United States Patent [19]

Kumada et al.

[11] **3,838,678**

[45] **Oct. 1, 1974**

[54] **APPARATUS FOR PRECISELY SLICING A CRYSTAL IN A CRYSTAL FACE THEREOF**

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[22] Filed: **June 5, 1973**

[21] Appl. No.: **367,190**

[30] **Foreign Application Priority Data**

June 5, 1972 Japan 47-55055

[52] **U.S. Cl.** .... **125/13 R,** 51/73 R, 51/277

[51] **Int. Cl.** **B28d 1/04**

[58] **Field of Search**..... 51/73 R, 277; 125/12, 13 R, 125/14, 35

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[57] **ABSTRACT**

An apparatus for precisely slicing a crystal in a crystal face thereof, wherein the orientation of the crystal fixed to a specimen rest is measured in a crystal orientation identifying device by X-ray irradiation, the crystal is rotationally moved to a crystal slicing device which is located at a place separate from the crystal orientation identifying device and which has a cutting edge coplanar with an X-ray irradiation standard face of the crystal orientation identifying device, and the crystal is sliced under the state in which it is fixed again with a determined orientation on the basis of the measured result, whereby the crystal can be sliced in the predetermined orientation at extraordinarily high precision at an error within 0.1 milliradian and efficiently in short time without the necessity for detaching the crystal and the specimen rest from a supporting portion of the apparatus.

3 Claims, 4 Drawing Figures

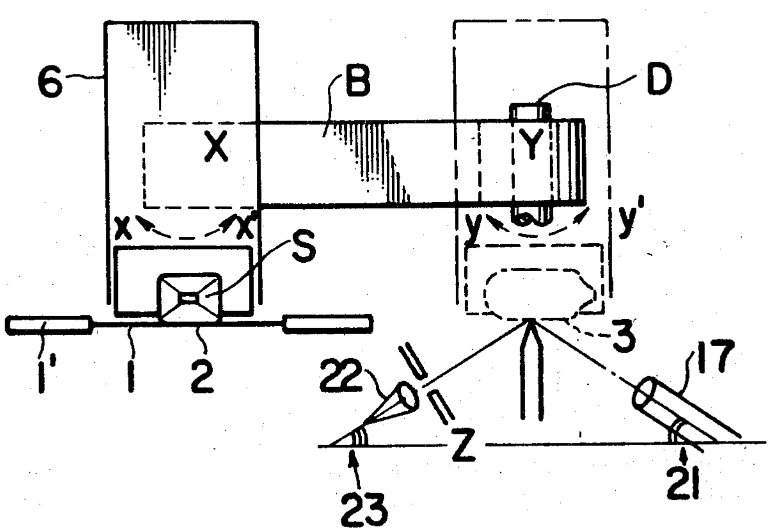


FIG. 1

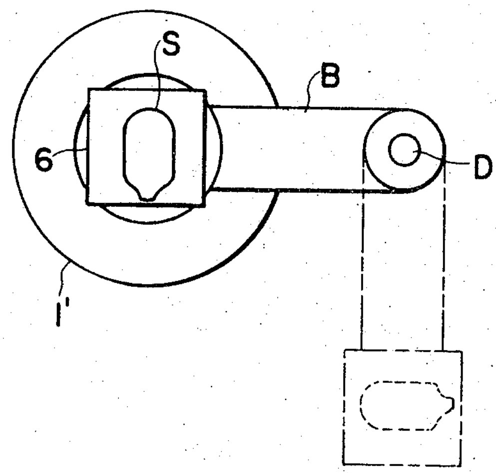


FIG. 2

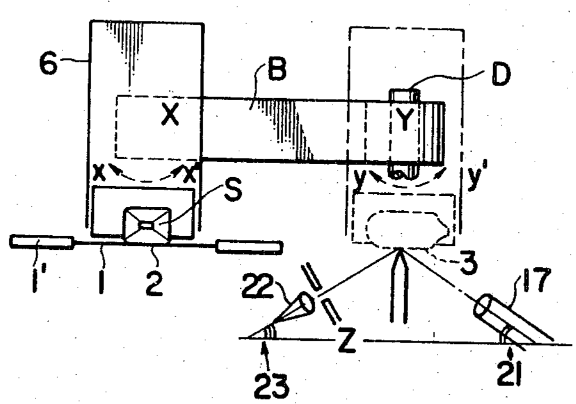


FIG. 3

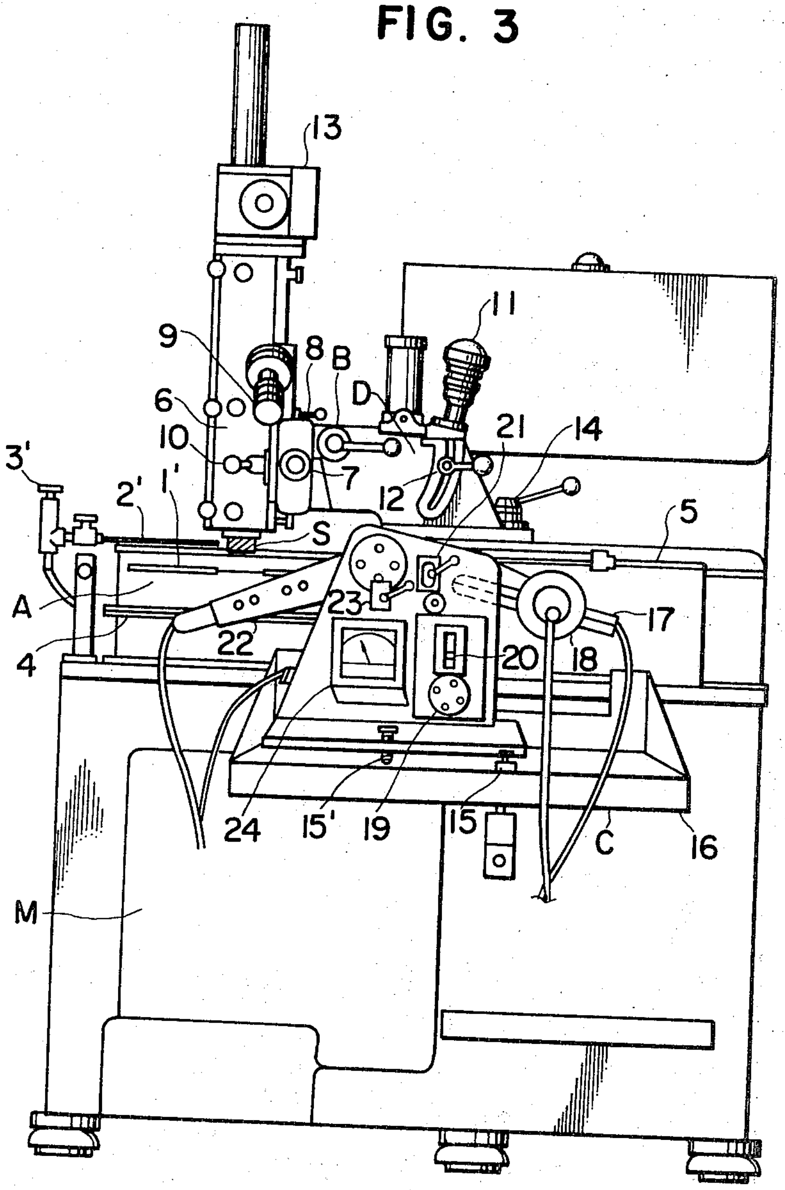
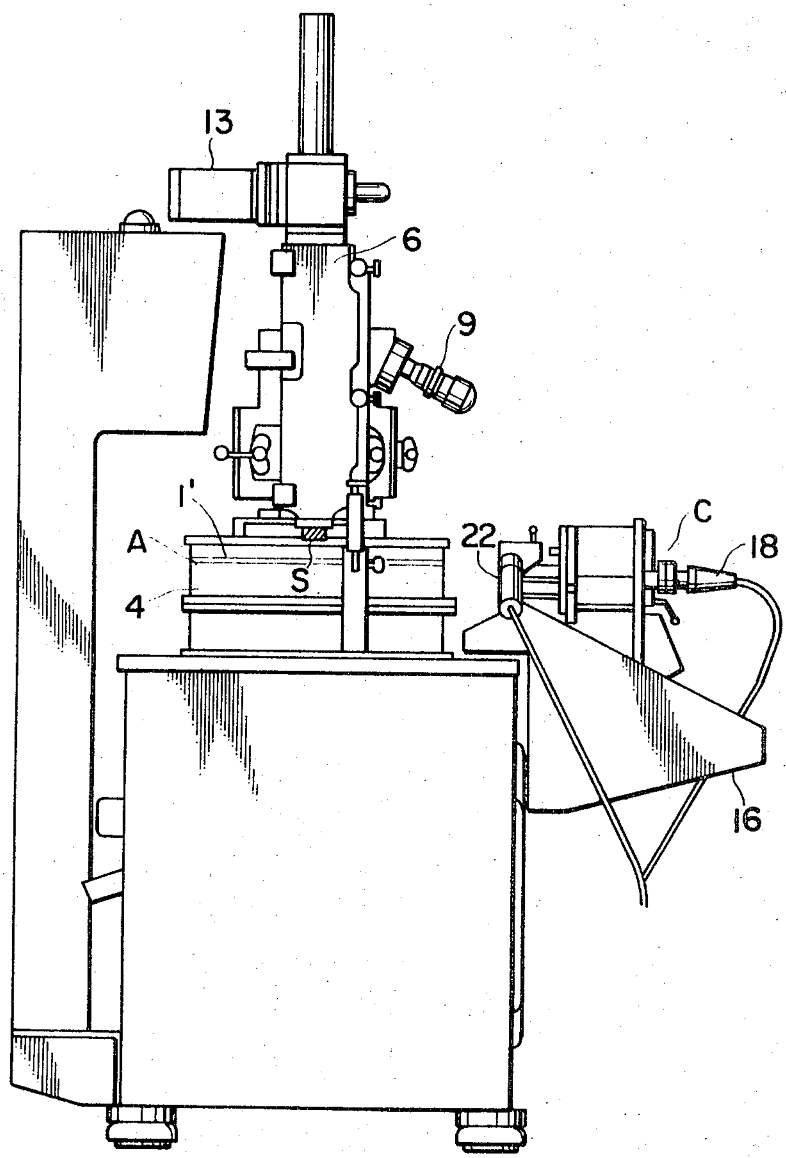


FIG. 4



APPARATUS FOR PRECISELY SLICING A CRYSTAL IN A CRYSTAL FACE THEREOF

BACKGROUND OF THE INVENTION

The present invention relates to improvements in apparatus for precisely slicing a crystal in a crystal face thereof.

With the advancement of opto-electronics, electrooptic materials and elements employing crystals tend to be widely utilized. In general, optical elements have questionable transparency and uniformity. The element accordingly must be precisely worked after being formed to any desired configuration. In particular, the precision of a polished face is a factor which determines the quality of the optical element. A variety of methods of lapping or polishing faces at high precision have therefore been developed.

It is impossible, however, to apply a working method for optical materials, such as the method of lapping a face at high precision, to the working of electrooptic crystals. The main reason for this is that the conventional optical materials are optically isotropic, whereas the electrooptic cyrstals are, in general, optically anisotropic. With the electrooptic crystal, a worked face need be held at a fixed orientation with respect to a crystal axis on account of the optical anisotropy. In the case where the orientation of the worked face deviates from the fixed one, optical properties change according to the deviation, and this leads to degradation of the accuracy of the device as an electrooptic element.

Since the single crystal of KH_2PO_4, for example, has a great electrooptic effect, it is used for a momentary open shutter, a light modulator and various other elements exploiting the electro-optic effect. Taking the KH_2PO_4 (hereinbelow termed KDP which is short for Kaliumdihydrogenphosphate (potassium dihydrogen phosphate)) crystal as an example, there will be described the importance of the working precision.

KDP is paraelectric at room temperature, and is an optically negative uniaxial crystal belonging to the tetragonal system. The indices of refraction are ω = 1.5095 (the refractive index along the major axis of elliptically polarized light) and ϵ = 1.4684 (the refractive index along the minor axis of eliptically polarized light). The optic axis of KDP is identical with the *c*-axis of the crystal. Therefore, when a plate with two mutuallyopposing faces cut perpendicularly to the *c*-axis (hereinafter termed the C-plate) is inserted between two crossed Nicols whose polarization planes are arranged orthogonally to each other, a light shutter element is produced.

In more detail, the birefringence for light incident in parallel with the *c*-axis of the crystal is null. The incident linearly-polarized light is transmitted without being subject to any change, and is broken by the rear polarizing plate. Consequently, the quantity of light passing through the rear polarizing plate (hereinbelow termed the analyzer) is null. In contrast, when a voltage is applied to the crystal, a birefringence Δn is exhibited even for the light among the *c*-axis owing to the electrooptic effect. In general, the transmitted light becomes elliptically polarized light. The birefringence is proportional to the voltage, and is represented by:

$$\Delta n = n^3 \cdot f \cdot E \quad (1)$$

where n denotes the index of refraction, f the electrooptic coefficient and E the magnitude of electric field. The light I transmitted through the analyzer is expressed in terms of the incident light I_0 as follows:

$$I = I_0 \sin^2(d\ \Delta n/\lambda\ \pi) \quad (2)$$

where d denotes the thickness of the crystal and λ the wavelength of the incident light.

From equations (1) and (2),

$$I = I_0 \sin^2(d\ n^3\ f/\lambda\ \pi\ E) \quad (3)$$

so that the transmitted light is a maximum at $E = \lambda/(2\ d\ n^3 f)$. To sum up, with the light shutter device employing KDP, when no electric field is impressed ($E = 0$) the state is established under which $I = 0$ or the quantity of the transmitted light is a minimum (I_{min}); whereas, when the electric field of $E = \lambda/(2\ d\ n^3\ f)$ is impressed, the state is established under which $I = I_0$ or the quantity of the transmitted light is a maximum (I_{max}). Thus, the contrast ratio (I_{max}/I_{min}) of the light shutter ought to become infinity.

The normal of an actual crystal face, however, does not perfectly agree with the *c*-axis, but it deviates therefrom by the component of a working error. For this reason, even when light is brought into incidence perpendicularly to the crystal plate, the birefringence for the incident light does not become zero. Letting θ be the deviation between the normal and the *c*-axis, the birefringence Δn can be approximated for small values of θ as follows:

$$\Delta n = (8/\pi) \times 10^{-2}\ \theta^2 \quad (4)$$

Since θ is not zero, $I_{min} \neq 0$, and

$$I_{min} = I_0 \sin^2\ (d \cdot 8 \times 10^{-2}/\lambda\ \theta^2) \quad (5)$$

Since d/λ *is usually* 10^4, equation (5) approximately corresponds to the following equation (6):

$$I_{min} = I_0 \sin^2\ (10^3\ \theta^2) \quad (6)$$

Accordingly, the contrast ratio can be expressed as the following equation:

$$I_{max}/I_{min} = 1/\sin^2\ (10^3 \times \theta^2) \approx 10^{-6} \times \theta^{-4} \quad (7)$$

Therefore, in the case where it is desired to set the contrast ratio of the light shutter element at an order of at least 10^6, the working precision requires that the error be confined to within 1 milliradian with respect to the orientation.

As regards the mere measurement of the orientation of the crystal, it is generally easy to attain a precision of 0.1 milliradian by the use of a commercially available product, such as a standard crystal orientation test unit. It has been the subject of those skilled in the art, however, to determine how a face to be made identical to the fixed orientation face of the crystal having been measured by the crystal orientation test unit or the like.

In the prior art, a goniometer head is commonly used for the crystal orientation test unit and for a crystal slicing device First of all, a crystal is fixed to a goniometer of the slicing device, and is properly sliced. After the slicing, the crystal is detached from the goniometer of the slicing device. It is fixed to the goniometer of the crystal orientation test unit, and has the orientation of the sliced face measured. If any deviation in orientation is found, the crystal is fixed to the goniometer of the slicing device again and is sliced after correction of the orientation. Thereafter, these procedures are repeatedly carried out to reduce the deviation between the sliced face and the fixed orientation.

The inventors repeated the troublesome and inefficient operations as stated above, and searched for the limitation of errors. The conclusion is that, even when close attention is paid to the operations, θ cannot be made less than 1 milliradian.

More specifically, in an apparatus in which the slicing device and the orientation measuring device are respectively independent, a rest for fixing the specimen is made common to both the devices, and thus, any setting error due to the detachment of the specimen is minimized. Nevertheless, an error of approximately $\pm$ 0.5° is inevitable.

The reason for this error will be as stated below. In order that the crystal may be set to achieve a good reproducibility even when the set and reset of the crystal are frequently conducted, a robust supporting jig ensuring a certain fixation precision is required. Further, a considerable force also acts on the crystal during the slicing of the crystal, so that the supporting portion should be made rather robust. The requirement of robustness and the requirement that the orientation of the crystal be highly precisely and smoothly moved by a small angle with the center at the crystal face by the use of a precision goniometer, have been found to be contradictory. Particularly, the detachment of the crystal is the main factor for the lowering of the precision. It has been forecast that, if the operation can be done without the detachment of the crystal, the precision will be enhanced as expected.

Under the present situation of the art, it is difficult to find a method which precisely cuts the crystal on the X-ray goniometer as it is held thereon. That is to say, the measurement of the orientation by X-rays and the slicing of the crystal by the slicing device cannot avoid being carried out in separate places.

On the other hand, a method is presently adopted widely in which, although the slicing and the orientation measurement by X-rays are conducted in separate places, the slicing to the fixed orientation is completed during the state under which the specimen and the rest are held fixed to the slicing device. According to this method, an extreme end part of a crystal is thinly cut away by means of the slicing device made of diamond grindstone, the sliced face of the small piece cut away has its orientation separately measured by means of the X-ray orientation test unit, the rest on which the remaining crystal is mounted is manually moved to the fixed direction and has its position corrected by the component of the orientation error, and the crystal is sliced. The above procedures are repeated until the predetermined angle is attained. With the measurement of orientation according to this method, (1) conditions of the external shape of the cut-away small piece as are ascribable to the cutting, such as swell (bowling) and parallelism, lead directly to orientation errors. For example, in order to acquire an orientation precision within 30 inches, the swell need be restrained to below 0.5 μ for a specimen being 10 mm long. (2) When, for the measurement of orientation, the cut face is adsorbed to a base by a vacuum chuck, dust particles smaller than 1 μ need be avoided in order to attain the measurement accuracy within 30 inches. On account of such problems, the orientation precision after the cutting becomes as bas as approximately $\pm$ 0.1°. In addition, this method has the disadvantage that the specimen is wasted since several small pieces are cut away, therefore, a considerable time is required for the orientation measurement.

A further prior art method is the etched pattern method or the like, which consists in the combination between means to optically measure the orientation of a crystal and a slicing device, and according to which, although the measurement of orientation and the slicing are executed in separate places, a rest supporting the crystal thereon is slidingly moved for operations on a movable guide between the optical means for the orientation measurement and the slicing device without detaching the crystal from the rest. This method can really reduce the errors induced by the foregoing inefficient operations of setting and resetting the crystal onto the rest. It raises anew, however, the problem of the precision of the surface roughness in the rest moving means including the movable guide. Desirably, the contact portions between the rest and the movable guide are of a small number, and the alterations in position between them are smoothly effected. This, however, is subject to technical limitations. Besides, it is undeniable that the optical measurement of orientation is much lower in precision as compared with the measurement of orientation with X-rays. With this method, it is accordingly quite impossible to expect the slicing of a crystal at high precision.

SUMMARY OF THE INVENTION

An object of the present invention is to provide apparatus for precisely slicing a crystal in a crystal face thereof, which can slice various crystals in predetermined orientations at extraordinarily high precision and efficiently in a short time.

The apparatus of the present invention for precisely slicing a crystal in a crystal face thereof is characterized by comprising a specimen mounting block which holds the crystal in a manner to be rotatable and slidable in an arbitrary direction, a crystal orientation identifying device which sets a standard face for X-ray irradiation and measures the orientation of the crystal by the X-ray irradiation, a crystal slicing device which is separated from the crystal orientation identifying device to a position defining a certain angle (for example, 90°) with respect to a rotary shaft and which has a cutting edge for slicing the crystal in a predetermined orientation, means which can rotationally move the specimen mounting block between the crystal orientation identifying device and the crystal slicing device through a specimen supporting arm portion so as to form a vertical plane with respect to the rotary shaft, the arm portion bridging the specimen mounting block and the rotary shaft, and means for making adjustments so that the cutting edge of the crystal slicing device and the X-ray irradiation standard face of the crystal orientation identifying device may be contained on an identical plane, whereby the apparatus can slice the crystal in the predetermined orientation at an error within 0.1 milliradian with such extraordinarily high precision which has a hitherto been impossible to perform efficiently in a short time.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic cross-sectional view illustrating the principle construction of one form of the apparatus of the present invention for precisely slicing a crystal in a crystal face thereof;

FIG. 2 is a schematic vertical sectional view of the apparatus for precisely slicing a crystal as illustrated in FIG. 1;

FIG. 3 is a front view showing the external appearance of the apparatus for precisely slicing a crystal according to an embodiment of the present invention; and

FIG. 4 is a side view showing the external appearance of the apparatus for precisely slicing a crystal as shown in FIG. 3.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIGS. 1 and 2 are respective diagrams of the outlines along a cross section and a vertical section through a crystal slicing device, a crystal holder and an orientation identifying device of the apparatus of the present invention for precisely slicing a crystal in a crystal face thereof.

A crystal S attached to a specimen mounting block 6 disposed at an extreme end part of the crystal holder B is set at a predetermined orientation by the orientation identifying device C composed of an X-ray collimator 17 and a proportional counter tube 22. Thereafter, the whole crystal holder B is rotated by 90° from a position shown by dotted lines in FIG. 1 to a position shown by full lines in the same figure. Then, the crystal S is sliced by the slicing device A. Herein, the position of the slicing device A with respect to a rotary shaft D of the orientation identifying device C need not always define the angle of 90°, as in the above case.

Such positional change through rotation requires a smaller number of contact portions at movement as compared with the prior art positional alteration device based on sliding movement on a movable guide. The former therefore has the advantage that it can be smoothly performed.

In order to attain a good flatness of the sliced face of a crystal, there were examined more than ten slicers, including an inside diametral diamond cutter (or ID cutter), an outside diametral diamond cutter or OD cutter), a wire saw and so forth. It has been found that the best result with respect to the flatness of the sliced face is obtained with the ID cutter.

In this case, it is necessary to previously bring into coincidence the edge face of a diamond blade of the slicing device A and the standard face of the X-ray collimator 17 of the orientation identifying device C. In more detail, the slicing edge face 1 of the slicing device and the sliced face 2 of the crystal are within an identical plane, as shown in FIG. 2. Therefore, in order to rotate the rotary table by 90° and to bring the sliced face 2 of the crystal into a fixed position for X-ray measurement the sliced face 2 must be brought off the plane of the slicing edge face 1, and thereafter rotated by 90° into the fixed position. Here, the fixed plane (the standard face of the X-ray collimator 17 for X-ray irradiation) 3 of the fixed position must be so set as to be the same as the plane of the slicing edge face 1. At this time, the sliced face 2 must be always brought to the fixed plane 3 at an error within 1 μ. Further, the slicing edge face 1 must be always located on the same plane as the fixed plane 3. Therefore, in the case where the blade has become old by repeated slicing operations and where it is to be replaced with a new one, the edge face of the new blade must be secured onto the same plane as the fixed plane 3 at the error within 1 μ. The apparatus according to the present invention for precisely slicing a crystal in a crystal face thereon solves the problems.

FIGS. 3 and 4 show a front view and a left side view, respectively, of the apparatus according to the present invention for precisely slicing a crystal in a crystal face thereof. In these figures, an inside diametral cutting wheel 1' of the slicing device A can have its speed varied within a range of 2,000 – 4,000 r.p.s. by means of a high-speed spindle and an electric motor M. Cutting liquid (or cutting oil) is supplied by a nozzle 2' via a regulating valve 3' from a liquid source. Outside the cutting wheel 1', a cover 4 is disposed which serves to prevent the cutting liquid and cut powder from being scattered.

In order to effect the cutting feed smoothly and with high precision, the whole unit of the crystal holding arm portion B is fixed to an automatic feed table 5 by a whirl clamp handle 14, the automatic feed table 5 having as its guide face a face parallel to the diamond wheel 1'. By loosening the whirl clamp handle 14, the crystal holding arm portion B can be rotated through an arbitrary angle on the automatic feed table 5 and at a level with a rotary shaft D.

The specimen mounting block 6 is provided with an aligning knob 7 for setting the specimen S at the central part of the diamond wheel 1', and a clamp handle 8 for the knob 7. It is further provided with a longitudinal-angle-dial 9 imparting a rotation in the longitudinal direction ($x - x'$ direction) about an X-axis and a clamp handle 10 therefor, and a cross-angle-dial 11 imparting a rotation in the cross direction ($y - y'$ direction) about a Y-axis and a clamp handle 12 therefor. The indexing in the direction of thickness is conducted by vertically moving the specimen mounting block 6 with a pulse motor 13. The indexing region is variable in a range of 0.001 – 3 mm.

The orientation identifying C is fixed to a goniometer frame 16 in front of the slicing device A by a coarse adjustment screw 15 and a fine adjustment screw 15'. The coarse adjustment screw 15 and the fine adjustment screw 15' serve to set the standard face Z of the collimator 17 relative to the slicing face of the diamond wheel 1'.

An X-ray tube (of, for example, CuKαX-rays) 18 has an output of 1 kW. After being reflected by the face of the specimen S, X-rays radiated from the collimator 17 are detected by the counter 22, and are indicated by a rate meter 24. The counter 22 is fixed to an arbitrary angle by a counter fixing knob 23. The collimator 17 is inclined from the standard face by a θ-angle driving dial 19 so as to define the Bragg reflection angle 2θ of the predetermined crystal face. Then, it is fixed by a

θ-ray clamp dial **21.** The θ-angle driving dial **19** can vary and set the angle 2θ within a range of 0° – 40° at a precision of 0.0027°, and indicates the the set value 2θ on a θ-angle indicator **20.** Illustrated in FIGS. **3** and **4** is the state of slicing of the specimen. At the measurement of the orientation, a state is established under which the specimen mounting block **6** is positioned on the orientation identifying device C.

In the case of slicing the crystal in the determined orientation by the use of the apparatus of the present invention, the collimator **17** is first set to the 2θ-value of the predetermined crystal face by the θ-angle driving dial **19** in order to identify the orientation of the crystal. Subsequently, the specimen face is irradiated by an X-ray beam, and the longitudinal-angle-dial **9** and the cross-angle-dial **11** are regulated so that the quantity of X-rays detected by the counter **22** may reach a maximum value.

Thus, the predetermined crystal face is set, and the orientation measurement is completed. Thereafter, the crystal holder B is rotated by 90°. The indexing, the feed speed, the number of revolutions of the spindle, etc., are set at the optimum conditions. The slicing is conducted. The indexing region is 0.001 – 3 mm as previously mentioned, the feed speed is 0.5 – 50 mm/min, and the number of revolutions of the spindle is 2,000 – 4,000 r.p.s. The operation is fully automatic.

The following table lists the comparisons between the results of performance by the apparatus of the present invention for precisely slicing a crystal in a crystal face thereof and the results of slicing by various prior art methods of slicing a crystal results of slicing by various prior art methods of slicing a crystal in a predetermined orientation. As understood from the table, with the prior art techniques, the precision of the slicing orientation is at most 0.1° or so, while the measurement of orientation generally requires a period of time of at least thirty minutes. In contrast, in accordance with the apparatus of the present invention, the precision of the slicing orientation is 20 inches (approximately 0.1 milliradian) or so, while the measurement of orientation can be carried out in an extremely short time of 2 – 3 minutes. It is accordingly apparent that the effect of the present invention is very great.

As described above, the apparatus according to the present invention for precisely slicing a crystal in a crystal face thereof can largely enhance the prior art techniques. In contradiction to the prior art, it can slice various crystals in predetermined orientations at extraordinarily high precision and in a short time. It is therefore remarkably effective in practical use.

What is claimed is:

1. Apparatus for precisely slicing a crystal in a crystal face thereof, comprising: a specimen mounting block

TABLE

Methods of Measuring Orientation		Error of Slicing Orientation	Time required for measuring Orientation	Failure of Specimen, Utility Degree of Same	Interlocking with Slicing Device	Merits and Demerits
X-ray Methods	back Laue pattern	± 1°	Over 1 hour	No failure	None, Common rest	Requires skill in reading Laue spot, Long time, Poor precision
	spectrometer	± 1°	Approx. 20 min.	Poor utility due to preliminary Slicing	Common rest	Orientation error caused by swell and poor parallelism of small cut-away piece
Optical Methods	natural habit	± 1°	Approx. 30 min.	No failure	Partial	Covenient and easy for crystal with well-developed face
	etched pattern	± 1°	Approx. 20 min.	Destructive (especially, thin specimen)	Present	Requires to accumulate detailed data between crystal orientation face and etched pattern
	conoscopic figure	± 0.5°	Approx. 30 min.	No failure	Partial	Applicable only to specific crystal having optical anisotropy
Mechanical Methods	compressed pattern due to plastic deformation, etc.	± 5–6°		Destructive	None	Destructive, poor orientation precision
Method of the Invention		Within ± 0.01° (approx. 0.1 m rad)	2–3 min.	No failure	Integral	Making slicing device and orientation measuring device integral, thereby enabling fixed-orientation slicing at high precision in short time

to hold the crystal, adjusting means including a rotary shaft and supporting arm portion to support said block to be rotatable and slidable in an arbitrary direction, crystal orientation identifying means for measuring the orientation of said crystal by X-ray irradiation by setting a standard face for the X-ray irradiation, a crystal slicing device which is separated from said crystal orientation identifying means at a position defined by an angle of rotation about said rotary shaft and which has a cutting edge face for slicing said crystal in a predetermined orientation, means for rotationally moving said specimen mounting block between said crystal orientation identifying means and said crystal slicing device through said supporting arm portion so as to form a vertical plane with respect to said rotary shaft, said arm portion bridging said specimen mounting block and said rotary shaft, and means for adjusting the relative positions of said cutting edge face of said crystal slicing device and the X-ray irradiation standard face of said crystal orientation identifying means to locate them on an identical plane.

2. The apparatus according to claim **1**, wherein said crystal orientation identifying means comprises an X-ray collimator and a counter and means for setting said collimator and said counter at positions defining the Bragg reflection angle of the predetermined crystal face.

3. The apparatus according to claim **1**, wherein said crystal slicing device comprises an inside diametral diamond cutter.

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