Light-Figure Microscope Newly Designed and Its Crystallographic Application to Metal Specimens*

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Light-figure microscope has been newly devised for the rapid, accurate and perfect orientation determination of crystal grains of microscopic size. This microscope consists of two main parts: one is an optical system which produces a clear-cut light figure in the viewing field of the microscope and the other a goniometric mechanism which measures the orientation angles. Full accounts are given of the construction of the microscope, its principle and the procedure and accuracy of the orientation determination with actual examples. It can be applied to large single crystals as well as to crystal grains of the smallest diameter of 15μ with an accuracy well within $\pm 0.2^\circ \sim 0.5^\circ$. It can also serve as a usual metallurgical microscope.

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I. Introduction

It has been well established that, when a fine beam of light is allowed to fall on a crystal surface etched properly beforehand, the reflected light (or the refracted light in the case of transparent crystal) forms on a screen† a light pattern of a regular shape. This so-called light figure is made by the reflection or scattering of incident light beam from facets, grooves or edges of etch figures produced by etching on the crystal surface. The arrangement of facets, grooves or edges of etch figures reflects the crystallographic symmetry of the crystal surface on which the etch figures are revealed, and correspondingly the light figure shows the same symmetry as that of the crystal surface concerned. Namely, in cubic crystals, light figures of the tetragonal, digonal and trigonal symmetries are produced inevitably by the $\{100\}$, $\{110\}$ and $\{111\}$ surfaces, respectively. This phenomenon can be used for the rapid and accurate determination of the crystal orientations.

The two of the present authors (Watanabé and Yamamoto) have so far applied the light figure method to the determination of orientations of single crystals and crystal grains of metals, semiconductors, ionic crystals and oxides⁽¹⁾. It has been shown that the orientation determination by light figures can be conducted simply with an accuracy comparable or superior to the X-ray diffraction method⁽²⁾, if we have some elementary knowledge of crystallography. But the light figure method was inadequate for minute crystals or

crystal grains less than $0.5 \sim 1$ mm in diameter, because the optical instrument used was devised for large single crystals⁽³⁾.

In the course of some work on metal crystals, it became necessary to perform orientation determinations of small crystals or crystal grains in polycrystals, for instance, in order to obtain statistical information about deformation and recrystallization textures or about sintered particles and to check the preferred orientation of silicon iron plates or Alnico V magnets. The fundamental method of orientation determination is an X-ray diffraction method. But this method is time consuming and needs an expensive instrument for the orientation work of crystal grains less than 50μ in diameter, since it requires a micro beam and a long time exposure.

Recently, the maximum-reflection method has been successfully applied to crystal grains having a size as small as $10 \times 10\mu^2$ by Taoka et al.⁽⁴⁾ The instrument devised by them is called the Gonio-microscope. With this instrument, it is possible to determine the crystal orientation readily with a precision within $\pm 0.5^\circ$. The difficulties usually encountered in methods of this type are in getting well-defined etch pits which are composed of flat facets parallel to low index crystallographic planes. While, in the light figure method, these difficulties are readily overcome and moreover the orientation work can be simplified.

A light-figure microscope which can apply to crystal grains as small as 15μ in diameter as well as to large single crystals has been newly devised on the base of the gonio-microscope. Its construction, principle, operation and accuracy are reported with actual examples in the present paper.

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† It stands between the specimen and a light source in the case of reflection, and backwards the specimen in the case of refraction.

(1) For example, M. Yamamoto and J. Watanabé: Kinzoku Butsuri (Metal Physics), **5** (1959), 196 (in Japanese).

(2) M. Yamamoto and J. Watanabé: Oyô Butsuri (J. Appl. Phys.), **24** (1955), 122 (in Japanese); Sci. Rep. RITU, **A 9** (1957), 24.

(3) M. Yamamoto, J. Watanabé and H. Suenaga: Oyô Butsuri (J. Appl. Phys.), **32** (1963), 834 (in Japanese); Sci. Rep. RITU, **A 17** (1965), 243.

(4) T. Taoka, E. Furubayashi and S. Takeuchi: Japanese J. Appl. Phys., **4** (1965), 120; T. Taoka, K. Ogasa, E. Furubayashi and S. Takeuchi: J. Japan Inst. Metals, **30** (1966), 620; T. Taoka, T. Tameto, K. Ogasa, E. Furubayashi, S. Takeuchi, J. Imamura and H. Hayakawa: Praktische Metallographie, **5** (1968), 22.

II. Construction

The detailed construction of the microscope is shown in a side view of Fig. 1 and its appearance in Photo. 1. The microscope consists of two main parts; an optical system which produces a sharp light figure in a view field of the microscope and a goniometer which measures orientation angles. Light beam emitted from tungsten bulb ① passes through several lenses and two diaphragms which are properly arranged, and falls on a limited area of an appropriately etched surface of the crystal specimen ⑤ mounted on the specimen stage. The reflected light produces a light figure in the microscope and it can be seen in an eye-piece ⑩ with an aid of a Bertrand's lens ⑨. The relation of the crystal axes to the axis of the specimen crystal can be known

Fig. 1 Construction of the light-figure microscope.
① Tungsten bulb (8~20 W, 4.5~7.0 V) ② Condenser lens ③ Illuminator diaphragm ④ Field diaphragm ⑤ Specimen crystal ⑥ Objective lens ⑦ Beam splitter ⑧ Erecting prism ⑨ Bertrand's lens ⑩ Protactor eye-piece ⑪ Bertrand's lens ⑫ Photo lens ⑬ Camera ⑭ Vertical circle ⑮ Horizontal circle ⑯ Illuminator for metallography

Photo. 1 Appearance of the light-figure microscope.

from the angles which are read off directly on the horizontal circle ⑮ and vertical circle ⑭ of the goniometer and on the protactor built in the eye-piece, respectively, in such a position that the light figure may be seen symmetrically around a center of the view field of the microscope, that is, the incident light beam may fall perpendicularly on the crystal plane concerned.

1. Principle of the image formation of light figures

The light path producing a light figure in the microscope is illustrated in Fig. 2. Let us suppose that a collimated light beam illuminates an etch pit of tetragonal pyramid shape which is produced on the {100} plane of a cubic crystal. Then, the incident beam is reflected from facets, A, B, C and D of the etch

Fig. 2 Light path producing the light figure.

pit, and after passing through an objective the components of the reflected beam converge at A_1 , B_1 , C_1 and D_1 on the back focus F' of the objective. This reflectogram is a light figure of tetragonal symmetry which consists of four light spots A_1 , B_1 , C_1 and D_1 . When we set the focus on the back focus F' of the objective with the aid of the Bertrand's lens, the magnified image of the light figure can be observed as A_3 , B_3 , C_3 and D_3 in the view field of the microscope, as shown in Fig. 2.

It is to be noticed that the size of the light figure thus prepared varies with a distance between the objective and the specimen surface, though it appears always on the back focus of the objective. When the crystal surface is set inside the focal length of the lens, the size of the light figure becomes larger, since the convergent components of the reflected light beam from the facets of the etch pits separate from each other. However, the light figure becomes invisible at a certain distance owing to the reflection out of the view field of the microscope. On the other hand, when the crystal surface is placed outside the focal length of the objective,

the size of the light figure is small, but it becomes also invisible at a certain distance because the reflected light beam does not enter the objective. Thus, it is most favourable to set the crystal surface at the working distance of objective. At this position, the microscope affords an unbroken view of the light figure, and moreover the surface structure of a crystal can also be just in view when the Bertrand's lens is removed from the optical system.

2. Optical system

The optical system produces a bright light with parallelism of high degree and its illuminating area can be adjusted in a wide range.

As seen from Fig. 1, the light emitted from a tungsten bulb ① (8~20 W, 4.5~7.0 V) passes through a collector lens ②, an illuminator diaphragm ③, a field diaphragm ④ and a convex lens, and converges at a back focus of an objective, and after passing through it, a collimated beam projects on an etched crystal surface ⑤ which is mounted on the specimen stage. The parallelism of the incident light beam can be adjusted by changing a hole size of the illuminator diaphragm ③. The diameter of this hole can be changed as 0.1, 0.2, 0.4 and 6 mm by the turret, respectively. The optical system makes a reduced image of the hole on the back focus of objective, so that a smaller hole can produce a more highly collimated beam though its brightness becomes weaker. The image of illuminator diaphragm produced on the back focus of the objective can serve as a screen to receive the light figure.

The field diaphragm ④ is also provided with holes

0.1, 0.2, 0.4 and 6 mm in diameter. Its reduced image is produced by the optical system on the working distance of the objective, at which the crystal surface is held. Then, an illuminating area on the crystal surface can be changed by a selection of the hole size of the field diaphragm ④. It ranges from 25μ to 1.5 mm in diameter under the objective $\times 20$ and from 15μ to 0.9 mm under the objective $\times 30$. It is to be added that the objectives are specially designed ones which have a long working distance.

The Bertrand's lens ⑨ is built in a small box which is attached between the erecting prism ⑧ and the eyepiece $\times 10$ ⑩. When it slides into the optical path, the light figure produced on the back focus of objective can be observed in a magnification of 4.5 in the eyepiece, while, when it slides out of the optical path, the surface structure of a crystal can be observed in a magnification of 200 or 300.

The microscope is fitted with the eyepiece carrying the cross hair and the circular graduation of 360° , divided into 1° . This protoractor is useful for the orientation work. It must be noted that the optical system was constructed in such a way that its optical axis might coincide with a center of cross-hair in the eyepiece.

The illuminator for producing light figures is not so suitable for observing the surface structure because the resolving power is lower than that of an ordinary microscope owing to the long tube length. The other illuminator ⑬ is preferable for usual metallography. For photographing, a reflected light beam is splitted sideways by a beam splitter ⑦, and produces an image

Photo. 2 Etch pits and the corresponding light figures of the $\{100\}$ plane of a copper crystal, which are produced with various illuminating conditions. (Etching: 10 percent aqueous solution of ammonium persulphate, several minutes)

of light figure or surface structure of a crystal on a film in Leica-type camera ⑬. The Bertrand's lens ⑪ is used for photographing light figures.

Photo. 2 shows etch pits and the corresponding light figures of the {100} plane of a copper crystal, which are produced under various illuminating conditions. The light figures were photographed on a high sensitive film (ASA 200, Fuji SSS, Neopan), and the exposure time varied from 15 seconds to 3 hours with different hole sizes of illuminator and field diaphragms. It can be seen that the sharpness and intensity of light figures may depend upon the hole sizes of both diaphragms. When the hole size is smaller, the light figure is more sharply resolved into spots or lines although its intensity becomes weaker.

3. Goniometer

When a collimated light beam is allowed to fall perpendicularly on a low-index crystallographic plane, the corresponding light figure can be observed symmetrically around a center of cross-hair in an eye-piece of the microscope. For attaining such a disposition, the specimen crystal and the incident light beam are properly rotated by the goniometer. The goniometer is a two-circle type. The horizontal circle ⑮ is provided with the specimen stage and cross-slides, and can be rotated up to $\pm 110^\circ$. While, the vertical circle ⑭ is attached to the microscope arm in which the optical system is built and can be rotated together up to $\pm 90^\circ$. The goniometer is arranged in such a way that the rotation axis of the horizontal circle may coincide with an incident direction of light beam when the vertical circle is set at zero point, and moreover the rotation axes of both circles may intersect at the working distance of objective. Accordingly, the incident light invariably projects on a fixed area of crystal surface even when the goniometer is rotated in any ways.

Now, in Fig. 3, we take the rectangular coordinate system XYZ, of which the X axis coincides with the

rotation axis of the vertical circle and Z axis coincides with that of the horizontal circle. When an arbitrary direction $\vec{OP}$ in a crystal specimen coincides with an incident direction of light beam by rotating the horizontal circle by an angle φ_0 and then the vertical circle by an angle θ_0 , (θ_0, φ_0) represents the angular coordinate of $\vec{OP}$. Then, if we take the other direction $\vec{ON}$ which is represented by the angular coordinate (θ_c, φ_c) , the angle δ between $\vec{OP}$ and $\vec{ON}$ is given by

$$\cos \delta = \cos \theta_0 \cdot \cos \theta_c + \sin \theta_0 \cdot \sin \theta_c \cdot \cos (\varphi_0 \sim \varphi_c). \quad (1)$$

This is a fundamental expression for determining the angle between any two directions by this goniometer. If (θ_0, φ_0) is assigned to the geometrical axis of a specimen crystal and (θ_c, φ_c) to the normal of the crystal plane of which the light figure is observed, the angle between these directions can be obtained from eq. (1). The angles θ and φ can be read off at least 0.1° with verniers, respectively.

The specimen stage used for the rod crystals is shown in Photo. 3. This stage is mounted on a cross-slide which can travel ± 12.5 mm from its center along two perpendicular directions on a horizontal plane (XY plane

Photo. 3 Specimen stage for rod crystals.

Fig. 3 Illustration of the goniometry of the horizontal circle and the vertical circle.

in Fig. 3) and is adjustable by means of micrometer screws. This stage unit enables us to aim at a given area of the crystal surface and to set the rod axis of a circular rod crystal or the long axis of a plate crystal at the angular coordinate $(\theta_0 = 90^\circ, \varphi_0 = 0^\circ)$ (Y axis in Fig. 3). Therefore, we can easily select any grain of a microscopic size and determine the angle which the specimen axis makes with the normal of (hkl) plane, when the goniometer is adjusted so that the symmetry center of the (hkl) light figure may coincide with the center of cross hair in the eye-piece and the angular coordinate (θ_c, φ_c) of the normal of (hkl) plane is recorded by means of the vertical and horizontal circles of goniometer, respectively.

However, the only one angle δ thus determined cannot determine the relation between crystallographic axes and the specimen axis, and at least one more angle must be determined. This may be satisfied usually by repeating the procedure with another $(h'k'l')$ light figure. Such a procedure is possible for a large single crystal of the cubic type, but is impossible for other crystals owing

to a low crystal symmetry or a narrow free surface of a grain in polycrystals. A protoractor in the eye-piece is useful for determining the grain orientation perfectly by a single light figure. The details of the procedure to be taken will be described in the following.

III. Procedure, Actual Examples and Accuracy

1. Procedure

(1) Geometrical relations

Generally, a light figure consists of spots and lines which can be specified with crystallographic indices. For example, as shown in Photo. 2, the light figures of the $\{100\}$ plane of a copper crystal which are projected symmetrically around a center of the cross hair in the eye-piece reveal a cross of which four arrows correspond to $[010]$, $[001]$, $[0\bar{1}0]$ and $[00\bar{1}]$ axes, respectively⁽⁵⁾. This property can be applied to the perfect determination of grain orientation by the use of a single light figure.

In Fig. 4, we take a rectangular coordinate system XYZ as in Fig. 3, of which the X axis coincides with the rotation axis of the vertical circle and the Z axis with the rotation axis of the horizontal circle of the goniometer. We assume that the (hkl) light figure is made symmetrically around a center of the cross hair in the eye-piece, when the vertical circle rotates an angle θ_c and the horizontal circle rotates an angle φ_c from the zero position, respectively, or the normal of the (hkl) plane $\vec{OC}$ coincides with an incident direction of light beam as in Fig. 4. In this arrangement, the (hkl) plane corresponds to the XY' plane which inclines by an angle θ_c around the X axis, and its light figure appears on the xy plane in the microscope which lies

parallel to the XY' plane, the x and y axes being the projection of X and Y' or Y axes upon the xy plane, respectively. If the y axis makes an angle ω with the $[uvw]$ arrow of the cross of the (hkl) light figure, then the $[uvw]$ axis is projected on the XY' plane as $\vec{OA}$ distant by an angle ω from the Y' axis. When the geometrical axis of the specimen crystal, $\vec{OP}$, is at first set at the angular coordinate (θ_o, φ_o) , $\vec{OP}$ is located at the coordinate $\theta_o, \pi/2 - (\varphi_o - \varphi_c)$ after the rotation of angles θ_c and φ_c of the goniometer, as shown in Fig. 4. Then, the angle $\delta_{[uvw]}$ which the geometrical axis $\vec{OP}$ makes with $[uvw]$ axis $\vec{OA}$ is given by

$$\begin{aligned} \cos \delta_{[uvw]} = & \sin \omega \cdot \sin \theta_o \cdot \sin(\varphi_o - \varphi_c) \\ & + \cos \omega \cdot \sin \theta_o \cdot \cos \theta_c \cdot \cos(\varphi_o - \varphi_c) \\ & - \cos \omega \cdot \cos \theta_o \cdot \sin \theta_c. \end{aligned} \quad (2)$$

In the present microscope, two lines ($90^\circ \sim 270^\circ$) and ($0^\circ \sim 180^\circ$) of the cross hair in the eye-piece can be accurately set on the x and y (or X and Y) axes, respectively, so that an angle ω can be directly read off by means of a protoractor in the eye-piece. In the above procedure, the angle $\delta_{(hkl)}$ which the geometrical axis makes with the normal of the (hkl) plane, $\vec{OC}$, can be obtained simultaneously from eq. (1). When the rod axis of a circular rod crystal or the long axis of a plate crystal can conveniently be set at $(\theta_o = 90^\circ, \varphi_o = 0^\circ)$ as illustrated in II-3, eqs. (1) and (2) may be reduced simply to

$$\left. \begin{aligned} \cos \delta_{l(hkl)} &= \sin \theta_c \cdot \cos \varphi_c \\ \cos \delta_{t[uvw]} &= \cos \omega \cdot \cos \theta_c \cdot \cos \varphi_c - \sin \omega \cdot \sin \varphi_c, \end{aligned} \right\} \quad (3)$$

and since the plate normal of the plate crystal can be fixed at $(\theta_o = 0^\circ)$ simultaneously, we obtain

$$\left. \begin{aligned} \cos \delta_{n(hkl)} &= \theta_c \\ \cos \delta_{n[uvw]} &= -\cos \omega \cdot \sin \theta_c, \end{aligned} \right\} \quad (4)$$

where the suffices l and n denote the rod axis and the plate normal of the crystal specimen, respectively.

The geometrical relations (3) and (4) indicate that the two angles $\delta_{(hkl)}$ and $\delta_{[uvw]}$ which the geometrical axis of the specimen crystal makes with the (hkl) normal and the $[uvw]$ axis, respectively, can be determined by the use of a (hkl) light figure, if the angles θ_c and/or φ_c and ω are known. The procedure to be taken is as follows: — The specimen crystal is mounted on the stage in such a way that its geometrical axis is set at a fixed value of (θ_o, φ_o) with respect to the goniometer. Then, the goniometer is so adjusted that the symmetric center of the (hkl) light figure may coincide with the center of the cross hair in the eye-piece of the microscope, and the readings of the vertical circle and of the horizontal circle, θ_c and φ_c , are recorded. Moreover, a rotary line of the cross hair is put onto a $[uvw]$ arrow of the light figure and the reading of the protoractor in the eye-piece, ω , is taken. Finally, the required angles are calculated from these measured ones by means of eq. (2) or (3). It is needless to say that this procedure can be applied to a large single crystal as well as

Fig. 4 Illustration for the determination of crystal orientations by using only one light figure corresponding to the principal crystal plane.

(5) M. Yamamoto and J. Watanabé : J. Japan Inst. Metals, 20 (1956), 85; Sci. Rep. RITU, A 9 (1957), 410.

to a crystal grain in a polycrystalline aggregate. The smallest grain size to which the present procedure can be applied is 15μ in diameter which is equal to the smallest illuminating area of the present microscope. If the light beam illuminates two or more grains, light figures reflected from the grains superimposed in the view field of the microscope, the orientation work being impossible.

(2) Stereographic analysis

It is easy to find a crystal orientation by the use of a stereographic projection without calculation. Figure 5 illustrates the method of transferring the goniometric

Fig. 5 Stereographic determination of crystal orientations by using only one light figure corresponding the principal crystal plane.

data on a (hkl) projection, which may readily be visualized in comparison with Fig. 4. The pole of $[uvw]$ axis is at first plotted as the point A on a basic circle. At angular distance ω from A on the same circle, the pole Y' is taken. Through the poles Y' and (hkl) is drawn a diameter and then on this diameter the pole of the rotation axis of horizontal circle is obtained as the point Z distant by an angle θ_c from the (hkl) pole and the pole Y is plotted at the same angular distance from the pole Y' . Then, the pole of the rotation axis of vertical circle is represented as the point X on a basic circle, which is 90° apart from the poles Y and Z, respectively. It is seen that the points X, Y and Z thus obtained may correspond to the three principal axes of the XYZ coordinate system in Fig. 4. Then the point B is plotted at an angular distance $\varphi_0 - \varphi_c$ from the point Y on the meridian $\widehat{XY}$, and finally the geometrical axis of specimen crystal is taken at the point P distant by an angle θ_0 from the point Z on the meridian $\widehat{ZB}$.

When the rod axis of a circular rod crystal or the long axis of a plate crystal is set at ($\theta_0 = 90^\circ$, $\varphi_0 = 0^\circ$), the corresponding pole P is plotted at an angular distance φ_c from Y on the meridian $\widehat{YX}$, while the pole of the plate normal of the plate crystal coincides with the point Z. It is to be added that the stereographic analysis can also be made on a projection of which the

center is taken as the pole of the rotation axis of horizontal circle or the plate normal of plate crystal, Z. In practice, a Wulff's net 20 to 40 cm in diameter gives all the accuracy about $1/2^\circ$ for the orientation work. It may be found that the stereographic plotting is favourable for treating many crystal grains in a polycrystalline aggregate, such as a statistical analysis of recrystallization and deformation textures, since the measured data can be transferred directly and rapidly on the projection.

2. Actual examples and accuracy

Actual examples of crystal orientations determined by the present technique are given in Tables 1 and 2. Table 1 shows the results of a single crystal rod of white tin (~ 5 mm in diameter and several cm in length). In the table, θ_i , α_i and β_i denote angles which the rod axis makes with the $[001]$, $[100]$ and $[010]$ axes, respectively. The specimen crystal was etched for 30 seconds with aqua regia in order to obtain clear light figures⁽⁶⁾. The angles θ_e , φ_e and ω were measured by the use of the (100) light figure and its $[001]$ arrow. The accuracy of the measurement can be estimated as $\pm 0.2^\circ \sim 0.5^\circ$ (ref. Table 1 (a)). The value of θ_i , α_i and β_i calculated from the measured angles and those determined by the back-reflection Laue method are also given for comparison in the same table (Table 1 (b)), from which it can be seen that all the data are in good agreement with each other.

The orientations of crystal grains contained in a polycrystalline α -iron strip (3.5 mm in thickness, 7 mm in width and 1 cm in length) determined by the present technique are given in Table 2, in which α , β and γ are angles between the specimen axis and the $[100]$, $[010]$ and $[001]$ axes, respectively and the suffices l and n represent the angles referred to the long axis and to the plate normal, respectively. θ_c , ϕ_c and ω were measured with the (100) light figure and its $[011]$ arrow, which is produced by etching with 20 percent aqueous solution

Table 1 An actual example of the orientation determination by the present microscope for a single crystal rod of white tin. (diameter : 5 mm, length : several cm, etching reagent : aqua regia)

(a) The results of angle measurement

Measured point	φ_e (degree)	θ_e (degree)	ω (degree)
1	-2.1	7.3	81.3
	-2.6	7.1	81.1
	-2.7	7.2	81.5
2	-2.1	7.3	81.2
	-2.1	7.1	81.1
	-1.9	7.2	81.3
Final mean value	-2.2	7.2	81.2

(b) The results of orientation calculation

θ_i (degree)	α_i (degree)	β_i (degree)	Remark
79.1	82.8	13.2	Present method
79.7	81.9	13.1	Back Laue method

(6) M. Yamamoto and J. Watanabé : J. Japan Inst. Metals, 17 (1953), 68; Sci. Rep. RITU, A 7 (1955), 145.

Table 2 Other selected examples of the orientation determination by the present microscope for crystal grains of polycrystalline-iron strip. (thickness : 3.5 mm, width : 7 mm, length : 1 cm, etching reagent : 20% aq. sol. of $(\text{NH}_4)_2\text{S}_2\text{O}_8$)

Grain	Grain size (mm ²)	Orientation angle (degree)									Remark
		φ_c	θ_c	ω	α_l	β_l	γ_l	α_n	β_n	γ_n	
A	3	-19.5	1.9	59.1	88.2 88	84.6 85	5.7 6	1.9 2	89.4 89	91.8 92	Calculation Stereo-plot
B	1	-48.6	3.8	42.2	92.5 92	51.5 51	38.6 39	3.8 4	86.7 87	88.2 88	Calculation Stereo-plot

of ammoniumpersulphate⁽⁷⁾. The crystal orientation as calculated and plotted on a stereographic projection from measured angles are given in the table, which shows good agreement between both data.

IV. Summary and Conclusion

The light-figure microscope has been devised for the perfect, accurate and rapid determination of orientations of crystal grains in polycrystalline aggregate. The microscope consists of an optical system and a goniometer. A clear-cut light figure is produced by reflection of incident light beam from the small area of an etched surface of the specimen crystal which is mounted under an objective, and can be observed in an eye-piece. By using single light figure, the crystal orientation can be

perfectly determined with use of the goniometer and the protoractor in eye-piece. It can be applied to large single crystals as well as to crystal grains having the smallest size of 15μ in diameter with an accuracy $\pm 0.2^\circ \sim 0.5^\circ$. It has been found that the procedure for orientation work is much simpler than those in the X-ray method, and moreover the comparable precision is constantly retained. The microscope can also be used for metallography when the optical system is switched to those of a usual type.

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(7) M. Yamamoto : J. Japan Inst. Metals, 5 (1941), 324 ; M. Yamamoto and J. Watanabé : *ibid.*, 16 (1952), 136.