Nov. 8, 1949 M. H. BARNES 2,487,091

CUTTING CORUNDUM ROD

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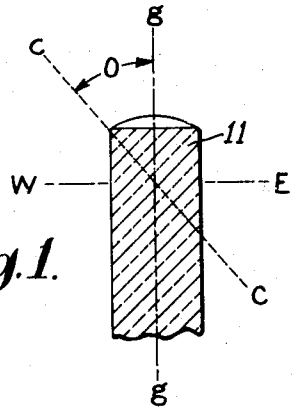


Fig. 1.

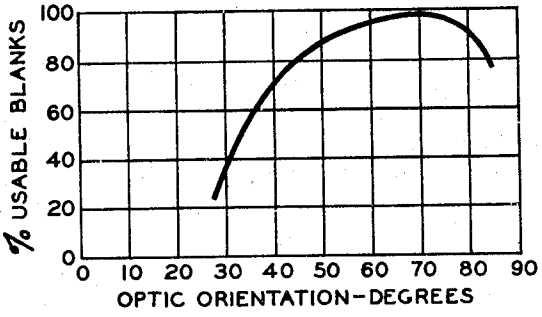


Fig. 2.

Fig. 4.

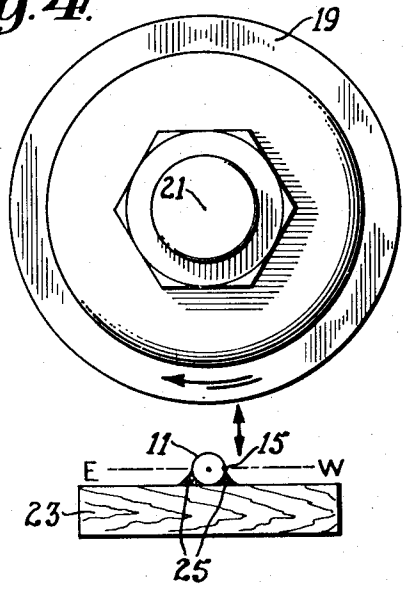
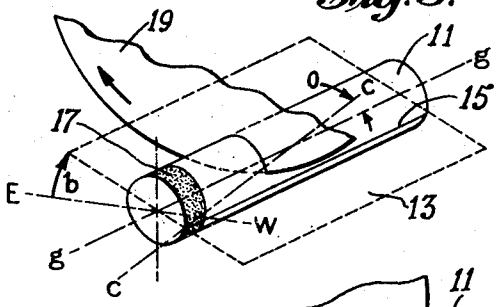


Fig. 3.



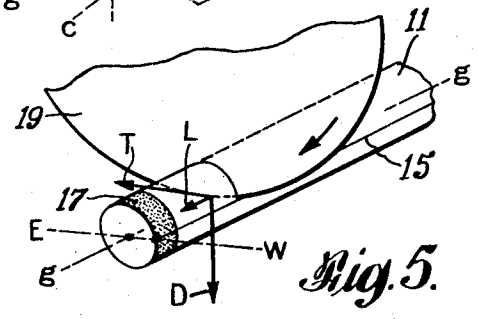


Fig. 5.

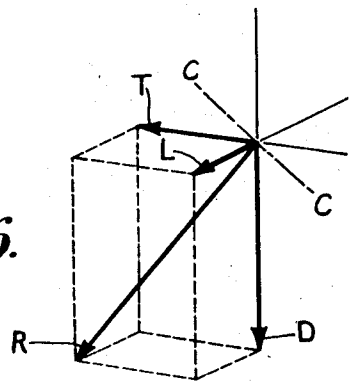


Fig. 6.

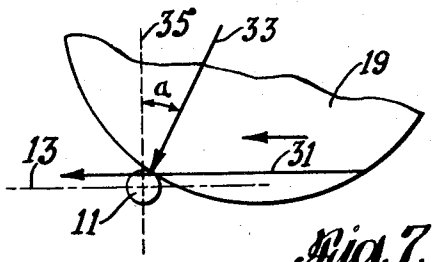


Fig. 7.

INVENTOR
MALCOLM H. BARNES
BY
ATTORNEY

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CUTTING CORUNDUM ROD

Malcolm H. Barnes, Kenmore, N. Y., assignor to The Linde Air Products Company, a corporation of Ohio

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15 Claims. (Cl. 125—12)

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My invention is a novel method for mechanically working unicrystalline corundum rods, as by cutting and grinding, so as to improve the yield of usable products obtained. Primarily, my method is concerned with increasing the yield of usable products obtained when cutting thin slices from such corundum rods. In addition, my invention pertains to the marking of unicrystalline corundum rods in a novel manner so that a rod can be positioned properly for cutting.

It has been customary to cut jewel bearing blanks from unicrystalline synthetic corundum boules of large diameter, such as about three-fourths inch, which may be white sapphire, blue sapphire, or ruby, depending on the presence or absence of coloring matter with the alumina of the boule. Such a boule is first split longitudinally along a central plane either by nicking the crown or by pinching the "foot" at the bottom of the boule, and the half-boules are then sliced transversely by a saw to form relatively large slices which are cut again and ground to produce bearing blanks of the desired size. In another procedure, thin rods are first cut from the half-boules and then sliced transversely. Both of these procedures are expensive, laborious, and wasteful of the large quantity of raw material which is removed by the saw in making the many necessary cuts.

Recently, there has been developed a method for growing unicrystalline synthetic corundum bodies in the form of elongated cylindrical rods of small diameter which can be controlled to approximate the desired diameters of different types of jewel bearing blanks. The rods as grown are clear, homogeneous, somewhat translucent in appearance due to the existence of minute crystal projections on their surfaces, and are quite stable when their diameters do not exceed three-sixteenths inch. Rods of greater diameter are usually unstable and tend to crack and split. In conventional boules the splitting plane contains the axis of growth so that rods machined from a half-boule obviously do not have the growth axis within their boundaries. In rods as grown by the recently developed method the growth axis is arranged substantially centrally within the rod. When stable synthetic corundum rods were first made, their suitability for jewel bearings was immediately recognized, but upon attempting to fabricate them into jewel bearing blanks by slicing them transversely of their longitudinal axes with a saw, or upon attempting to grind them in a centerless grinder, it was found that the average yield of usable product was much

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lower than had been expected. From some rods, which were selected at random from a group of apparently identical rods, excellent yields were obtained, whereas from other rods, very poor yields were obtained.

After extensive research into the subject of cutting and grinding synthetic unicrystalline corundum rods I found, surprisingly, that the yield varied greatly with variations in the optic orientation, and that the reason behind the unpredictable results obtained from apparently identical rods was the existence of different optic orientations in the crystals. Good to excellent yields were obtained upon cutting or grinding rods optically oriented within a certain range, whereas very poor results were obtained upon rods oriented outside of this range, as discussed in detail hereinafter. This feature of my invention originally was disclosed and claimed in my application Serial No. 503,240, filed September 21, 1943, of which the present application is a continuation-in-part.

Further research has shown that good cutting results depend not only upon the optic orientation of the rod being cut, but also upon the position of the optic axis with respect both to the saw and to the direction of saw motion.

Among the objects of my invention, therefore, are to provide a novel method for improving the yield of usable products obtained by mechanically working unicrystalline corundum rods, as by cutting and grinding, which involves selecting rods having preferred optic orientations; which involves so arranging such a rod with respect to a cutting or grinding tool that the optic axis of the rod assumes a predetermined preferred position relative to the tool; and which involves so arranging such a rod with respect to a cutting or grinding tool, that the forces applied to such rod by the tool are such as to give a good yield of usable product.

The above and other objects of the invention, and the best manner for attaining them, will become apparent from the following detailed description having reference to the annexed drawing, wherein:

Fig. 1 is an enlarged vertical midsectional view of a unicrystalline corundum rod illustrating the meaning of optic orientation;

Fig. 2 is a graph showing the relation between the optic orientation of corundum rods and the percentage yield of usable jewel bearing blanks cut from such rods;

Fig. 3 is an enlarged perspective view of a unicrystalline corundum rod marked in accordance

with my invention, and illustrating the meaning of various terms used in describing my method.

Fig. 4 is an end elevational view showing a circular saw in position for slicing bearing blanks from a corundum rod by plunge cutting;

Fig. 5 is a diagrammatic view in perspective showing a circular saw in the process of plunge cutting a slice from a corundum rod, and indicating the character of the forces applied to the rod by the saw;

Fig. 6 is a diagram analyzing the forces exerted by the saw on the rod, and their relation to the optic axis during a cutting operation; and

Fig. 7 is an end view showing diagrammatically a circular saw in position for cutting a slice from a corundum rod in such a way that the relative translational movement is effected along a non-diametrical chord of the saw.

Extensive research and experimentation on the mechanical working of synthetic unicrystalline corundum rods not exceeding a diameter of three-sixteenths inch, as by cutting or grinding them, have shown that there exists an important correlation between the crystallographic orientation of such rods and the yield of usable products obtained. Experiments conducted to date have shown that it is the optic orientation, or relation between the optic or *c*-axis of a synthetic corundum rod and its longitudinal axis, which exerts the greatest influence on the results obtained in cutting or grinding, but the orientation of the *a*-axes also probably exerts an as yet undetermined effect on the results.

As shown in Fig. 1, the optic orientation of a synthetic unicrystalline corundum rod 11 is expressed in degrees as the angle O between the longitudinal or growth axis *g*—*g* of the rod and the optic or *c*-axis *c*—*c* of the rod, the latter of which lies in the direction in which light can be passed through the crystal without being doubly refracted. In a single crystal of synthetic corundum, which crystallizes in the hexagonal system, there is only one such direction, and no light ray traveling through the crystal in a direction parallel to *c*—*c* will be doubly refracted.

When fabricating synthetic unicrystalline corundum rods, either clear or colored, by abrading material therefrom as in a sawing or grinding operation wherein pressure is applied transversely of the longitudinal axis of the rod, high yields of usable products such as bearing blanks are obtained from rods wherein the optic orientation is between 30° and 80°, and preferably between 40° and 80°, whereas poor yields are obtained outside of these ranges because the rods often crack and split. When the optic orientation is less than 30°, synthetic corundum rods even may split spontaneously before any attempt at fabrication has been made but, in any event, splitting or cracking almost invariably occurs when the rods are sawed or ground. Rods wherein the orientation is above 80° have many lateral notches, formed during rod growth, which frequently cause lateral cracking during grinding. Moreover notched rods require an excessive amount of grinding to eliminate the notches.

Since the optic orientation of a synthetic corundum rod changes gradually as the rod increases in length if the initial orientation is less than 90° when grown by the process described in my copending application Serial No. 503,240, it has thus far been impossible to obtain a rod which has absolutely uniform optic orientation throughout its length unless the initial orientation is 90°. As a practical matter the optic orientation change in a rod of the short length of 2 or 3 feet commonly grown, and of the preferred optic orientation of 30° to 80°, is practically negligible, so that if the orientation of the portion of a corundum rod to be fabricated is within the defined ranges, a good yield of usable products is obtained.

When unicrystalline corundum rods contain small amounts of material other than alumina, such as coloring oxides of chromium, titanium, or iron, the yield of usable product usually varies to some extent from the yield obtained with white sapphire rods which are pure alumina. That is to say, within the broad optic orientation range of 30° to 80°, there may be a narrower preferred range within which the corundum rod of modified composition gives the best results.

The critical nature of the effect of optic orientation on the fabrication of unicrystalline corundum rods is graphically illustrated in Fig. 2, in which the percentage yield of usable jewel blanks cut one at a time from synthetic white sapphire rods is plotted against the optic orientation in degrees. Of course, the actual results of cutting at some orientations were slightly above or below the curve of Fig. 2, which represents a fair average of the results obtained. As shown by the curve, a good yield of usable product was obtained with synthetic corundum rods optically oriented between 30° and 80°, and a still better yield was obtained in the preferred range of 40° to 80°.

The critical optic orientation range for cutting corundum rods holds true for all cutting procedures known to me, including those wherein the rod is rotated and wherein it is not rotated, as well as for both single slicing technique and gang sawing technique wherein many slices are cut simultaneously. Furthermore, this range is critical for the cutting of circular slices and elliptical slices from rods.

To recapitulate, one phase of my novel method for increasing the yield of usable product obtained by mechanically working unicrystalline corundum rods comprises selecting for fabrication those rods wherein the angle between the *c*-axis *c*—*c* and the longitudinal axis *g*—*g* is between 30° and 80°, and preferably between 40° and 80°, and mechanically working the selected rods by applying thereto a tool such as a saw or grinder. Since the novel method of growing synthetic corundum rods of predetermined crystallographic orientation described in my above mentioned copending application makes it possible to confine within any desired range the optic orientation of all rods grown, it is apparent that by growing rods within the preferred ranges most of the raw material appears in the final product, and very little is wasted.

I have also found that the yield of usable product obtained by cutting slices from a synthetic corundum rod with any suitable type of cutting device, such as a rotating circular saw, can be greatly increased by mounting the rod in such a position with respect to the saw that, of the total force applied by the saw to the rod, the force component parallel to the *c*-axis of the rod is approximately the minimum possible at any position of the rod with respect to the cutting device (ideally zero). In general, it can be stated that the force component parallel to the *c*-axis should not exceed 40% of the total force applied by the saw summed vectorially. Relative translational movement between the rod and the cutting device toward one another is then effected in a direction across the rod by moving the cutting de-

vice, the rod, or both. The best position of the rod for making the force vector parallel to the c-axis a minimum is established by fixing in a predetermined manner the plane defined by the growth axis *g—g* and the intersecting optic axis *c—c*. This is the only control necessary for rods of preferred orientation (around 70°) but under some circumstances, particularly at extreme values of the orientation range, it may also be necessary to position the c-axis *c—c* so that it extends in a predetermined direction. This best position of the rod is uniquely definable for any given rod once the direction of motion of the saw blade, the direction of progression of cut and the end of the rod from which the slice is to be cut are decided upon.

There are several types of rod cutting procedures to which the present invention applies. In plunge cutting, the center of the saw passes along an extended rod diameter as the saw passes through the rod. Cutting with a band saw which is a circular saw of infinite radius is thus an example of plunge cutting. More specifically with respect to plunge cutting with a circular saw as shown in Figs. 3 and 4, relative translational movement is effected in such a way that the longitudinal axis *g—g* of the rod traces a plane which passes adjacent to the center 21 of the saw 19, or stated otherwise, the center of the saw traces a straight line which passes adjacent to the longitudinal axis of the rod. Actually the saw or the rod may traverse an arc of such a large radius that it can in effect be considered a straight path. Single slices can be cut off by plunge cutting, or a plurality of slices can be cut simultaneously with a plurality of saw blades arranged side by side to form a gang saw.

Another type of cutting procedure, called off-center cutting, involves effecting relative translational movement between a circular saw 19 and the rod 11 along a non-diametrical chord 31 of the saw in the manner shown in Fig. 7. A gang of saws likewise can be used to cut simultaneously a plurality of slices by this off-center cutting procedure.

In both plunge cutting and off-center cutting circular slices can be produced by effecting the relative movement in a direction normal to the rod. Elliptical slices can be produced by biasing the saw with respect to the rod.

My experiments have shown, and theoretical and mathematical analyses have confirmed, that the present invention is applicable to all of the foregoing procedures, which are equivalent for practical cutting purposes. The most important criterion has been found to be that the force exerted on the rod parallel to its optic axis and directed toward the slice being removed shall be a minimum.

Actual cutting tests have shown that by far the best yield of usable products can be obtained by not only positioning the rod so that the component of force parallel to the c-axis is a minimum, but also by selecting rods wherein the angle between the c-axis and the growth axis is between 60° and 80°. Of course, when the rod is rotated during cutting, the former control has no significance and the only control of the process lies in the optic orientation of the rod being cut.

In order that corundum rods can be properly positioned by a cutting machine operator, in accordance with previously prepared instructions for cutting non-rotating rods, it is necessary to know, for each length of rod, the location of the plane 13 defined by the intersecting axes *g—g* and *c—c*. As shown in Fig. 3, for example, the elongated unicrystalline corundum rod 11 has been marked with a longitudinal surface mark 15 extending parallel to the longitudinal axis *g—g* of the rod and defining therewith the plane 13 which also contains the optic axis *c—c*.

At extreme values of the orientation angle O it is also necessary to consider the general direction of the c-axis, and even with rods of preferred orientation, proper control of this additional variable improves cutting yields. The general direction of the c-axis may be indicated by any suitable symbol e. g. by marking one end of the rod 11 with a band 17 of coloring material as shown in Fig. 3. Such symbol, when read in conjunction with the position of the longitudinal surface mark 15 and interpreted by a prearranged code, then indicates to the observer that the optic axis *c—c* extends in a certain general direction in the plane 13. For example, when the observer looks at the rod 11 in Fig. 3 from the side carrying the longitudinal mark 15, and has the end mark 17 at his left, he knows from the prearranged code that the optic axis *c—c* extends diagonally away from him from left to right.

Proper control of the c-axis direction with respect to a saw is necessary because, even if the position of the plane 13 is fixed with respect to the saw blade, there are still two possible c-axis directions for any optic orientation except 0° and 90°, the two different directions being interchangeable by rotation of the rod on its longitudinal axis through 180°. As a result, for a given set of forces exerted by a saw, the force component parallel to the c-axis will be greater when the c-axis extends in one direction with respect to the saw than when the rod is rotated 180° so that the c-axis extends in a different direction with respect to the saw. This is apparent from Fig. 6 showing the relative direction of the optic axis *c—c* with respect to an independent set of Cartesian coordinates defined by the forces exerted on the rod by a saw blade rotating clockwise. It is evident that the component of force parallel to the optic axis is much less when a rod is positioned with the optic axis *c—c* extending from the near right quadrant to the far left quadrant, as shown, than if the rod were rotated 180° on its longitudinal axis so that the optic axis *c—c* extended from the near left quadrant to the far right quadrant.

The location of the plane 13 so that the mark 15 can be applied to the rod, and the general direction of the c-axis so that the mark 17 can be applied to the end of the rod can be determined in any suitable conventional way, as by a polariscope or by X-ray methods. Crayon, ink, graphite, paint, or any other suitable means can be used for making the marks 15 and 17. When the rods are marked in this way, a cutting machine operator can position them quite accurately with a maximum error of 15° from the correct position.

The invention will be described more in detail hereinafter in connection with Figs. 4, 5, and 6 as applied to plunge cutting a single slice from a unicrystalline corundum rod 11 with a rotating circular saw 19. The rod 11 is first mounted firmly on a horizontal block of wood 23 by cement 25, after which the rapidly rotating saw blade 19 is pressed downward through the rod. One suitable type of saw blade 19 is a thin copper disc about 0.01 to 0.015 inch thick charged with diamond dust.

The rod 11 and saw 19 of Fig. 4 are shown in perspective in Fig. 5 to illustrate the relative magnitude and direction of the forces applied by the saw to the rod in plunge cutting. There are three mutually perpendicular forces acting upon the rod as it is being cut, these being a downward force D due to the downward movement of the saw, a longitudinal force L due to the wobble of the saw, and a transverse force T due to the frictional drag of the saw against the rod. Although the saw 19 exerts longitudinal forces in two opposite directions on the two pieces of the rod 11 on opposite sides of the cut, it is necessary only to consider the force toward the end from which the thin slice is being cut, because the force in the opposite direction is exerted on the well supported main body of the rod and is not effective to break or crack the thin slice being removed. The downward force D is roughly three times as great as the transverse force T although the mesh of diamond powder used may affect this ratio. The longitudinal force L does not bear a direct relation to D and T, but depends on the planeness of the saw, the tightness of the bearings, and similar factors affecting wobble.

In plunge cutting with gang saws the longitudinal force L is less significant because there are always two saw blades on opposite sides of each slice supporting the slice against breakage. This tends to meet the principal criterion of this invention by keeping at a minimum the force parallel to the *c*-axis and directed toward the slice being removed.

Referring back to Figs. 3 and 4, the proper positioning of the rod 11 with respect to the saw 19 will be described. Actual experiments on plunge cutting have shown that an excellent yield of usable products in the form of thin jewel bearing blanks is obtained when the translational movement of the saw 19 relative to the rod 11 is in a direction between 0° and 30° to the normal to the plane 13. It is apparent that this condition can also be expressed in these words: that the plane 13 makes an angle *b*, measured in a specific direction as indicated in Fig. 3, of between 0° and 30° with the line EW when the latter is normal to the direction of relative movement.

The results of numerous plunge cutting tests on unicrystalline corundum rods having various orientations O, and positioned at different angles *b*, are tabulated below. Yields of circular usable jewel blanks are expressed as percentages of the total number of slices cut in each instance. Approximately the same number of test cuts were made at all the different combinations of optic orientation O and angle of inclination *b*.

Results of cutting tests

Angle O	30°	60°	75°	90°
Angle *b*:	*Per Cent*	*Per Cent*	*Per Cent*	*Per Cent*
0°	0	97	88	0
30°	0	95	54	48
60°	0	54	0	9
90°	0	21	0	3

At first glance it would seem that the above test results do not harmonize completely with the results plotted in Fig. 2. However, the two different sets of tests were made at different times with different cutters, and with a higher standard of "usable jewel blanks" for the tests tabulated above. Notwithstanding the difference in yields, it is apparent that both sets of test results support the 60° to 80° range of optic orientation within which the best results are obtained.

In off-center cutting wherein the relative movement between a rod 11 and a saw 19 is along a non-diametrical chord 31 of the saw, as shown in Fig. 7, the direction of progression 33 of the cut into the rod constantly changes as the depth of the cut increases and gradually approaches the normal 35 to the plane 13. However, the principles discussed previously herein apply, and experience has shown that the best cutting results can again be obtained by so positioning the rod 11 that the normal to the plane 13 makes an angle *a* with the constantly changing direction of progression 33 of the cut, which angle *a* remains within the 0° to 30° range as the cut progresses.

I have described the principles of my invention above as applied to specific cutting and grinding procedures by way of illustration only. It is apparent that changes in procedure can be made by those skilled in the art within the scope of the invention as defined in the appended claims.

I claim:

1. A method for increasing the yield of usable product obtained by mechanically working by abrasion unicrystalline synthetic corundum rods grown in rod form, which method comprises selecting for fabrication those rods wherein the angle between the *c*-axis and the longitudinal axis is between 30 and 80 degrees, and mechanically working the selected rods by abrading material therefrom with a tool such as a saw or grinder.

2. A method for increasing the yield of usable product obtained by mechanically working by abrasion unicrystalline synthetic corundum rods grown in rod form, which method comprises selecting for fabrication those rods wherein the angle between the *c*-axis and the longitudinal axis is between 40 and 80 degrees, and mechanically working the selected rods by abrading material therefrom with a tool such as a saw or grinder.

3. A method for increasing the yield of usable product obtained by mechanically working by abrasion unicrystalline synthetic corundum rods grown in rod form and having a diameter not exceeding three-sixteenths inch, said rods having their growth axes substantially centrally therein, said method comprising selecting for fabrication those rods wherein the angle between the *c*-axis and the longitudinal axis is between 30 and 80 degrees, and mechanically working the selected rods by abrading material therefrom with a tool such as a saw or grinder.

4. A method for cutting a slice from a unicrystalline corundum rod comprising mounting said rod in such a position with respect to a saw that of the total force applied by the saw, the force component parallel to the *c*-axis of the rod and directed toward the slice being removed is approximately the minimum possible for any position of said rod with respect to said saw; and effecting relative movement between said rod and said saw in a direction across said rod.

5. A method for cutting a slice from a unicrystalline corundum rod comprising mounting said rod in such a position with respect to a saw that of the total force applied by the saw, the force component parallel to the *c*-axis of the rod and directed toward the slice being removed does not exceed 40%; and effecting relative movement be-

tween said rod and said saw in a direction across said rod.

6. A method for cutting slices from unicrystalline corundum rods comprising selecting such a rod having an angle between its c-axis and its longitudinal axis of between 30° and 80°; mounting said rod in such a position with respect to a saw that of the total force applied by the saw, the force component parallel to such c-axis and directed toward the slice being removed is approximately the minimum possible at any position of said rod with respect to said saw; and effecting relative movement between said rod and said saw in a direction across said rod.

7. A method for increasing the yield of usable product obtained by cutting a unicrystalline corundum rod with a saw, which method comprises effecting relative translational movement between said saw and said rod while holding said rod in such a position that the normal to the plane defined by the c-axis and the longitudinal axis of said rod makes an angle between 0° and 30° with the direction of progression of the cut through said rod.

8. A method for increasing the yield of usable product obtained by cutting with a saw a unicrystalline thin synthetic corundum rod grown as a rod having a diameter not exceeding three-sixteenths inch and having its growth axis substantially centrally therein, which method comprises effecting relative translational movement between said saw and said rod while holding said rod in such a position that the normal to the plane defined by the optic axis and the longitudinal axis of said rod makes an angle between 0° and 30° with the direction of progression of the cut through said rod.

9. A method for increasing the yield of usable product obtained by cutting a unicrystalline corundum rod with a saw, which method comprises selecting such a rod having an angle between its c-axis and its longitudinal axis of between 30° and 80° and effecting relative translational movement between said saw and said rod while holding said rod in such a position that the normal to the plane defined by the c-axis and the longitudinal axis of said rod makes an angle between 0° and 30° with the direction of progression of the cut through said rod.

10. A method for increasing the yield of usable product obtained by plunge cutting a unicrystalline corundum rod with a saw, which method comprises effecting relative translational movement between said saw and said rod in a direction between 0° and 30° to the normal to the plane defined by the c-axis and the longitudinal axis of said rod.

11. A method for increasing the yield of usable product obtained by plunge cutting a unicrystalline corundum rod with a saw, which method comprises effecting relative translational movement between said saw and said rod in a direction substantially normal to the plane defined by the c-axis and the longitudinal axis of said rod.

12. A method for increasing the yield of usable product obtained by plunge cutting a unicrystalline corundum rod with a saw, which method comprises selecting such a rod having an angle between its c-axis and its longitudinal axis of between 30° and 80°, and effecting relative translational movement between said saw and said rod in a directon such that the normal to the plane defined by the c-axis and the longitudinal axis of said rod makes an angle between 0° and 30° with such direction of movement.

13. A method for increasing the yield of usable product obtained by plunge cutting a unicrystalline corundum rod with a saw, which method comprises selecting such a rod having an angle between its c-axis and its longitudinal axis of between 30° and 80°, and effecting relative translational movement between said saw and said rod in a direction substantially normal to the plane defined by the c-axis and the longitudinal axis of said rod.

14. A method for increasing the yield of usable product obtained by cutting with a saw a unicrystalline corundum rod, which method comprises effecting relative movement between said rod and said saw in a direction along a non-diametrical chord of said saw while holding said rod in such a position that the normal to the plane defined by the optic axis and the longitudinal axis of said rod makes at all times an angle between 0° and 30° with the constantly changing direction of progression of the cut through said rod.

15. A method for increasing the yield of usable product obtained by cutting a unicrystalline corundum rod with a saw, which method comprises determining the position of the c-axis of said rod, placing on the side surface of said rod a mark extending longitudinally along said surface and lying in the plane defined by said c-axis and the longitudinal axis of said rod, and effecting relative translational movement between said saw and said rod while holding said rod in such a position, as indicated by the position of said mark, that the normal to the plane defined by said mark and the longitudinal axis of said rod makes an angle between 0° and 30° with the direction of progression of the cut through said rod.

MALCOLM H. BARNES.

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