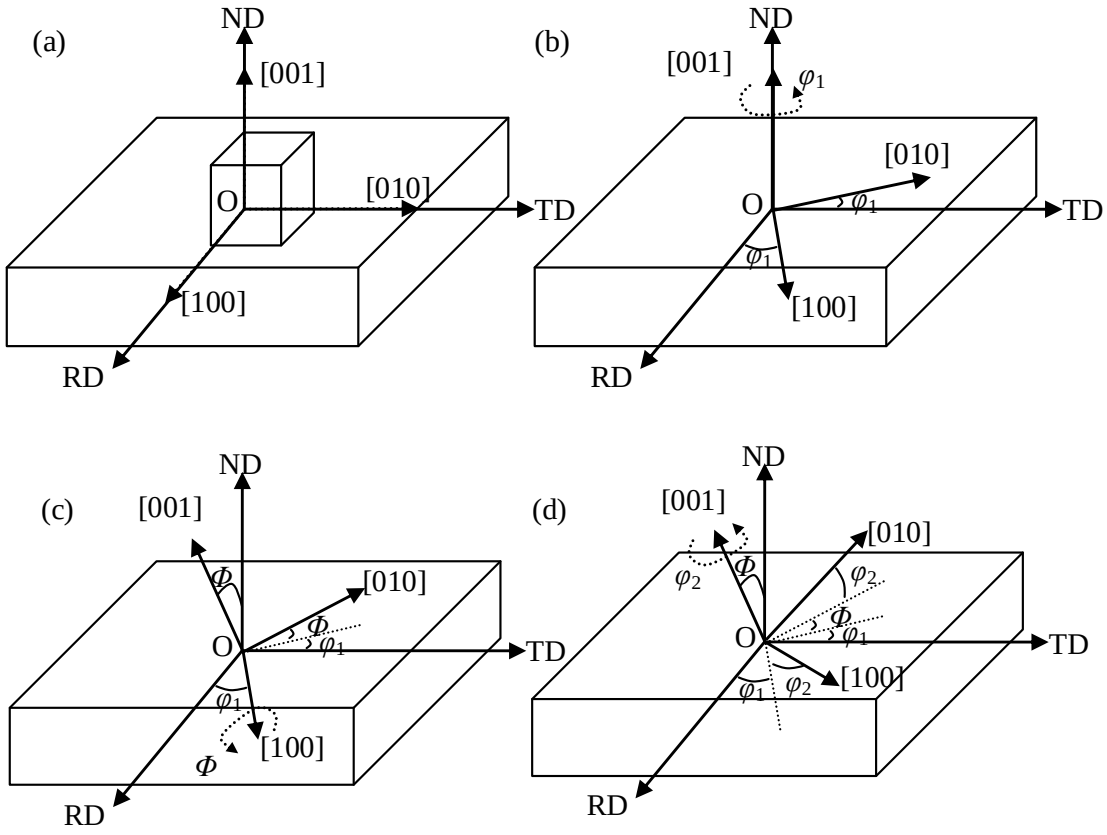
The rotation representation method uses Euler angles to describe the crystal orientation. Euler angles use three independent rotation angles φ_1, Φ and φ_2 to represent the initial position. [100], [010] and [001] of the crystal are related to the sample coordinate system. ***RD***, ***TD***, and ***ND*** coincide.

The crystal rotation process is: first, the crystal rotates φ_1 around [001], then rotates Φ around [100], and finally rotates φ_2 around [001]. The specific rotation operations of these three angles, namely Euler angles, are shown in the figure.

12.2 Fundamentals of Crystallographic

- Establish of the crystal orientation coordinate system

The crystal rotation process is: first, the crystal rotates φ_1 around [001], then rotates Φ around [100], and finally rotates φ_2 around [001]. The specific rotation operations of these three angles, namely Euler angles, are shown in the figure.



12.2 Fundamentals of Crystallographic

- Crystal orientation numerical representation method and conversion

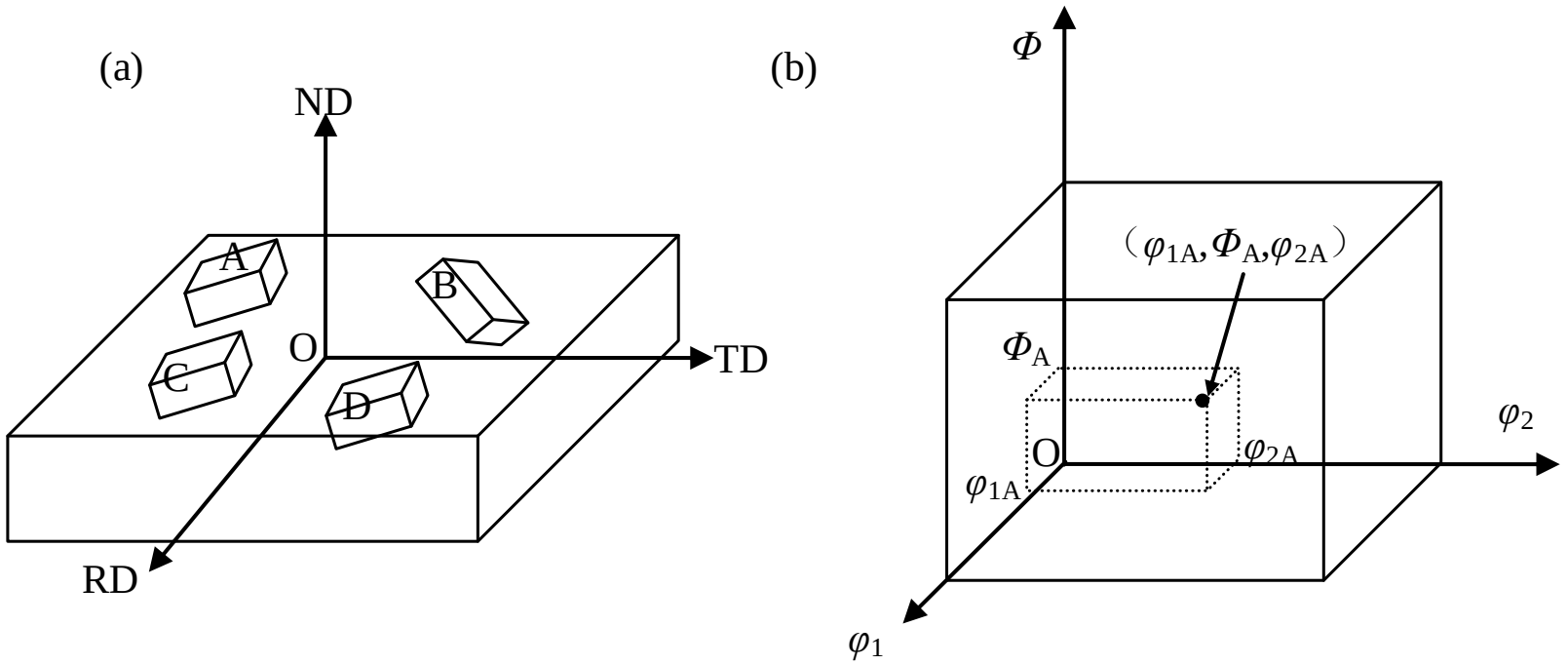
The numerical representation methods of crystal orientation mainly include index, matrix, Euler angle, and axis angle pair.

1) Index method: expressed by (***hkl***)[***uvw***], that is, the (***hkl***) crystal plane in the crystal is parallel to the rolling surface of the plate, and the [***uvw***] direction is parallel to the rolling direction.
2) Matrix method: expressed by an orientation matrix, that is, the angle relationship between the coordinate system of the crystal and the axes of the sample coordinate system.
3) Euler angles and Euler space: represented by φ_1, Φ and φ_2. The three Euler angles can be used to establish a coordinate system to form Euler space.
4) Axis angle pair: expressed by θ[uvw], that is, the crystal rotates θ angle with [uvw] as the axis, and the crystal coordinate system will coincide with the sample coordinate system

12.2 Fundamentals of Crystallographic

- Crystal orientation numerical representation method and conversion

The figure shows the sample coordinate system, crystal orientation, and Euler space. In Euler space, a point (φ_1 Φ φ_2) can represent a crystal orientation.



Sample coordinate system and crystal orientation and Euler space

12.2 Fundamentals of Crystallographic

- Crystal orientation numerical representation method and conversion

The crystal orientation can also be expressed by the normal of a certain crystal plane (***hkl***) and the orientation of the two mutually perpendicular crystal directions [***uvw***] and [***xyz***] on the crystal plane in the sample coordinate system. These three directions can form a standard orthogonal matrix, called the change matrix ***g1***.

$$g_1 = \begin{bmatrix} u & x & h \\ v & y & k \\ w & z & l \end{bmatrix}$$

[***x y z***], [***h k l***], and [***u v w***] are the indices of the unit vectors in their respective directions, that is, the normalized indices. The crystal undergoes three Euler angle rotation operations, and the rotation matrix ***g2*** can also represent its crystal orientation.

12.2 Fundamentals of Crystallographic

- Crystal orientation numerical representation method and conversion

$$g_2 = \begin{bmatrix} \cos\varphi_2 & \sin\varphi_2 & 0 \\ -\sin\varphi_2 & \cos\varphi_2 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\Phi & \sin\Phi \\ 0 & -\sin\Phi & \cos\Phi \end{bmatrix} \begin{bmatrix} \cos\varphi_1 & \sin\varphi_1 & 0 \\ -\sin\varphi_1 & \cos\varphi_1 & 0 \\ 0 & 0 & 1 \end{bmatrix} =$$

$$\begin{bmatrix} \cos\varphi_1\cos\varphi_2 - \sin\varphi_1\sin\varphi_2\cos\Phi & \sin\varphi_1\sin\varphi_2 + \cos\varphi_1\cos\varphi_2\cos\Phi & \sin\varphi_2\sin\Phi \\ -\cos\varphi_1\sin\varphi_2 - \sin\varphi_1\cos\varphi_2\cos\Phi & -\sin\varphi_1\sin\varphi_2 + \cos\varphi_1\cos\varphi_2\cos\Phi & \cos\varphi_2\sin\Phi \\ \sin\varphi_1\sin\Phi & -\cos\varphi_1\sin\Phi & \cos\Phi \end{bmatrix}$$

Let ***g1***= ***g2***, we can get the interchange formula of Miller index and Euler angle.

$$\Phi = \arccos l$$

$$\varphi_2 = \arccos\left(\frac{k}{\sqrt{h^2 + k^2}}\right)$$

$$\varphi_1 = \arcsin\left(\frac{w}{h^2 + k^2}\right)$$

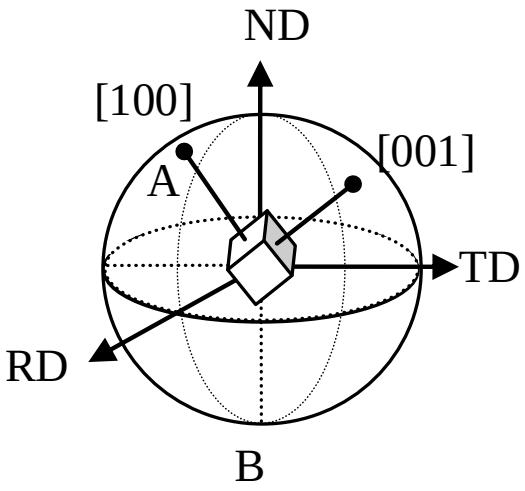
12.2 Fundamentals of Crystallographic

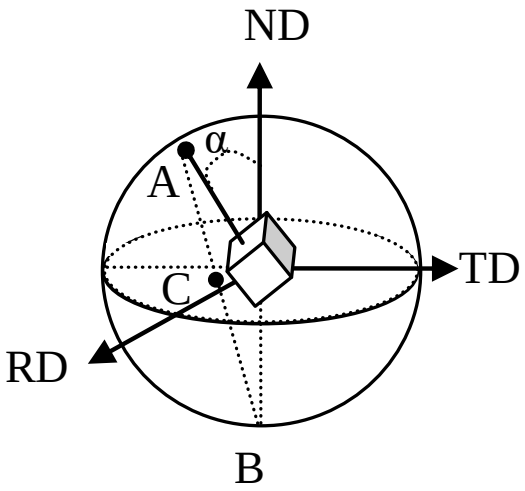
- Polar figure

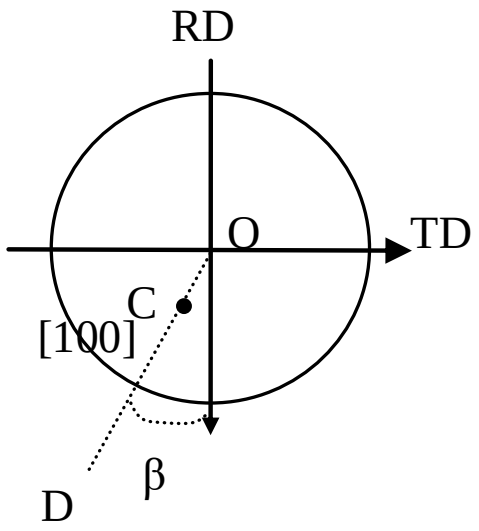
As shown in the figure, the unit cell is placed at the center of the sample coordinate system ***RD***-***TD***-***ND***, ***B*** is the reference point, and the plane where ***RD*** and ***TD*** are located is the projection plane, then point ***C*** is the pole of the [100] crystal direction. From the figure, we can get [001] polar axis ***r*** as:

$$r = \sin\alpha\cos\beta\, k_1 + \sin\alpha\sin\beta\, k_2 + \cos\alpha\, k_3$$

In the formula, k_1, k_2 and k_3 are the unit vectors in the ***RD***, ***TD*** and ***ND*** directions.





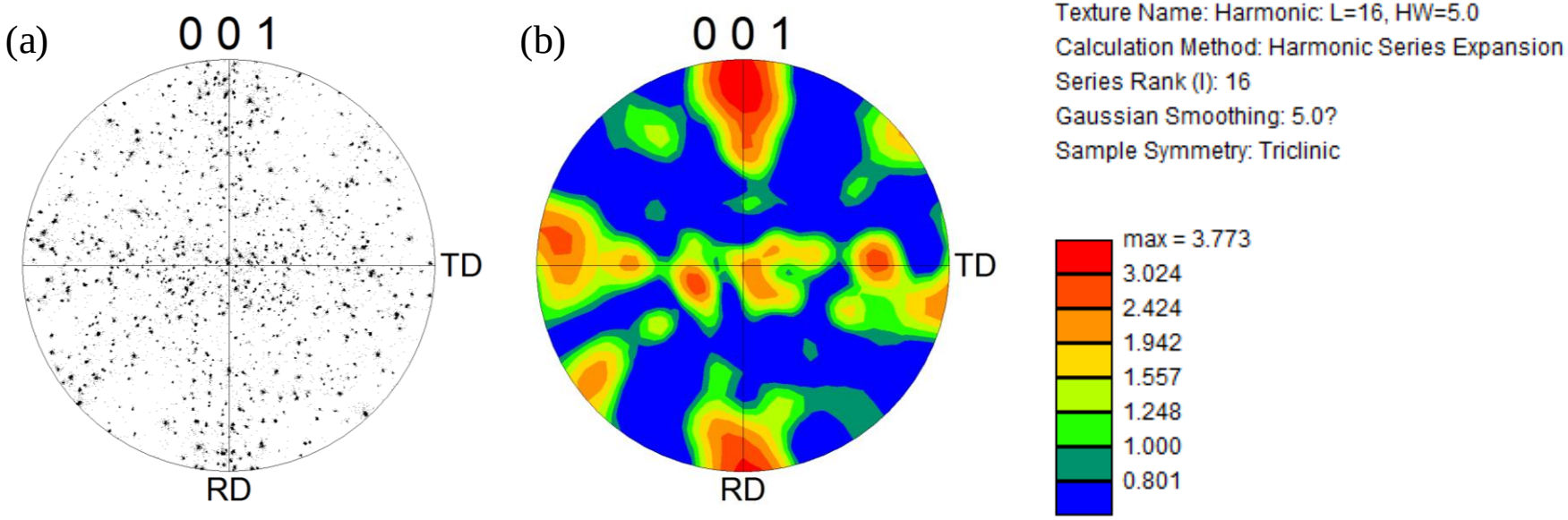


12.2 Fundamentals of Crystallographic

$$r = \sin\alpha\cos\beta\, k_1 + \sin\alpha\sin\beta\, k_2 + \cos\alpha\, k_3$$

- Polar figure

As shown in Figure **a,** the distribution of 001 poles is discrete, indicating that the polycrystalline grain orientation is chaotic; when polycrystalline exists, the poles are unevenly distributed. The pole density represents the orientation intensity, and the intensity level is expressed in color or Represented by isopycnic lines, see Figure **b**.

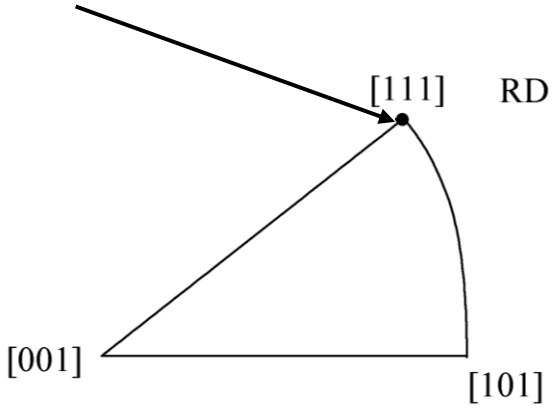


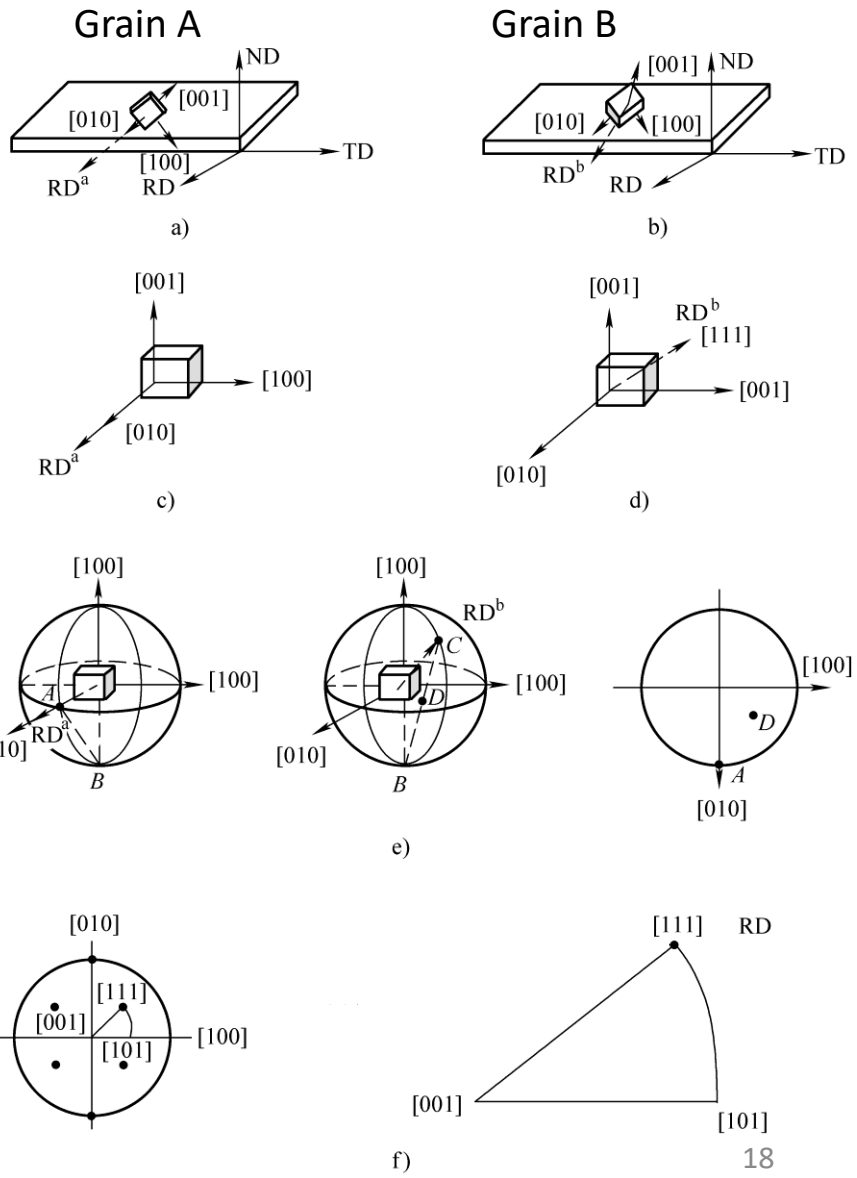
12.2 Fundamentals of Crystallographic

- Inverse polar figure

The construction process of the inverse pole figure is shown in the figure. The inverse pole figure often takes the unit projection triangle to describe the position of the sample coordinate axis in the crystal coordinate system.

This point reflects the relationship between the ***RD*** direction of the external sample coordinate system of a certain grain and the coordinate system.

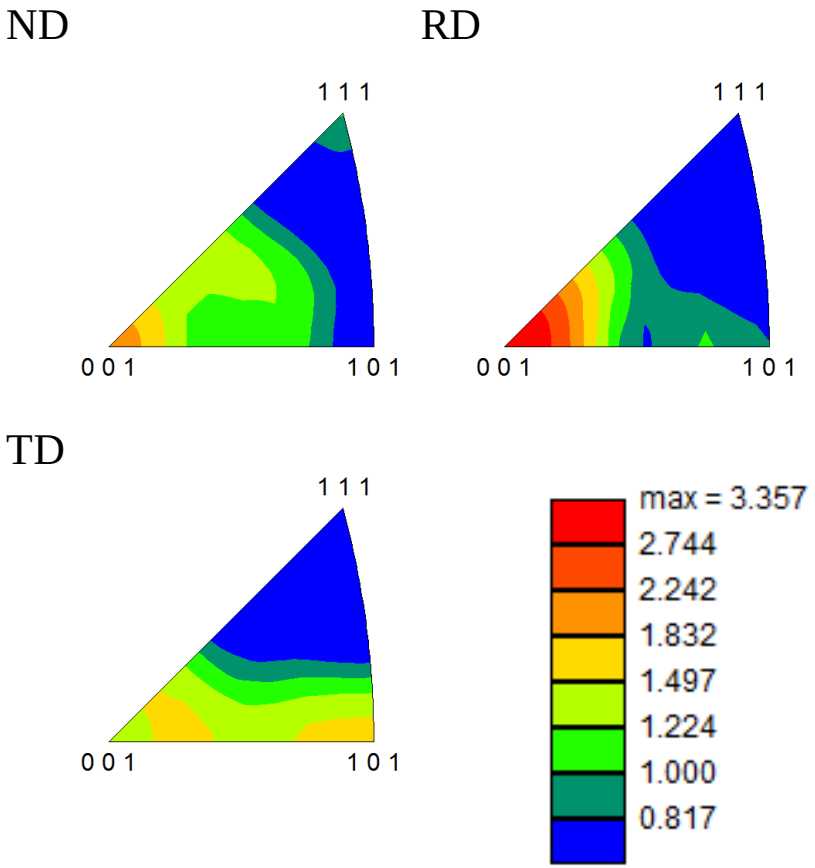


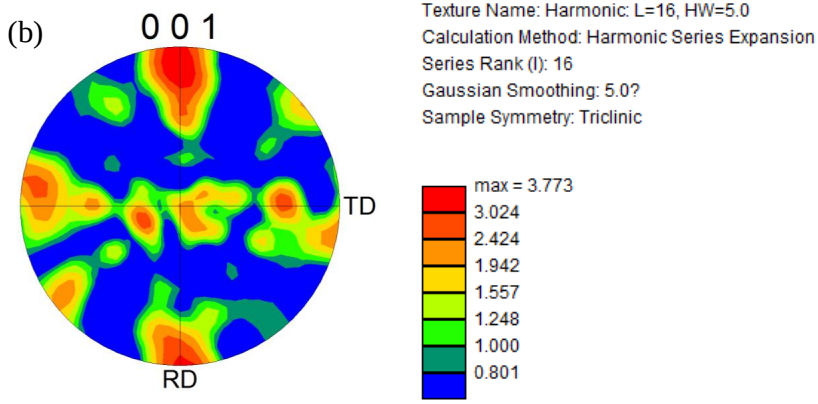


12.2 Fundamentals of Crystallographic

- Inverse polar figure

The figure shows the ***ND***, ***RD,*** and ***TD*** reverse pole diagrams of nickel. It can be seen that the pole density near ⟨**001**⟩ in the ***RD*** inverse pole diagram is the highest, indicating that the [001] crystallographic direction of most grains is parallel to the rolling direction ***RD***. This conclusion is consistent with the results given in the Figure below.

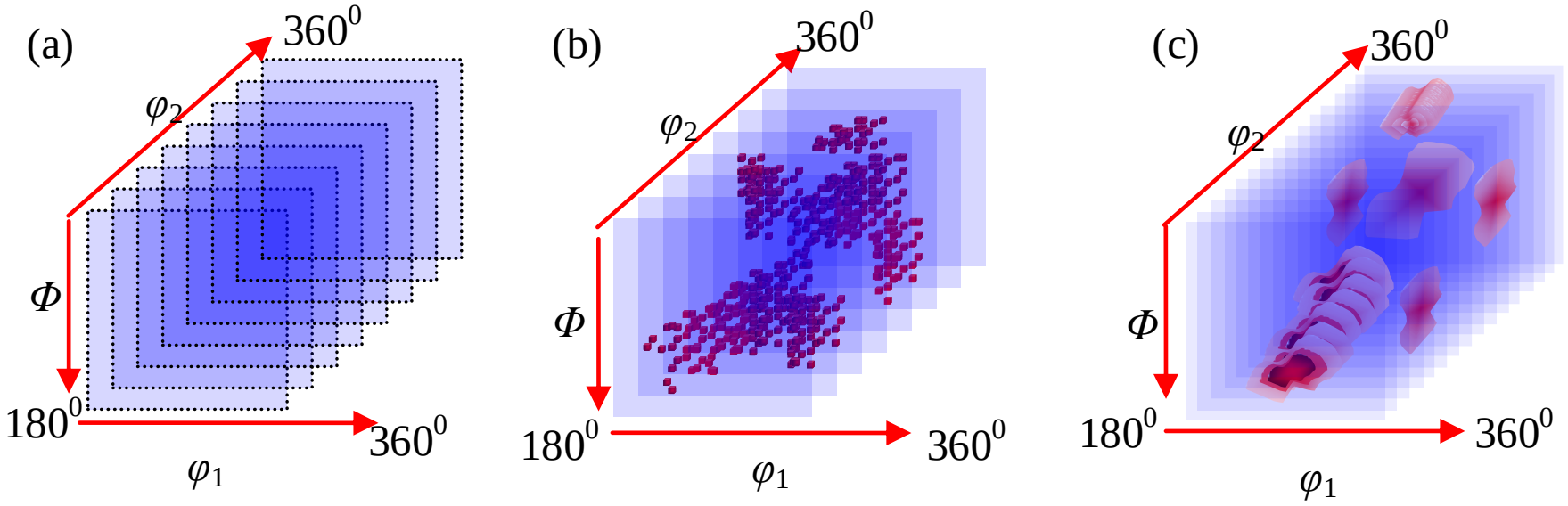




12.2 Fundamentals of Crystallographic

- Orientation distribution function ODF

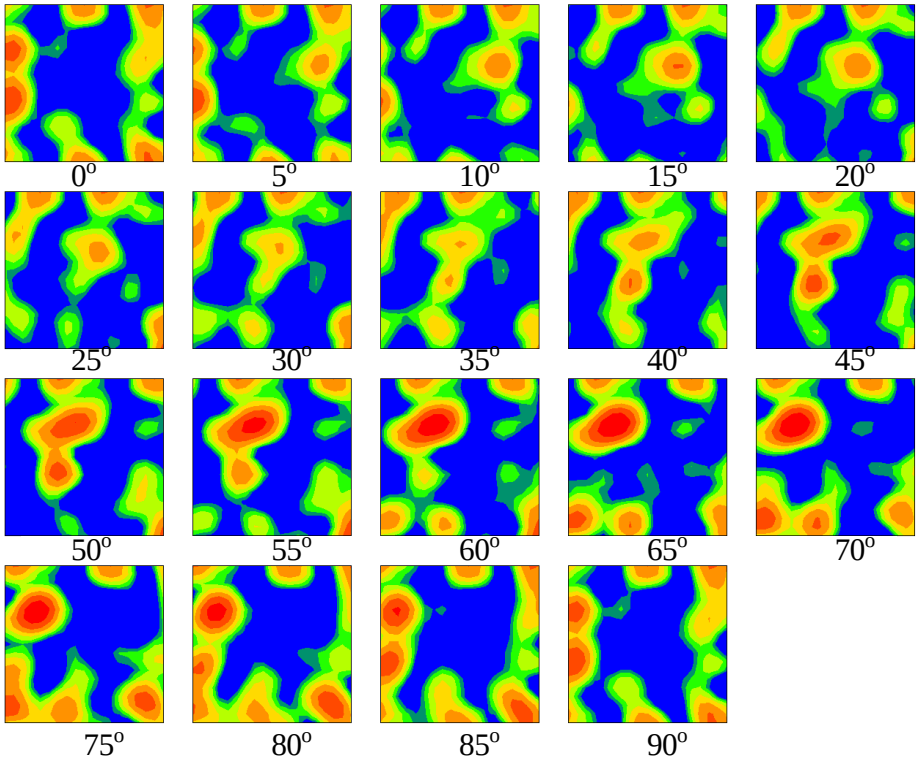
Using the distribution density $f(g)$ of $g(\varphi_1, \Phi, \varphi_2)$ in the orientation space, the orientation distribution of the entire space can be expressed, which is called the spatial orientation distribution function (ODF). As shown in Figure, ODF Reflects the three-dimensional spatial orientation distribution.

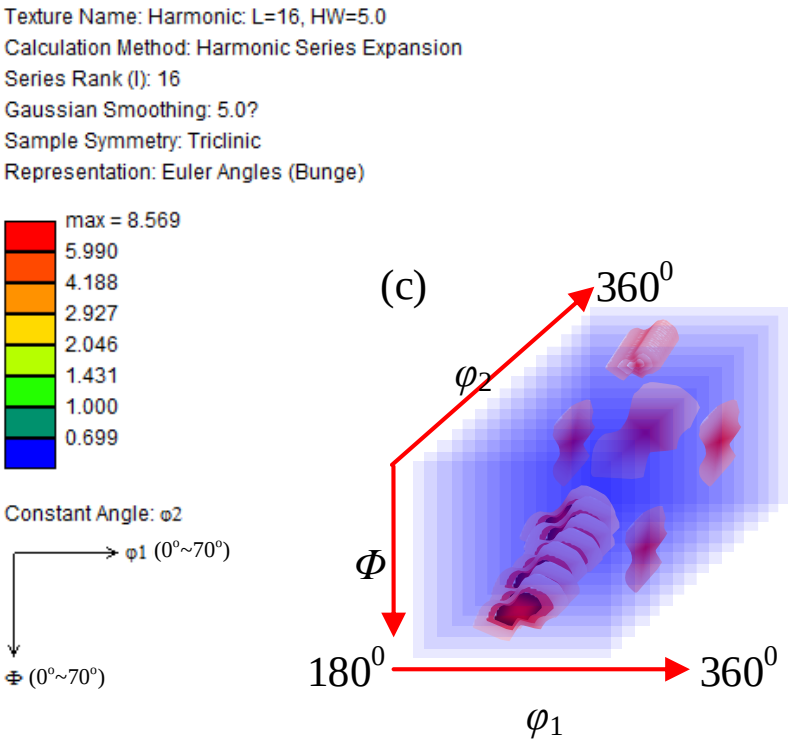


12.2 Fundamentals of Crystallographic

- Orientation distribution function ODF

For ease of use, the cross-section diagram of φ_2 is usually used, as shown in the figure.

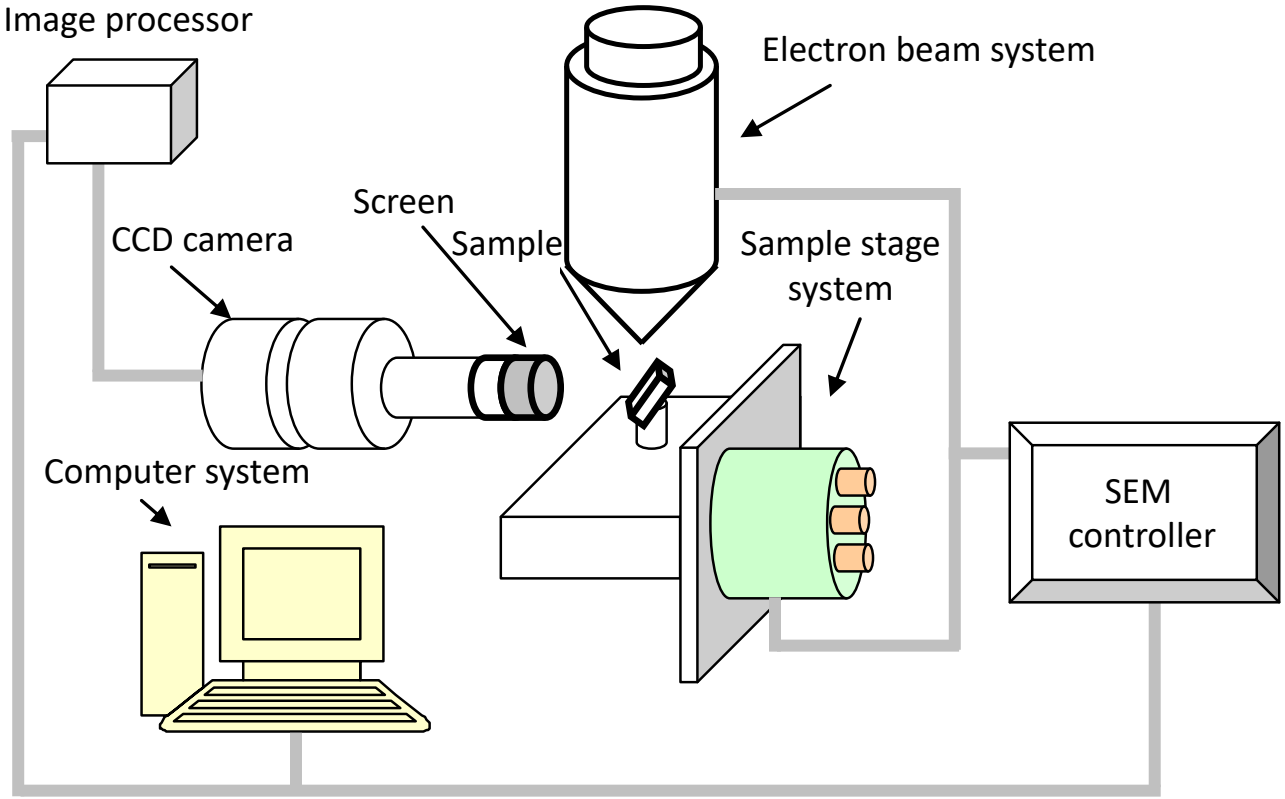




12.3 Electronic backscatter diffraction technology hardware system

- Overall layout of the hardware system

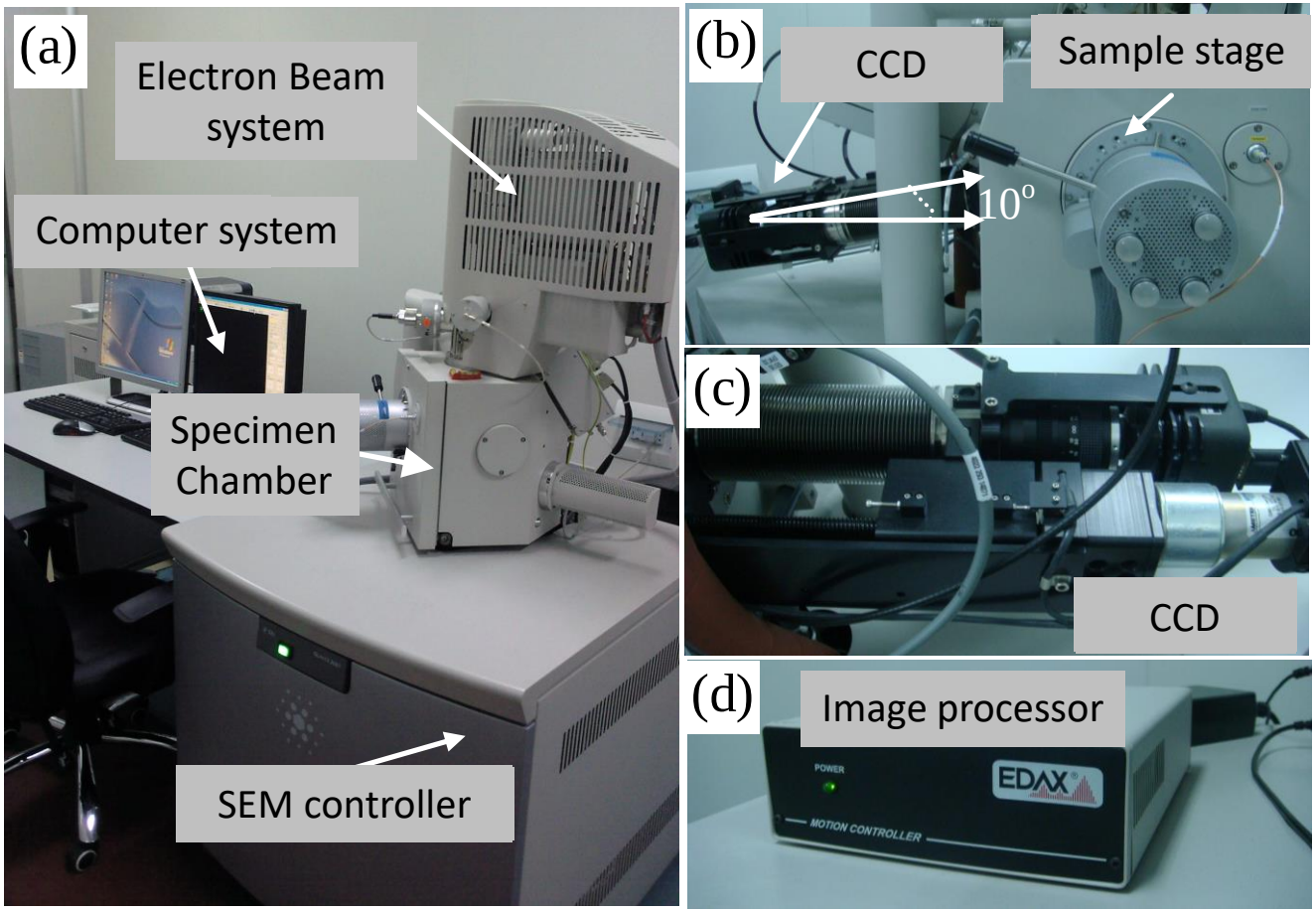
The EBSD analysis system is shown in the figure. The entire system consists of the following parts: sample, electron beam system, sample stage system, SEM controller, computer system, high-sensitivity CCD camera, image processor, etc.



12.3 Electronic backscatter diffraction technology hardware system

- Overall layout of the hardware system

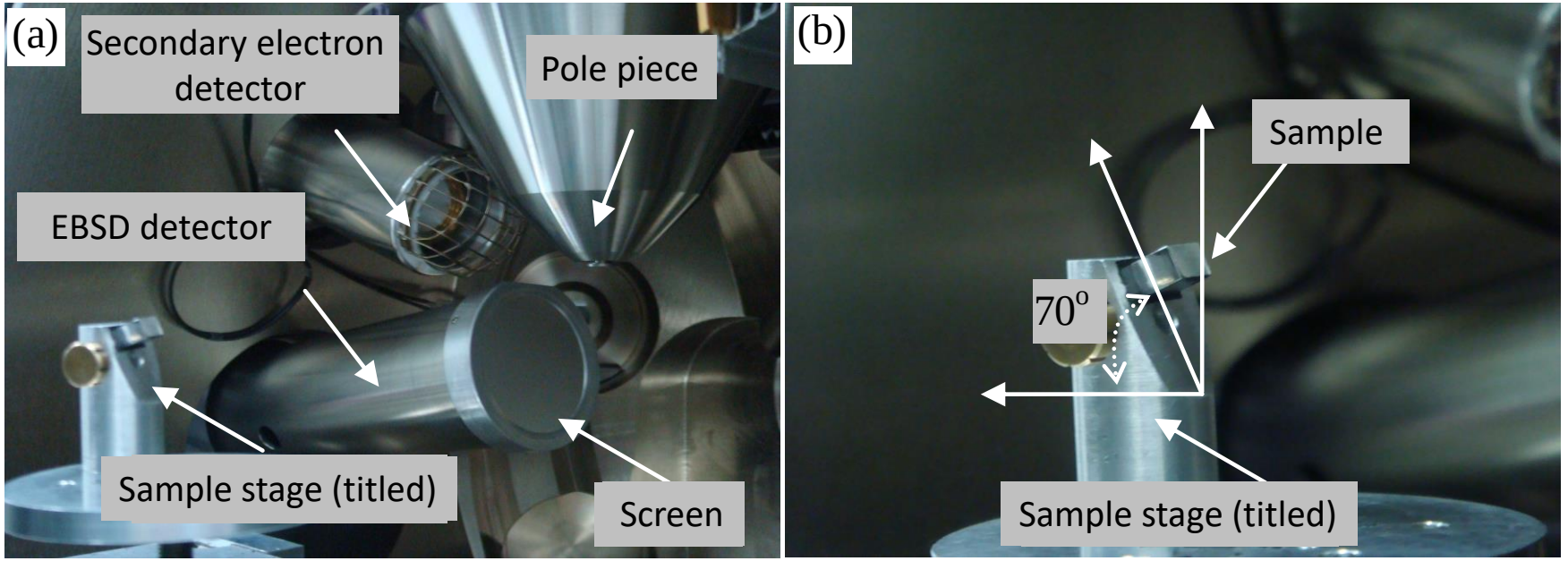
The EBSD analysis system is used as a scanning electron microscope accessory, and the actual photos are shown.



12.3 Electronic backscatter diffraction technology hardware system

- Overall layout of the hardware system

The position of the EBSD probe in the SEM electron microscope sample chamber is shown in Figure a; during analysis, the sample needs to be tilted 70 °. Generally, a prefabricated sample stage tilted 70 ° can be used, as shown in Figure b.

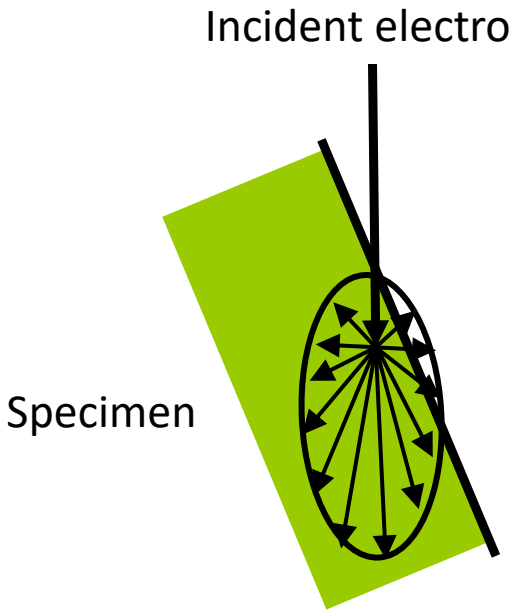


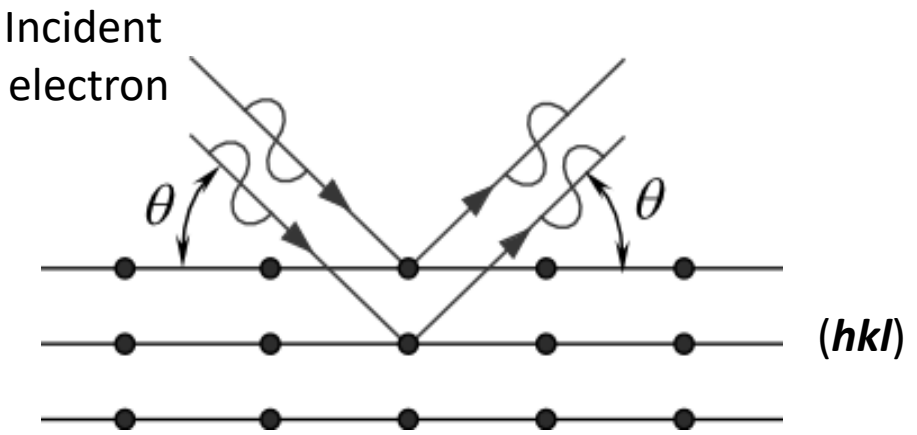
12.4 Electronic backscatter diffraction technology hardware system

- Principles of electron backscatter diffraction technology and pattern calibration

Principles of electron backscatter diffraction technology

When an electron beam is incident into the crystal, it will undergo inelastic scattering and propagate in all directions. The scattering intensity decreases as the scattering angle increases. If the scattering intensity is represented by the length of the arrow, the intensity distribution will be droplet-shaped, as shown in the figure.





12.4 Electronic backscatter diffraction technology hardware system

- Principles of electron backscatter diffraction technology and pattern calibration

Principles of electron backscatter diffraction technology

Due to the inelastic scattering of incident electrons by the sample, a point “light source” is formed at the incident point that emits in all directions in space. The angle between the electrons in some directions and the (***hkl***) crystal plane is the Bragg angle θ.

The electrons in these directions constitute a half-vertex.

The electrons whose scattering direction is located on the conical surface with an angle of $90°-\theta$ are incident on the (***hkl***) crystal plane because they satisfy the Bragg condition $\lambda=2d\sin\theta$, and the electrons with the diffraction direction will form a half-vertex angle of $90°-\theta$.

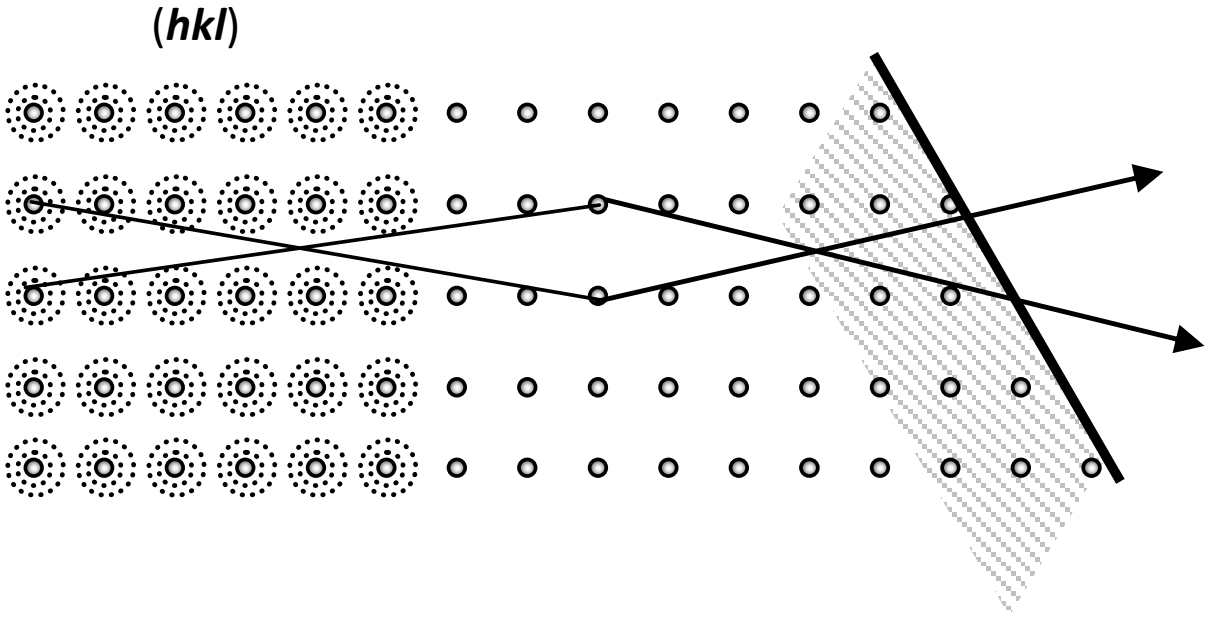
Similarly, the diffracted beam from the ***(-h-k -l***) crystal plane will also form a diffraction cone. See figure in the next page.

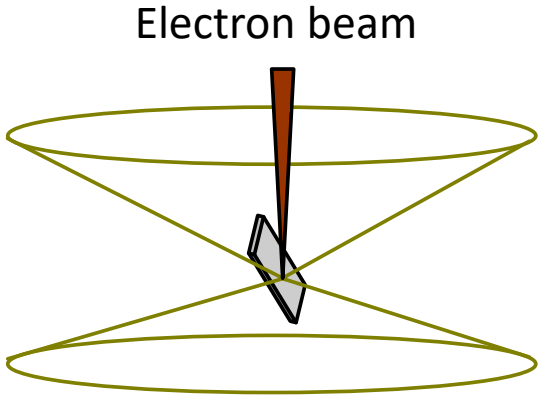
12.4 Electronic backscatter diffraction technology hardware system

- Principles of electron backscatter diffraction technology and pattern calibration

Principles of electron backscatter diffraction technology

The picture shows that the incident electrons are diffracted on both sides of the crystal plane, forming two symmetrical diffraction cones on both sides of the (***hkl***) crystal plane.





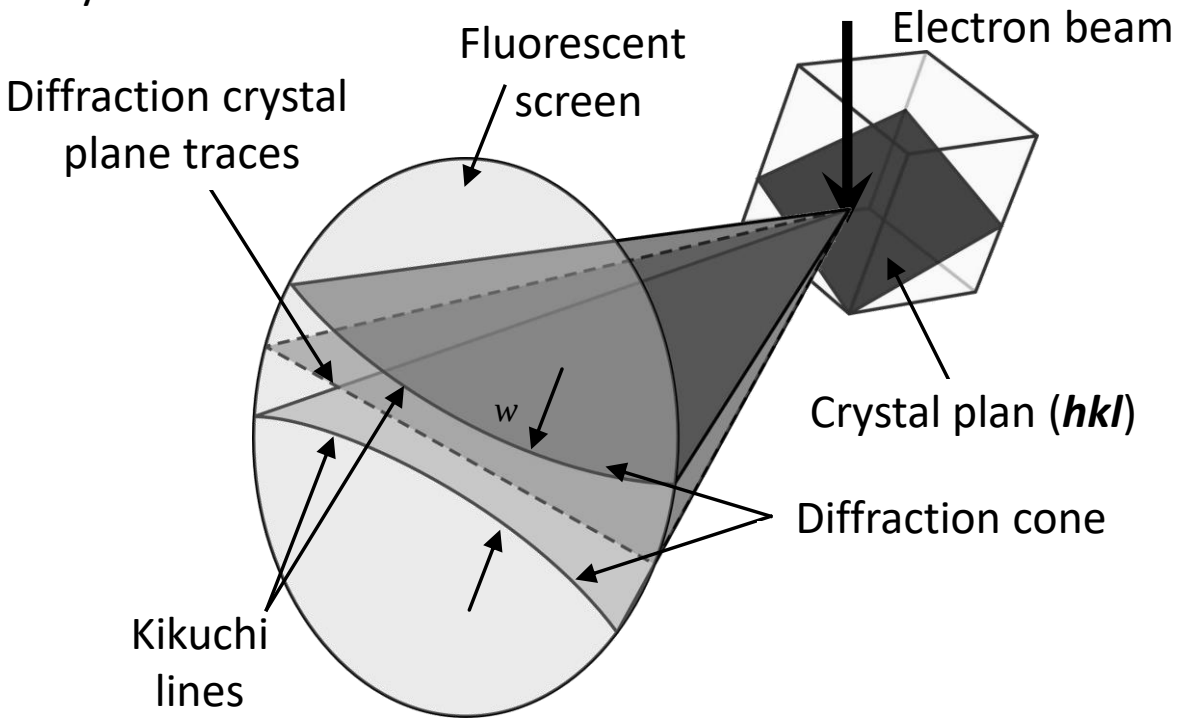
Two symmetrical electron diffraction cones

12.4 Electronic backscatter diffraction technology hardware system

- Principles of electron backscatter diffraction technology and pattern calibration

Principles of electron backscatter diffraction technology

The intersection lines between the two diffraction cones and the fluorescent screen of the CCD camera are a pair of hyperbolas. However, since the **θ** angle is very small and the diffraction cone surface is close to a plane, it is close to a pair of parallel lines. The center line of the Kikuchi line pair (belt) can be considered as the intersection line of the diffraction crystal surface and the fluorescent screen.

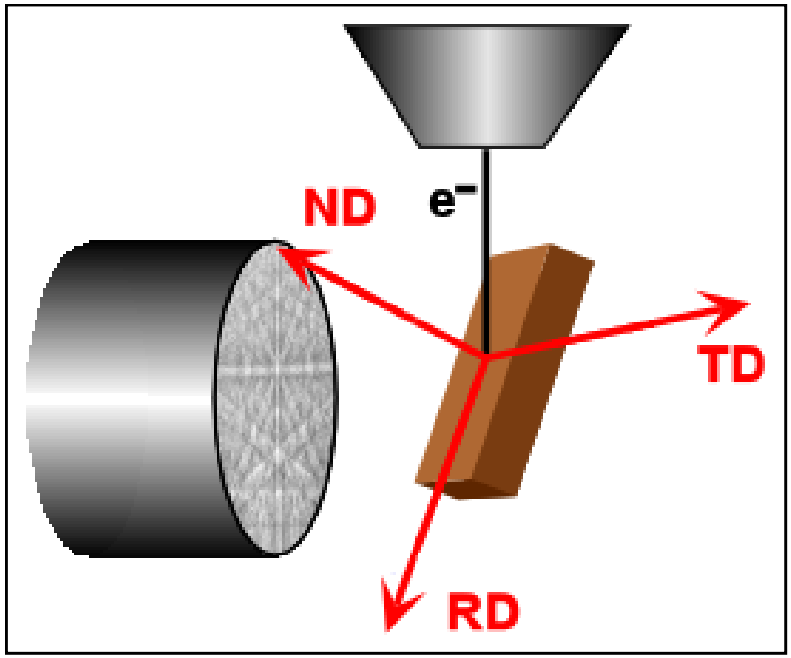


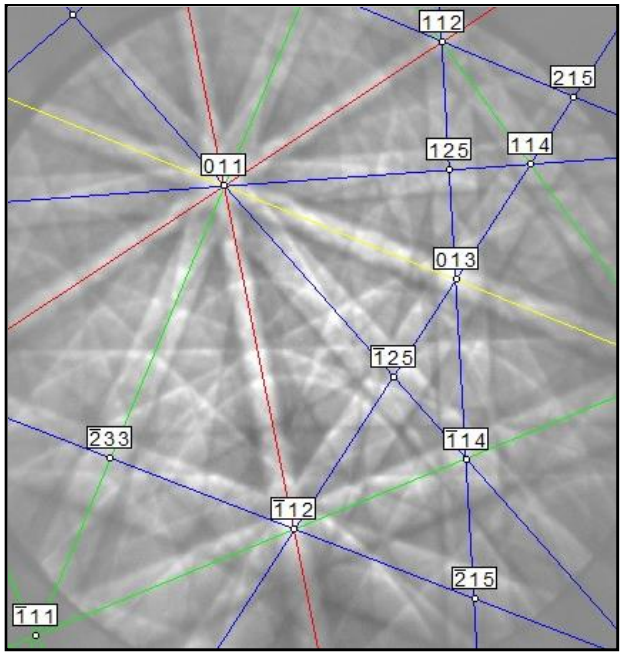
12.4 Electronic backscatter diffraction technology hardware system

- Principles of electron backscatter diffraction technology and pattern calibration

Principles of electron backscatter diffraction technology

The picture shows a typical Al Kikuchi pattern calibrated by a computer. During analysis, the sample is usually tilted **70°** to increase the signal intensity, and the CCD probe can collect the diffraction pattern from a thin layer of tens of nanometers on the sample surface.





Typical Kikuchi zone pattern of Al

12.4 Electronic backscatter diffraction technology hardware system

- Principles of electron backscatter diffraction technology and pattern calibration

Principles of electron backscatter diffraction technology

The electron backscattered diffraction pattern consists of multiple Kikuchi bands of varying widths. The intersection point of the Kikuchi zones is called the Kikuchi pole. The crystal planes corresponding to the Kikuchi zones intersecting at the same Kikuchi pole form a crystal zone. The direction represented by the Kikuchi pole is the common direction of the crystal faces of this crystal zone, that is, the crystal zone axis. The relationship between the Kikuchi band width ***w*** and the corresponding diffraction crystal plane spacing ***d*** is:

$$w = R\theta$$

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

R is the distance between the Kikuchi band on the fluorescent screen and the electron beam incident point on the sample; λ is the wavelength of the incident electron beam, because the wavelength change of most inelastically scattered electrons is very small within a few tens of nanometers on the surface of the sample.

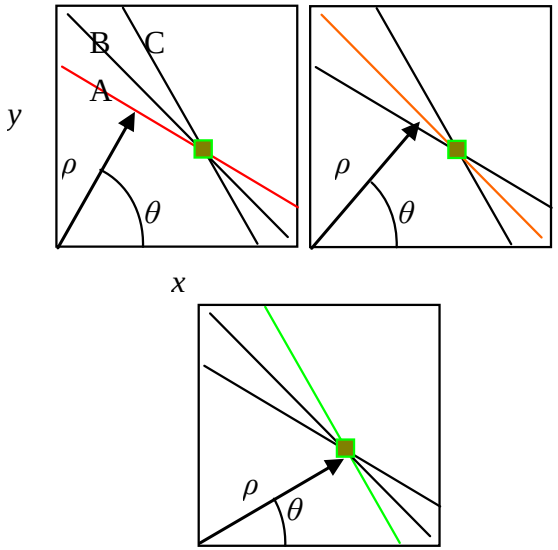
12.4 Electronic backscatter diffraction technology hardware system

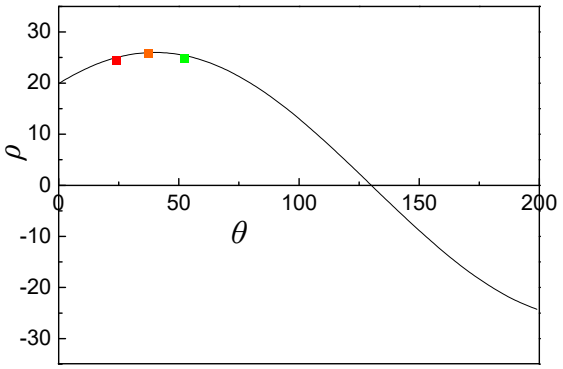
- Principles of electron backscatter diffraction technology and pattern calibration

Diffraction pattern calibration principle

The Kikuchi pattern is subjected to Hough transformation, and the Kikuchi polar index is calibrated according to the position of the Kikuchi belt and compared with the standard pattern. The above process is automatically performed by the computer as shown in the figure. A perpendicular line is drawn from the origin to the straight line, and the intersection coordinates are (x, y). If The length of the vertical line is ρ, and the angle θ between it and the x-axis has the following relationship.

$$\rho = x\cos\theta + y\sin\theta$$





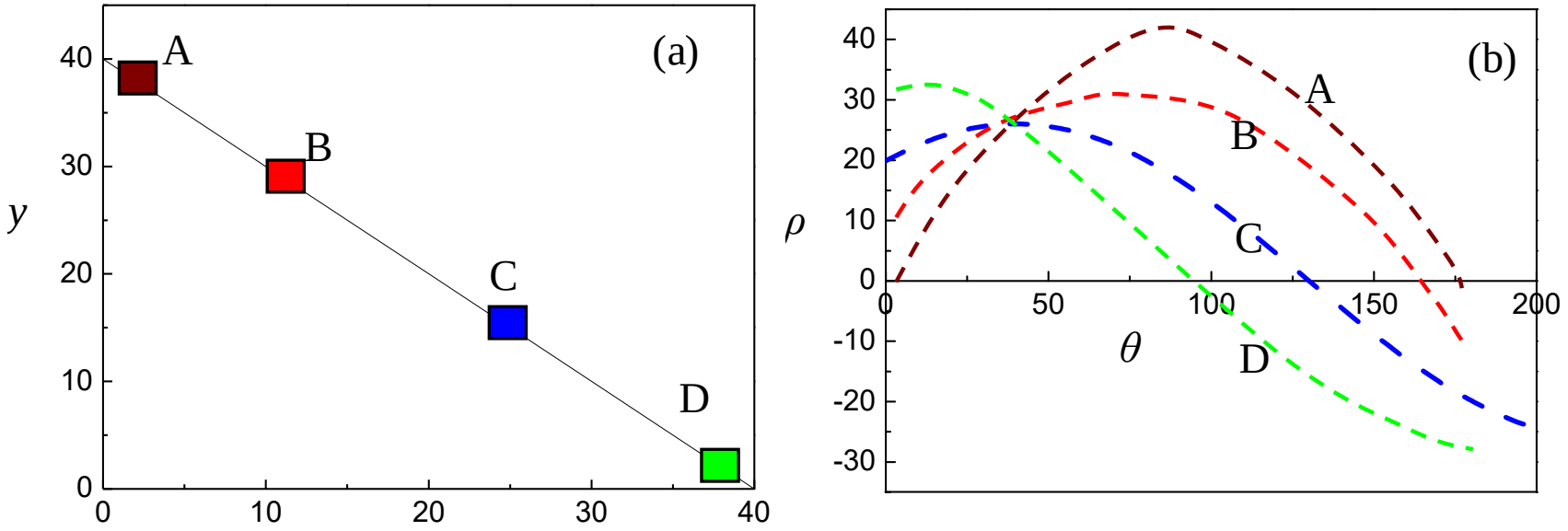
Hough transformation

12.4 Electronic backscatter diffraction technology hardware system

- Principles of electron backscatter diffraction technology and pattern calibration

Diffraction pattern calibration principle

As shown in the figure, Hough transformation can transform straight lines in image space into points in Hough space. The four points A, B, C, and D on the straight line correspond to four Hough sinusoids. The intersection points (ρ, θ) of these four Hough sinusoids are the positions of the straight lines corresponding to the Hough space points.



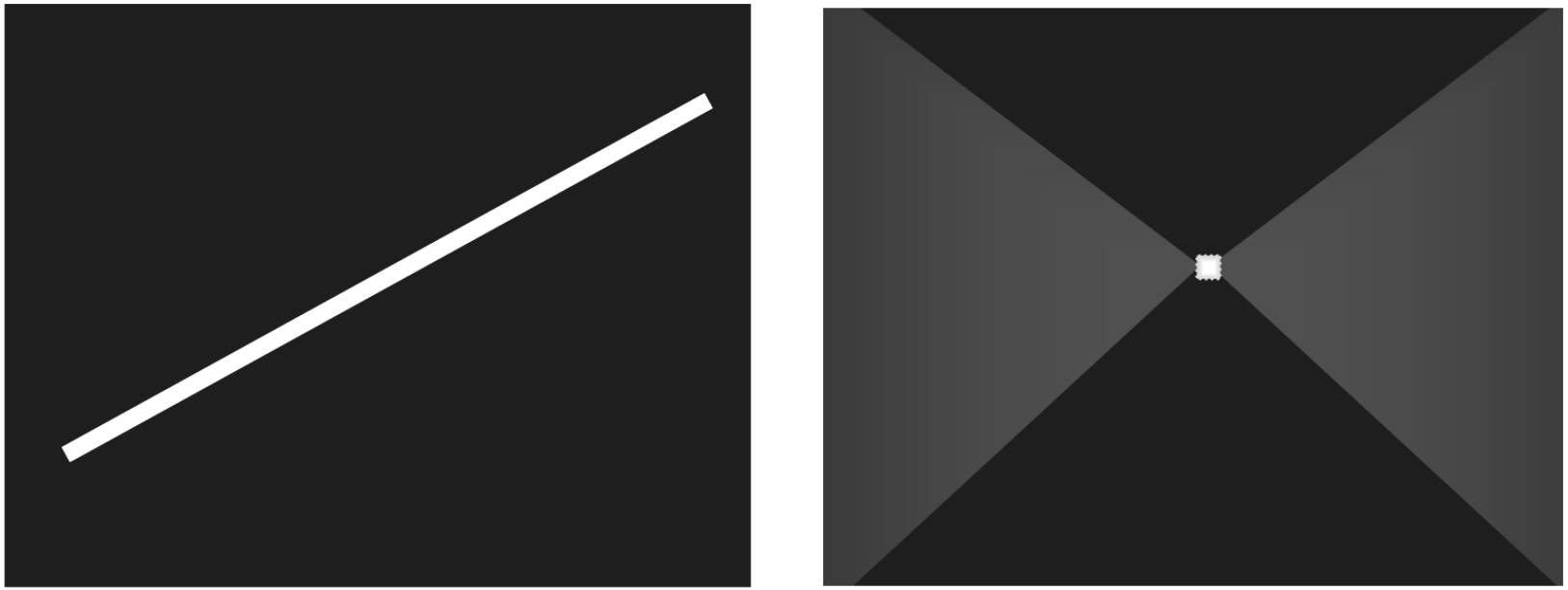
Hough transform line and point conversion

12.4 Electronic backscatter diffraction technology hardware system

- Principles of electron backscatter diffraction technology and pattern calibration

Diffraction pattern calibration principle

The picture shows the Hough transform simulation diagram. After Hough transformation, the Kikuchi band forms a point similar to a bow tie. The basic principle of Hough transform is to use the duality between points and lines to transform the curves in the original image space into points in the parameter space.



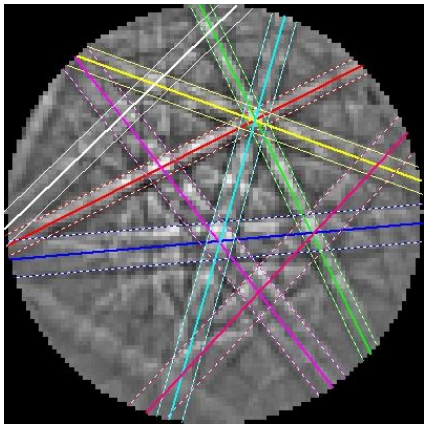
Hough transform line and point conversion

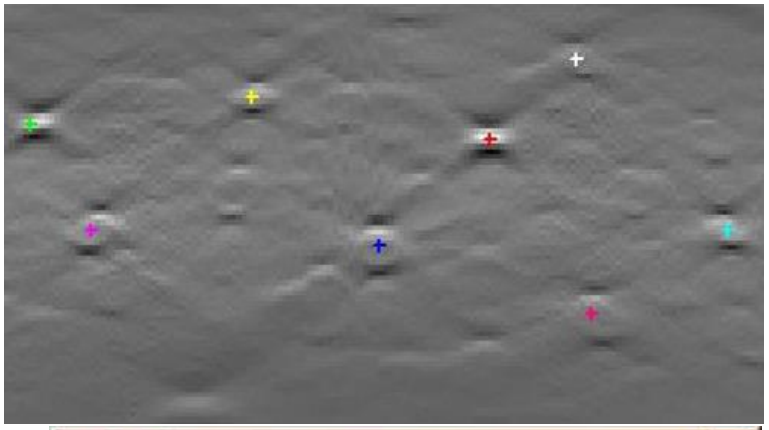
12.4 Electronic backscatter diffraction technology hardware system

- Principles of electron backscatter diffraction technology and pattern calibration

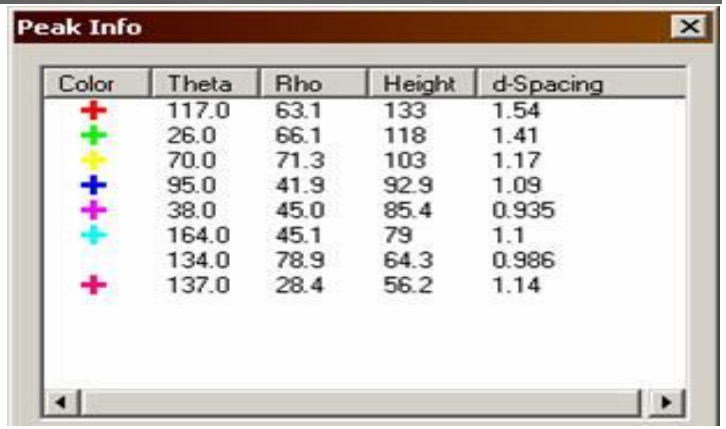
Diffraction pattern calibration principle

The picture shows the Hough transform image during pattern automatic calibration.





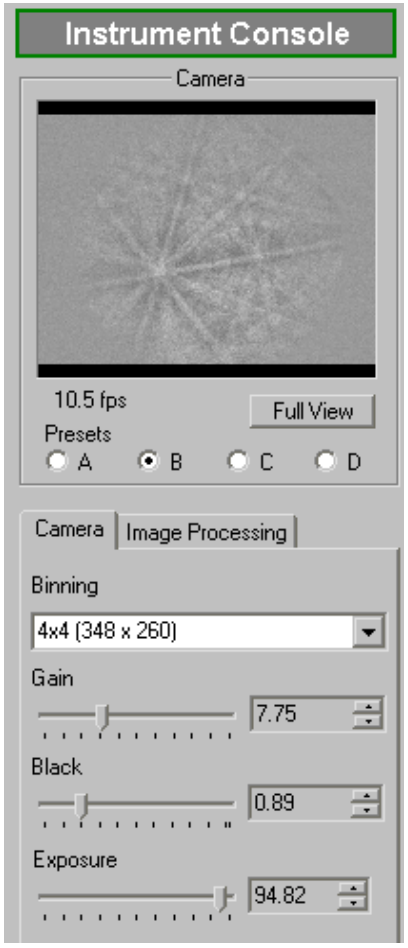
Hough transform line and point conversion

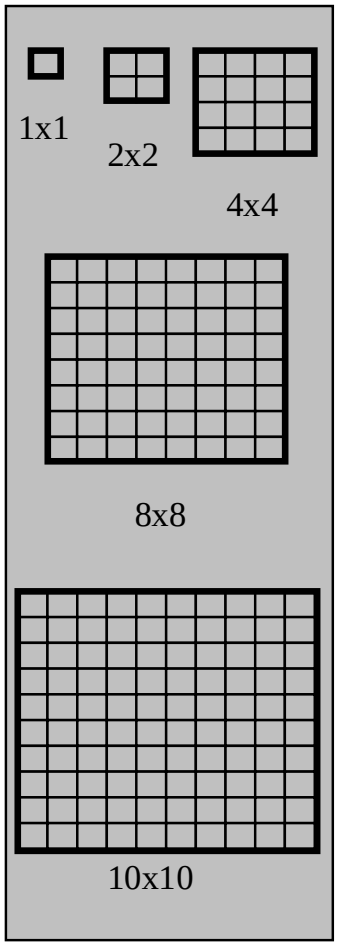


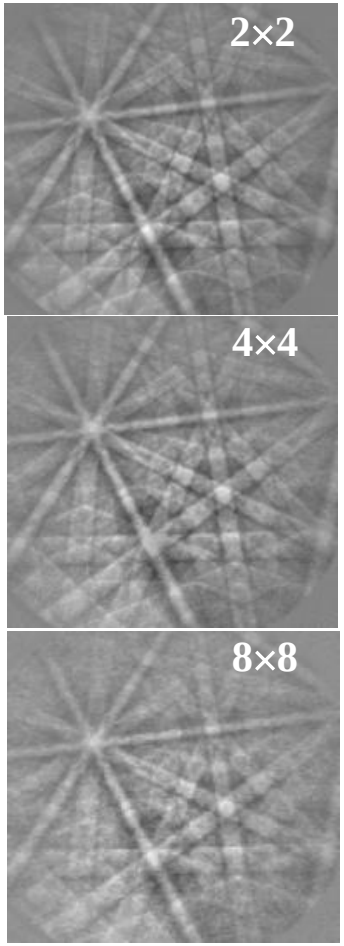
12.5 Electron backscatter diffraction imaging and analysis

- Camera operation

Open the camera control window, and according to the analysis needs, reasonably select and set the camera parameters. On the premise of satisfying the pattern clarity, shorten the pattern collection time as much as possible to increase the scanning speed.

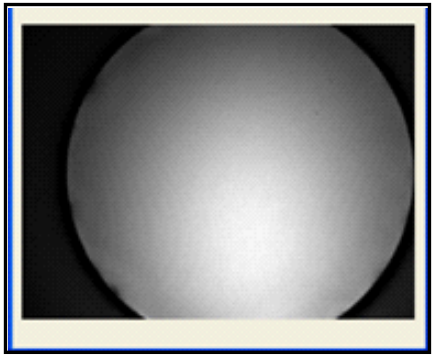






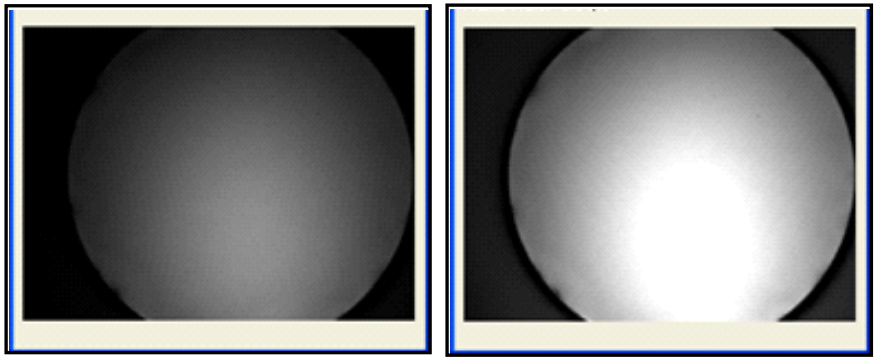
12.5 Electron backscatter diffraction imaging and analysis

- Camera operation



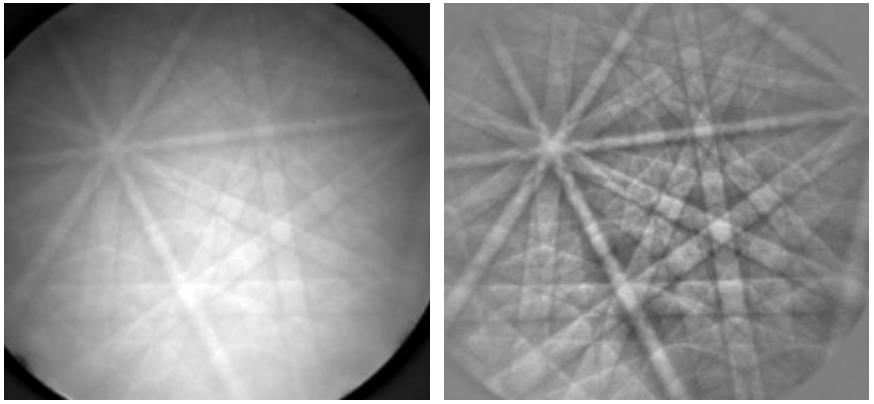
Optimal

Adjust the gain or exposure time to optimize the signal level, see Figure **a**. After determining the signal level, perform the background pull-out to improve the contrast and clarity of the pattern, thereby increasing the success rate of pattern calibration. The Kikuchi pattern before and after the background pull-out is shown in Figure **b**.



Under-saturated Over-saturated

Figure **a**



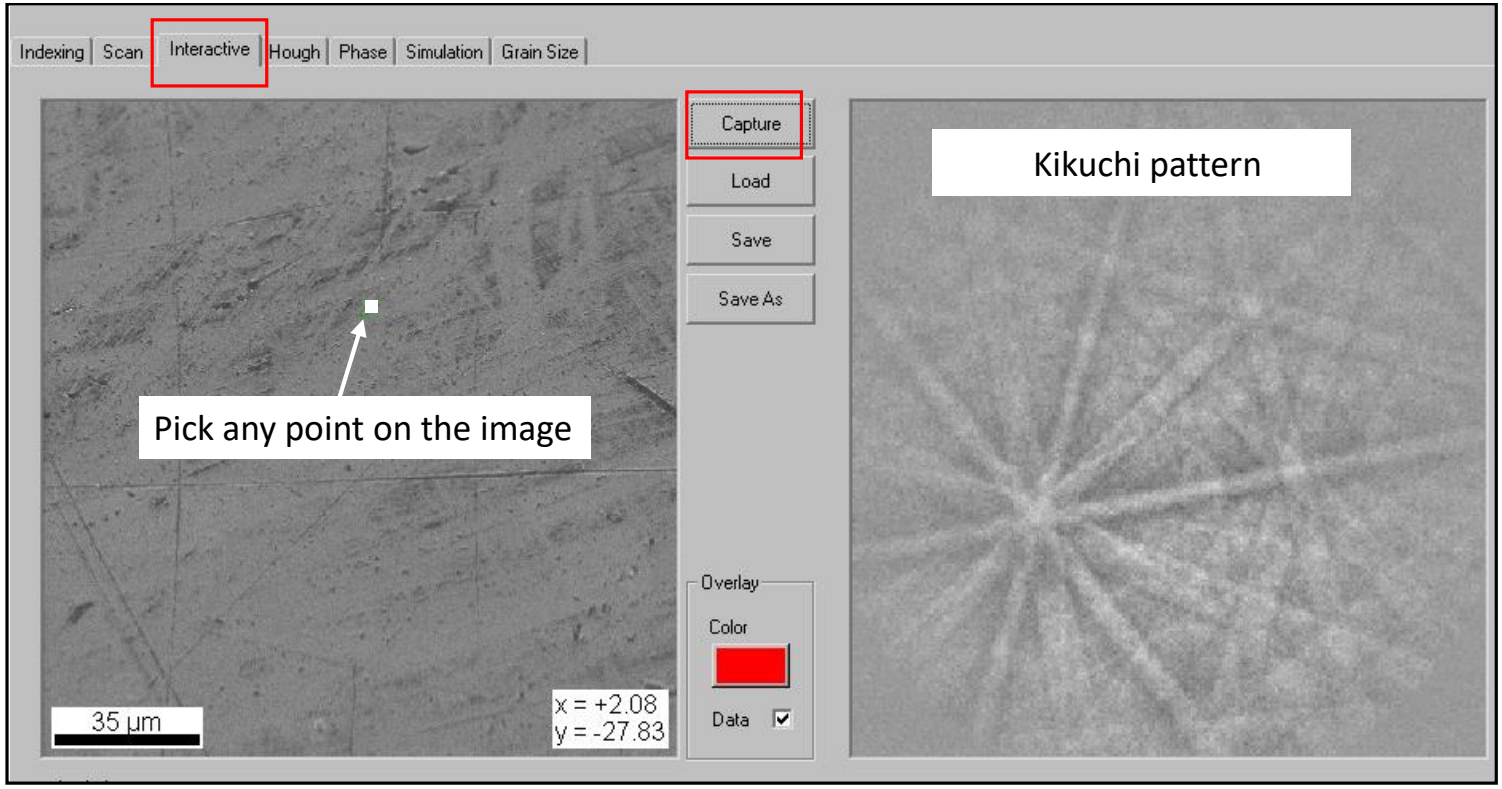
Before deduction After deduction

Figure **b**

12.5 Electron backscatter diffraction imaging and analysis

- Kikuchi belt collection

First, we collect an SEM image, select the area of interest, pick any point on the image, and preview the EBSD pattern, as shown in the figure.

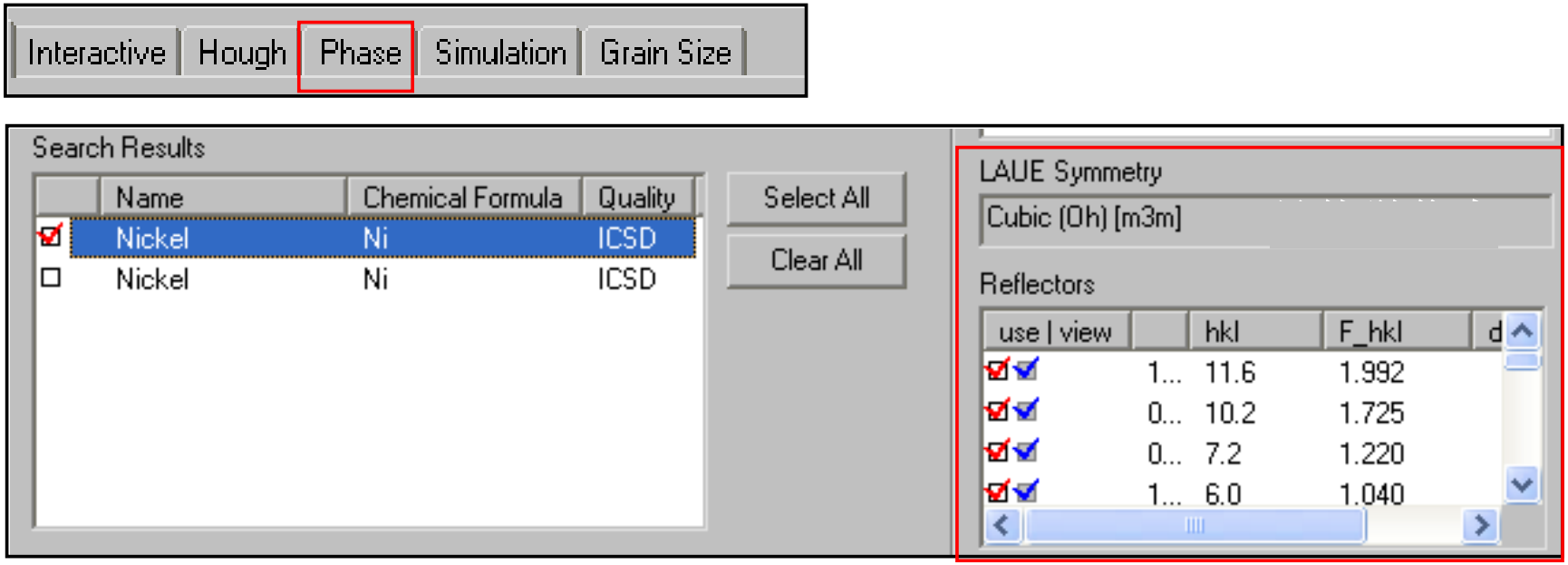


Interactive interface and pattern preview

12.5 Electron backscatter diffraction imaging and analysis

- Kikuchi belt collection

- Select the phase to be analyzed in the database to provide relevant crystallographic information required for pattern calibration. The figure shows the Ni database.
- According to the grain size, select the appropriate scanning step size and scanning area, collect EBSD patterns point by point, and automatically calibrate the computer program synchronously.

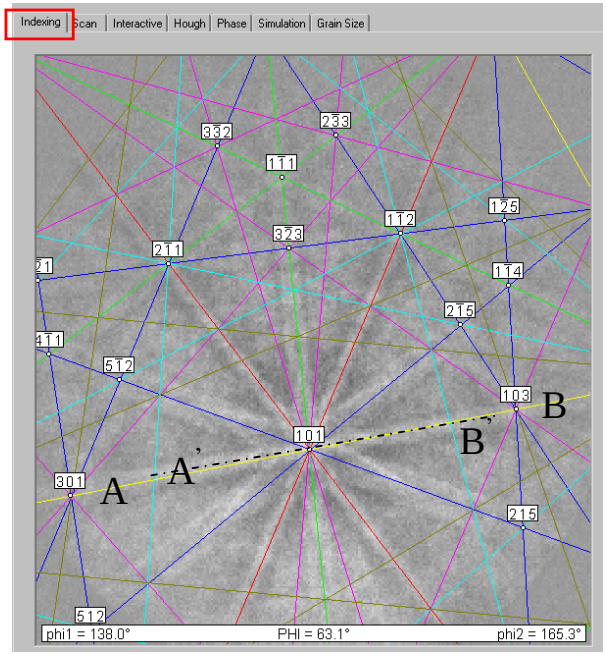


Database (Ni)

12.5 Electron backscatter diffraction imaging and analysis

- Kikuchi belt collection

The Kikuchi pattern calibration results are shown in the figure.

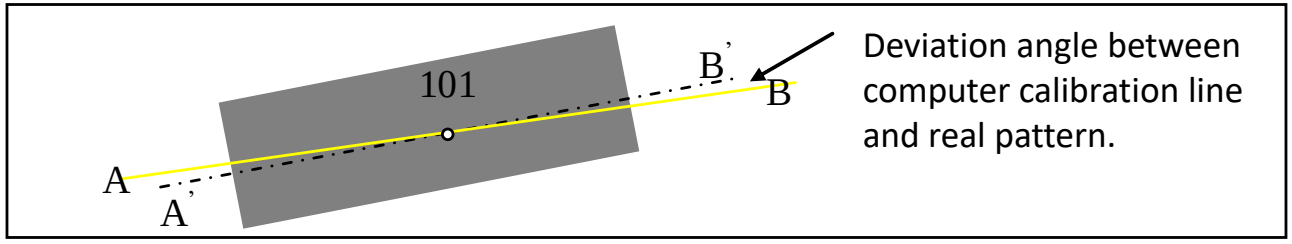


Solutions | HKLs | Parameters | Pseudosymmetry

Overall CI: 0.869

Phase	Votes	Fit [°]	CI	d-Space Fit	Rank Factor
☑ Nickel	83	0.71	0.869	1.00	1.00

Solution	Votes	Fit [°]	matched	d-Space Fit	Rank Votes
☑ 1	83	0.71	4	0.63	1253
☐ 2	10	1.74	10	0.59	120
☐ 3	4	1.98	10	0.84	48
☐ 4	4	2.08	10	1.03	42
☐ 5	4	2.13	10	0.61	48
☐ 6	2	2.43	10	0.98	30
☐ 7	1	2.08	8	0.68	7
☐ 8	1	2.36	9	0.95	11
☐ 9	1	2.39	10	1.22	12
☐ 10	1	2.41	10	0.91	13



Deviation angle between computer calibration line and real pattern.

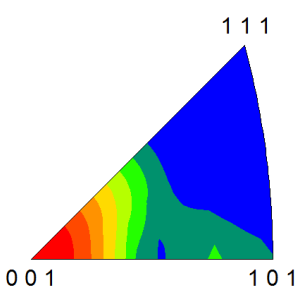
Ni's Kikuchi pattern calibration results

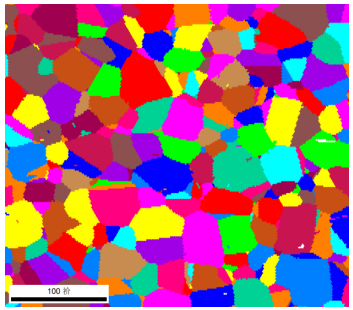
12.6 Electron backscatter diffraction technology data processing

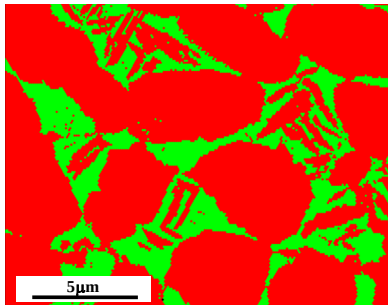
- EBSD patterns contain rich crystallographic information
- EBSD technology has a high degree of automation and fast analysis speed
- EBSD technology is powerful and easy to apply
- The application scope of EBSD technology is expanding day by day.

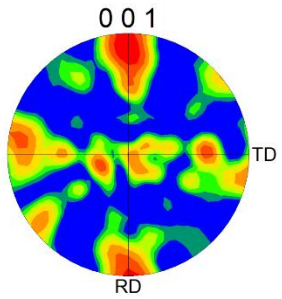
The main applications include:

1) Organism and orientation analysis
2) Analysis of grain shape and size distribution
3) Analysis of grain boundary properties
4) Deformation and recrystallization analysis
5) Physical phase identification and phase content determination
6) Determination of the two-phase orientation relationship





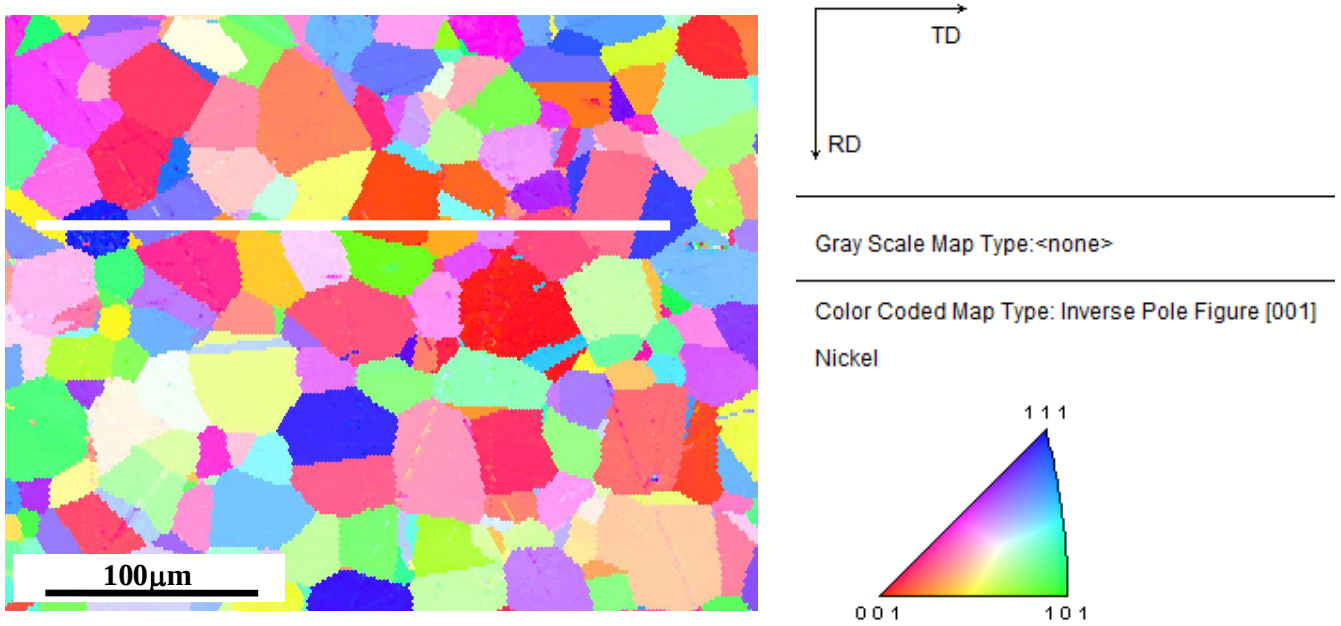




12.6 Electron backscatter diffraction technology data processing

- Grain orientation distribution and orientation difference

The picture shows the orientation imaging image showing the morphology of Ni grains. Grains with the same orientation are represented by the same color. The color of the grains in the figure is matched using the **ND** inverse pole figure, indicating that the normal line of the red grains is parallel to [001], and the normal directions of the blue and green grains are parallel to [111] and [101], respectively.



Ni grain orientation distribution diagram

12.6 Electron backscatter diffraction technology data processing

- Grain orientation distribution and orientation difference

Figure **a** shows the statistical diagram of the orientation difference of Ni grains. The orientation difference of most grains is less than **3°** or equal to **60°**.

Figure **b** shows the change of Ni grain orientation difference along a straight line. The orientation difference changes very little inside the grain (< **3°**); there is a sudden change in the orientation difference at the grain boundary, such as **15°**, **40°**, **60°**, etc.

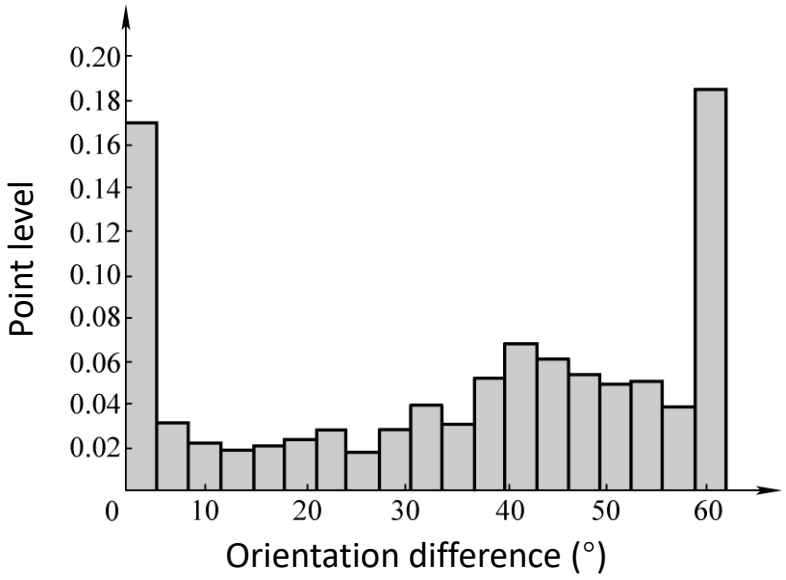


Figure **a**

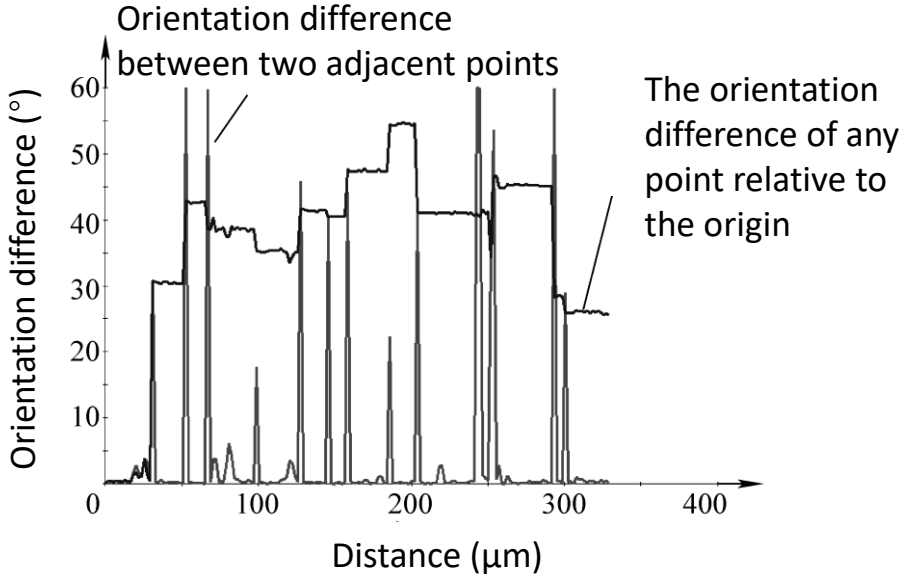


Figure **b**

12.6 Electron backscatter diffraction technology data processing

- Image quality map and stress strain analysis

1. The quality of a Kikuchi pattern refers to the sharpness (clearness) of the Kikuchi bands, expressed by the parameter IQ. IQ can be calculated based on the sum of the diffraction intensities of several Kikuchi bands in the pattern.
2. Many factors affect pattern quality IQ, including the type of material, sample surface state, stress and strain state, grain orientation, grain size, etc. In single-crystal materials, stress and strain gradients are the main factors that affect IQ changes.
3. For the same sample, the Kikuchi pattern quality IQ of different areas mainly depends on its stress or strain state. Therefore, IQ can evaluate the distribution of strain in the micro-region of the material.
4. Kikuchi pattern quality IQ imaging is used. The brightness level in the image represents the IQ. That is, the bright spots indicate that the pattern quality is good; the dark spots indicate that the pattern quality is poor, and there is a large strain at the corresponding sample position.
5. The IQ imaging method is suitable for measuring strain distribution within grains but is not suitable for measuring strain distribution between grains or different phases.

12.6 Electron backscatter diffraction technology data processing

- Image quality map and stress strain analysis

Pictures **a**, **b**, and **c** are all Kikuchi pattern-quality images. As can be seen from Figure **a**, the strain inside the grains is not uniform; there is a large difference in the degree of deformation of Al grains as shown in Figure **b**; in dual-phase titanium alloys, α -Titanium grains are brighter, while β -Titanium grains are brighter. The grains are darker. This difference may be due to the greater degree of deformation of α -titanium grains, or it may be due to the difference in the diffraction intensity of the two phases, see Figure **c**.

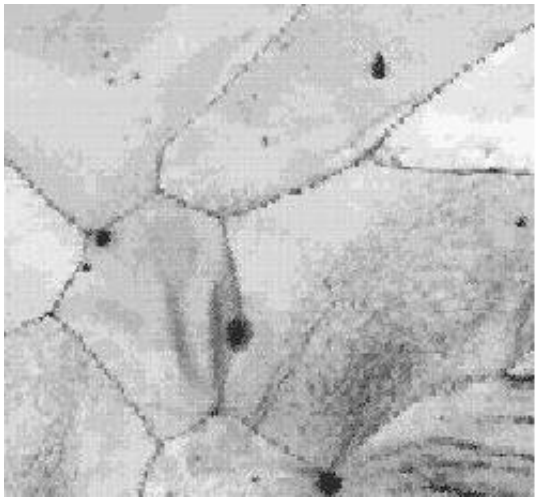


Figure **a**

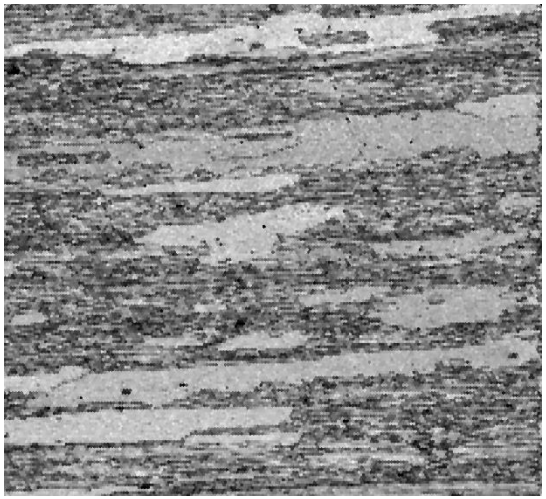


Figure **b**

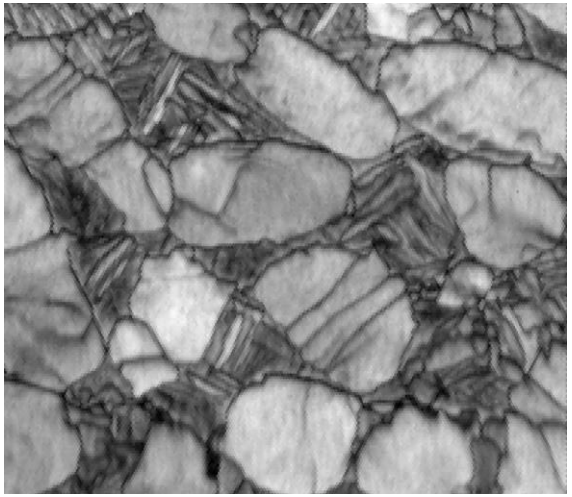
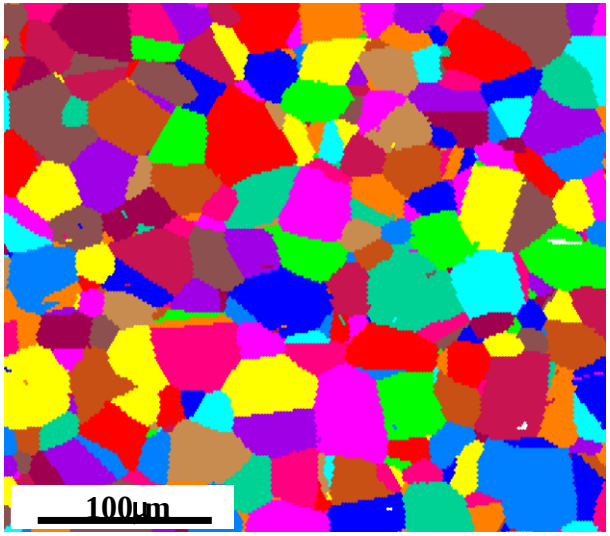


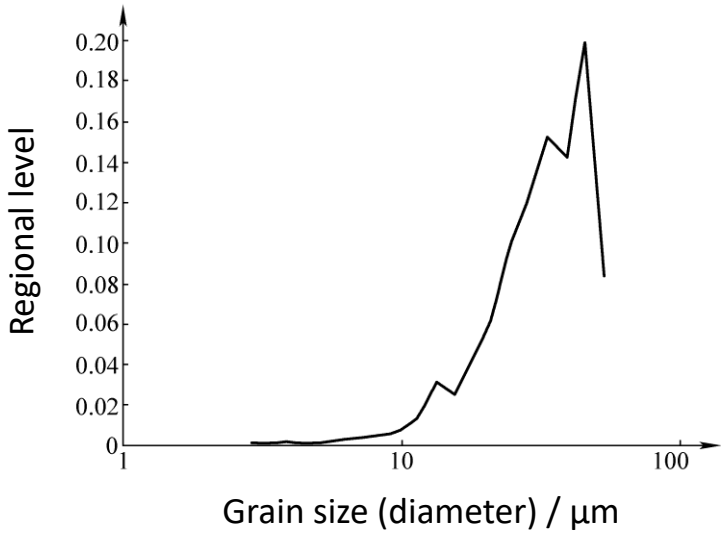
Figure **c**

12.6 Electron backscatter diffraction technology data processing

- Grain morphology and size analysis
- EBSD technology uses the orientation imaging method to obtain images showing the grain morphology, and at the same time, it can easily measure its grain size and size distribution. As shown in the figure, the largest number of grains with a diameter of about **20 μm**.
- The main factors that affect the grain size measurement results are the setting of the scanning step length and the orientation difference angle range.



Orientation imaging of nickel grain morphology

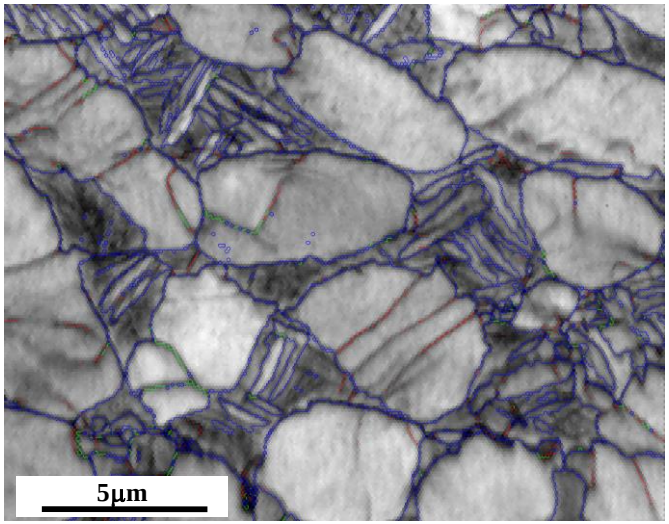


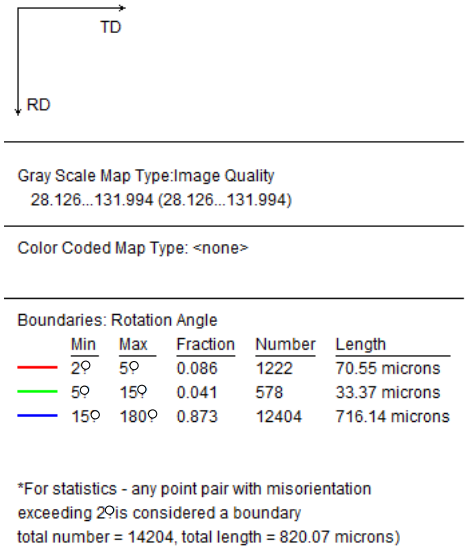
Nickel grain size distribution chart

12.6 Electron backscatter diffraction technology data processing

- Grain boundary type analysis

As mentioned before, EBSD technology can measure the orientation difference between grains. If the orientation difference is classified according to the angle range, it can distinguish between small-angle grain boundaries and high-angle grain boundaries and calculate the proportion of each grain boundary type.



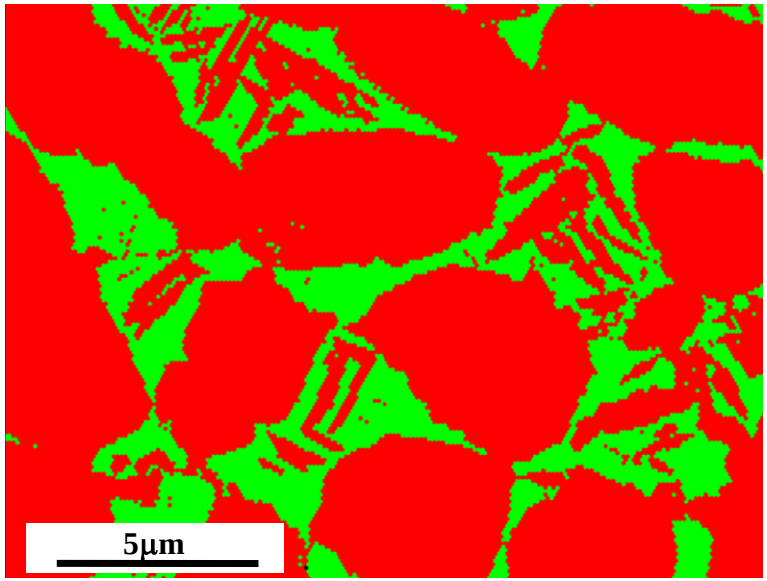


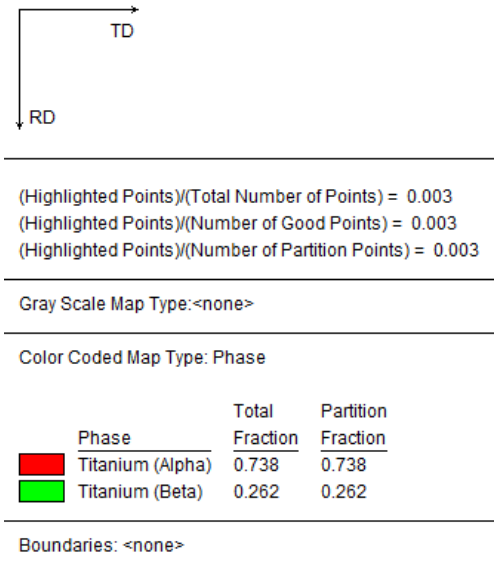
As shown in Figure, the grain boundaries of **5°~15°** are represented by green lines, accounting for 0.41%. According to the specific orientation difference, special grain boundaries such as twin and overlapping position lattice grain boundaries can also be determined.

12.6 Electron backscatter diffraction technology data processing

- Physical phase identification and identification and phase orientation relationship

Using the crystallographic data of known physical phases (you can use the database), and identifying the physical phases through diffraction pattern calibration, different phases are imaged with different colors, and the phase distribution image, as shown in the figure, can be obtained, and the proportion occupied by each phase can be calculated. In the fraction diagram, red represents α -titanium, and green represents β -titanium. α -titanium and β -titanium account for 73.8% and 26.2% respectively.





α , β Phase distribution image of dual-phase titanium alloy

12.6 Electron backscatter diffraction technology data processing

- Physical phase identification and identification and phase orientation relationship
- When two phases coexist in the analyzed area of the sample, there may often be a certain orientation relationship between the two phases. Commonly used methods to determine the orientation relationship include X-ray diffraction, transmission electron microscopy, and electron backscatter diffraction.
- The X-ray diffraction method has high analysis accuracy, and the analysis results have macroscopic statistical significance, but it requires using single crystal samples with a size larger than 0.1 mm.
- Although the analysis accuracy of the transmission electron microscopy electron diffraction method is slightly lower, polycrystalline samples can be used, and the morphology and distribution of the two phases can be observed simultaneously.
- The EBSD method for measuring the orientation relationship between two phases, except that the analysis accuracy is slightly worse than the X-ray diffraction method, takes into account the advantages of X-ray diffraction and transmission electron microscopy and has the characteristics of high analysis automation and fast analysis speed. In general, the electron-backscattered diffraction method has significant advantages in determining the orientation relationship between two phases.

12.6 Electron backscatter diffraction technology data processing

- Orientation Distribution Analysis

Compared with other methods, EBSD technology shows obvious advantages in orientation distribution analysis, mainly in the following aspects:

1) EBSD technology can not only quantitatively determine the proportion of grains with various orientations but also visually display the distribution of various orientations in the microstructure.

2) EBSD technology can also use textures described in various forms, such as pole figures, inverse pole figures, ODF, etc. Its advantage is that data processing is convenient and fast.

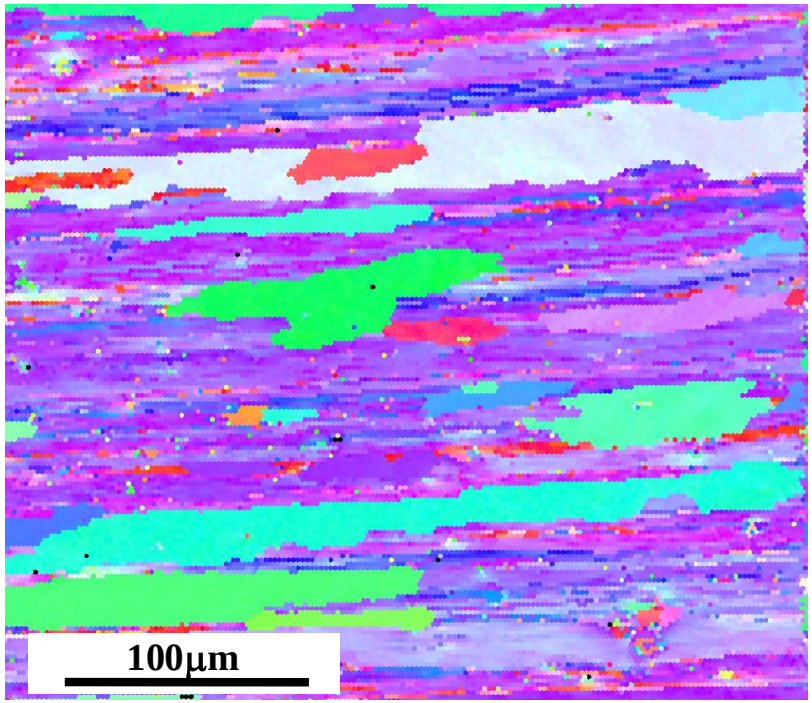
3) The EBSD technology method is flexible and can extract selected data in a larger area to measure micro-regions or selected texture; it can also select a certain orientation for imaging to display the grain morphology and distribution of that orientation.

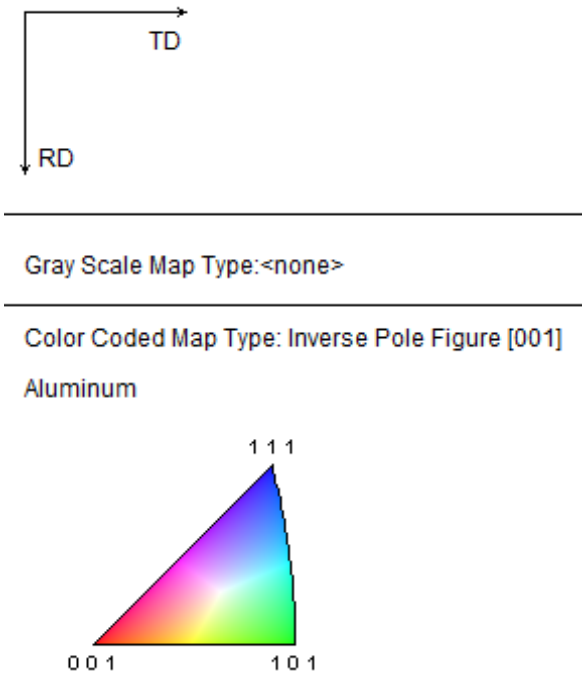
4) The results of texture measurement using EBSD technology deviate slightly from the actual situation.

12.6 Electron backscatter diffraction technology data processing

- Orientation Distribution Analysis

The picture is an imaging diagram of the orientation of deformed aluminum grains. Most of the deformed grains in the picture have similar colors, indicating that they have similar orientations. However, their index needs to be determined by pole figure, inverse pole figure, and ODF methods.

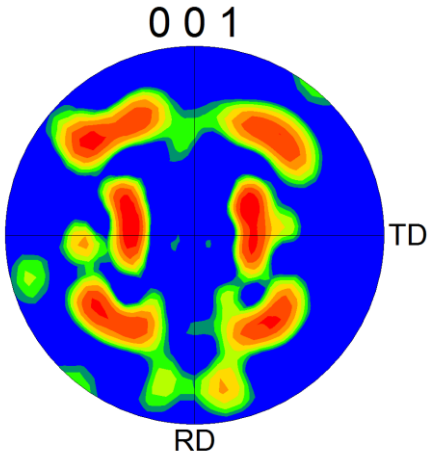


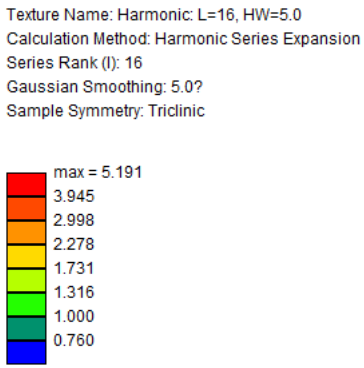


12.6 Electron backscatter diffraction technology data processing

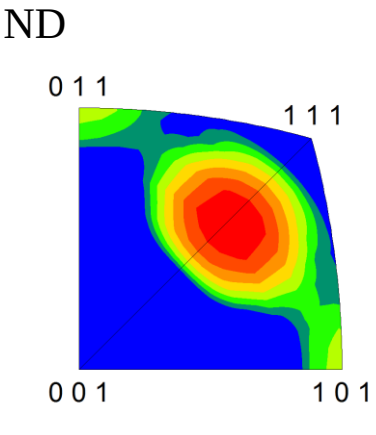
- Orientation Distribution Analysis

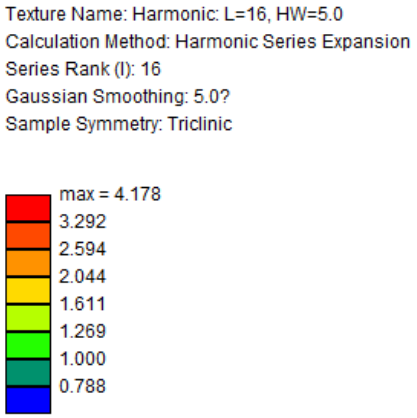
- Figure **a** shows the {001} pole figure of deformed aluminum grains. It can be seen that deformed aluminum shows an obvious preferred orientation in the [001] crystal direction.
- Figure **b** shows the ND inverse pole diagram of deformed aluminum. There is a high density near the 112 pole in the figure, indicating that the [112] direction is parallel to the normal direction of the sample coordinate system.





a. Deformed aluminum grain {001} pole





b. Deformed aluminum grain ND inverse pole diagram

12.6 Electron backscatter diffraction technology data processing

- Orientation Distribution Analysis
- The picture shows the ODF diagram of deformed aluminum grains. According to the orientation density distribution in the picture, the texture can be quantitatively described.