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X-RAY ANGLE SORTING OF SMALL-SIZE QUARTZ BLANKS USING THE Ω-SCAN – STATE AND PERSPECTIVE

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Abstract **– Recently developed angle-sorting machines for AT-cut quartz based on the Ω-Scan Method allow the measurement of small blanks down to about 1mm², the position-dependent measurement of wafers, as well as the determination of absolute cutting angles. The twin apparatus ("The Carousel") reduces the cycling time nearly to one third. Distributions of cutting-angles measured on wafers and blanks show that there can exist appreciable changes, which may have consequences referring to the active oscillator area. Therefore, the use of polycapillary optics is discussed to adapt the irradiated area to the active one as well as to avoid systematic errors measuring still smaller blanks. Very probably, these optics would also lead to significantly smaller statistic errors and/or shorter cycling times.**
Keywords **– Cutting-angle determination, quartz blanks and wafers, Ω-Scan Method, orientation non-uniformity, polycapillary collimator**

I. Introduction

About than ten years ago, the angle sorting of AT-cut quartz blanks of any shape by means of the Ω-Scan Method has been introduced [1]. Since this time, the machines could be improved concerning precision, accuracy and capability [2, 3]. The applicability could be extended to smaller and thinner blanks. On the other hand, also the position-dependent measurement of the cutting angle of wafers has been realized [4]. Recent results of the orientation changes in wafers led to the problem of its influence on the accuracy of measured cutting angles.

In this paper, the capability of the recently developed angle-sorting machines and the reliability of the angle measurement of small blanks will be reported. Some aspects of the forthcoming development concerning precision and accuracy of relevant cutting-angle values will be discussed as well as the possibilities to adapt the measuring area to that of technological interest.

II. New possibilities of AT-cut angle measurements

Recently, the conventional angle-sorting machine for AT-cut strips could be modified to measure blanks of sizes down to 1×1 mm^2 and 0.8×1.2 mm^2 (Fig. 1). For this purpose, the areas irradiated by the X-ray as well as by the laser beam had to be reduced (diameters about 0.6 mm) in order to be smaller than the minimal blank width considering additionally the handling tolerance. The main problems which had to be solved were those of the feeding and handling process due to electrostatics, positioning accuracy and separation of the single blanks. The standard deviation for the measurement of one and the same blank is about 3 to 4 arcsec., and thus nearly the same as for larger blanks. This could be achieved by compensating the loss due to lower intensity by the gain at the evaluation due to the smaller reflection-curve widths. Furthermore, the evaluation procedure has been extended to measure optionally absolute cutting angles, as discussed already in an earlier paper [5]. The procedure contains an additional measuring and evaluation step, performed automatically at the beginning of the measurement of a given charge of blanks. The user can select either the conventional evaluation using reference blanks or the new procedure giving the absolute "physical" cutting angle.

Fig.2 shows the new, modified version of the twin measuring apparatus ("The Carousel"). Similar to the apparatus presented some years ago [3] the blanks are measured simultaneously on two turntables, each of them fed now by two handling arms. All the other parts of the measuring and sorting system exist just once. Due to this new, more effective handling system, the sorting speed of this machine is nearly three times higher compared with the conventional single machine. A further advantage is that a fixed arrangement of X-ray tube, measuring stage and detector can be employed, due to a general reduction of the statistic errors in this geometry. Nevertheless, in the usual range of AT cutting angles the mean standard deviations are smaller than 3 arcsec. and do not exceed 5 arcsec. in the worst case. The evaluation provides the absolute value of the cutting angle. Because of the fixed arrangement there is

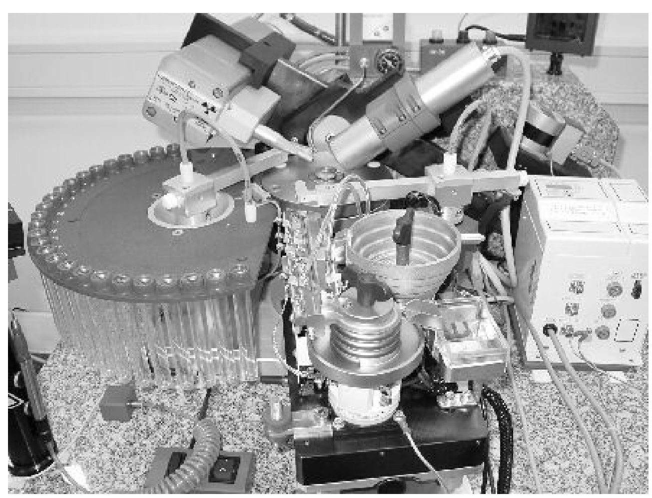


Fig. 1. View of the conventional AT-cut quartz angle-sorting machine adapted to the feeding, handling and measurement of small blanks.

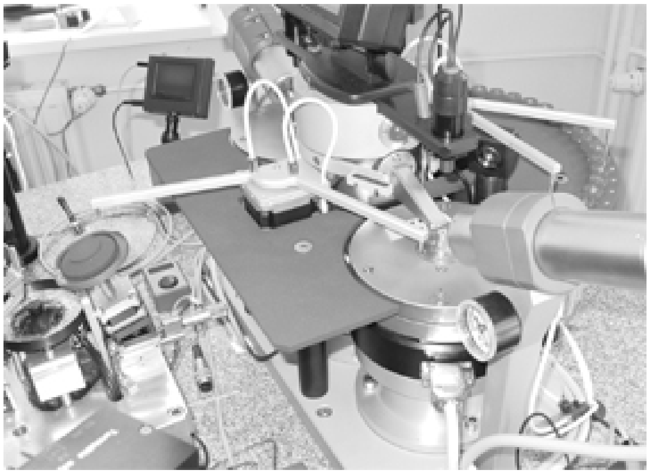


Fig. 2 View of the twin AT-cut quartz angle-sorting machine ("The Carousel").

no need for an additional measuring and evaluation step at the beginning of a new charge. However, due to the smaller incidence angle of the X-ray beam, the height of the turntable support is rather critical and must be calibrated especially carefully.

The third new developed machine (Fig. 3) allows the measurement of quartz wafers up to about 60×60 mm^2 size at a selectable number of measuring points. The wafer is shifted after each single measurement using the calculated value of the azimuthal orientation and considering the constant time for lifting the wafer from the turntable [4]. Up to 30 points can be measured. Their arrangement on the surface can be chosen nearly arbitrarily. The wafers are taken from boxes having the dimensions of the wafers and can be sorted into a number of similar boxes according to the suitably calculated representative cutting angle of the whole wafer or to other criteria to be chosen accordingly. The measuring arrangement is based on that of the conventional AT machine. Also in this case, the "relative" or, additionally, the "absolute" evaluation can be chosen.

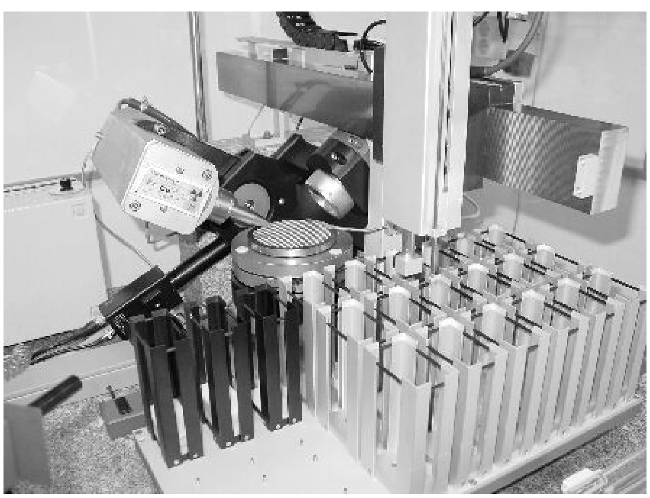
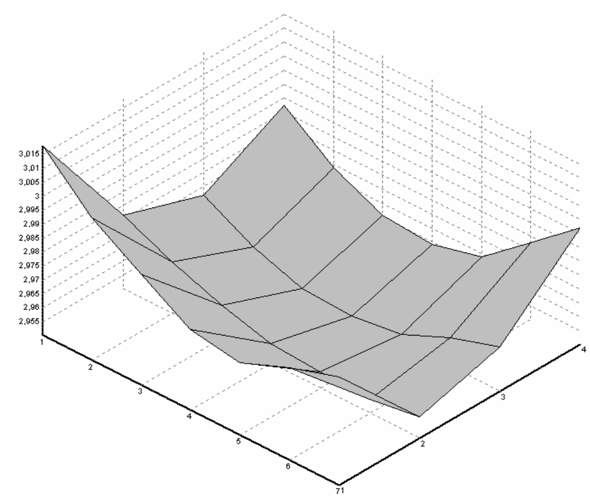


Fig. 3 View of the angle-sorting machine for AT-cut quartz wafers.

III. Non-uniformity of wafers and blanks

The results of the measurements on wafers of one type are shown in Fig. 4. 28 measuring points were taken with distances of about 8 mm. The results represent the components of the local cutting angles, i.e., the local lattice with respect to the local surface orientation. In principle, also the lattice angles as well as the surface orientation, both related to the rotation axis, can be plotted. They are influenced by the residual wobbling of the turntable and by incidental inclinations of the wafer on the support. However, the comparison of the corresponding plots with those given in Fig. 4 allows qualitative conclusions about the main contribution to the observed effect. Probably, the results reflect mainly the non-uniform surface preparation. One may conclude from the results of this type of wafers that the cutting angles of small blanks cut from them would appreciably scatter.



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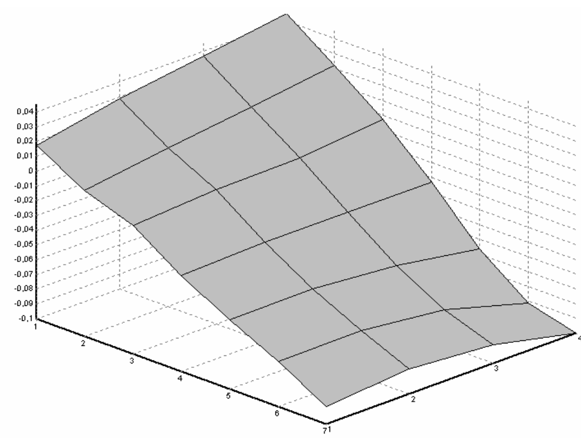

b

Fig. 4 Distribution of cutting angles over an AT-cut quartz wafer. Ordinate: angle in °; 7×4=28 measuring points. a) "True" cutting angle; b) X miscutting angle.

Additionally, also the blanks themselves can still be inhomogeneous with respect to the cutting angle. Such effects have also been shown on round blanks of 8 mm diameter (Fig. 5). The local cutting angles were measured shifting the blanks exactly on the turntable by means of a special shift mechanism. The measuring points were taken along a line, with distances of 0.5 mm. Also in this case appreciable changes of the local cutting angles have been found. The reproducibility of these results is demonstrated by the two sets of measuring points obtained by repeated runs. The origin of these effects seems to be the same as in the case of the wafers, based on similar arguments.

IV. Effect of the X-ray collimator system

It is an advantage of the Ω-Scan Method that the irradiated area is relatively large compared to other X-ray methods. With the exception of the smallest blanks this area is usually about 1 mm^2, integrating in this way over the non-uniform orientation distribution, if any, in the corresponding surface area. Generally, the cutting-angle value should be representative for the active volume or area of the oscillator produced from it. The active area is mainly that coated by the electrical contacts. If this is larger than the measuring area given by the X-ray and laser beam areas used up to now and the blanks are not uniform, then it would be preferable to enlarge also these areas. For the very small blanks their whole area should be irradiated. In order to discuss these questions in more detail, the influence of the X-ray beam-collimating system will be considered.

The X-ray beam collimator as used in the conventional machines consists only of a round or elliptical hole. The beam divergence is defined by its width together with the width of the nearly isometric tube focus and the distance between focus and hole. The divergence is nearly the same in horizontal and vertical directions. In the Carousel machine another arrangement is used with the line focus of the X-ray tube and a small slit instead of a hole. In this case, the divergences are very different in both directions.

The beam divergence is mainly responsible for the widths of the measured reflection curves. Their intensities depend also on the width of the hole or the slit and the distance. The reflection-curve width and the intensity determine in a rather complex manner the reproducibility of the measured peak positions and, therefore, that of the cutting angle. Simulation calculations have shown that for the used X-ray tube the arrangements are nearly optimal with respect to the standard deviations of the cutting angle (Fig. 6). This is true for the beam sizes as used up to now for larger blanks as well as those for the smallest blanks to be measured at present. That means that the use of essentially larger holes or slits in the case of larger blanks would lead to larger errors and, therefore, is not practicable. On the other hand, the need of appreciably smaller holes or slits in the case of still decreasing blank size would increase the standard deviation. Using irradiated areas comparable to the blank size can also lead to systematic errors as will now be discussed.

For the collimators as described above, the mean beam direction varies across the beam width and so is different for any points inside of the irradiated area. If this falls not completely onto the surface, a systematic error may result (Fig. 7). This error can be neglected if the irradiated area is cut off *perpendicularly* to the plane containing incident beam collimator and detector. Cutting off a part of the irradiated area *parallel* to this plane leads to a significant systematic error of the cutting angle. Cutting off, however, e.g., 2.5%, the error is estimated to be in the order of 10 arcsec. If the blank sizes will further decrease in the future and the same types of collimators will be used, these errors will become more critical due to the limited positioning accuracy.

Because the laser beam is a nearly parallel ray bundle, the problems discussed for the X-ray beam are not relevant for the laser beam. The area irradiated by the laser beam can be adapted to a large extent to the demands concerning blank size and integration area.

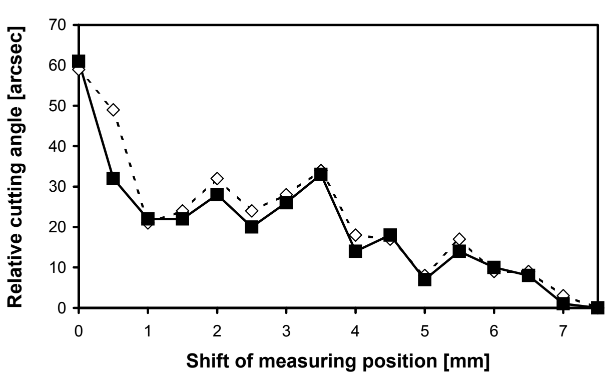

Fig. 5. Distribution of cutting angles along the diameter of an AT-cut quartz blank.
■ first run; ✧ second run.

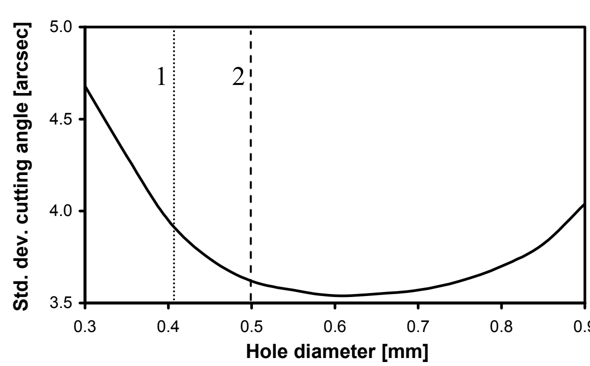

Fig. 6. Standard deviations of the cutting angle of AT-cut quartz vs. the vertical hole diameter of the collimator system.
Calculated by reflection-profile simulation.
hole diameter: 1 for smallest blanks; 2 for larger blanks

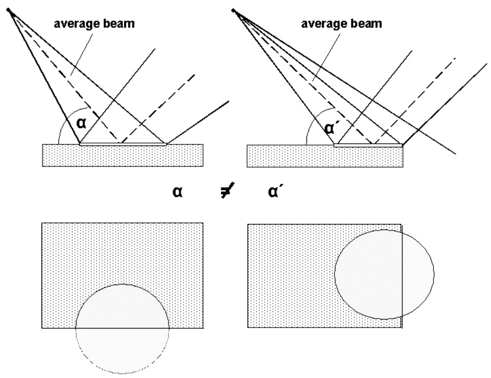

Fig. 7. The effect of cutting off the irradiated area due to wrong blank positioning for divergent-beam collimator.
On the left: cutting off parallel to the collimator-detector plane;
on the right: cutting off perpendicular to the collimator-detector plane.

A part of the problems connected with the presently applied X-ray collimator can be solved using an alternative X-ray optical system [6]. The demands as discussed before and the specific demands of the Ω-Scan Method might be fulfilled by polycapillary optics [7]. They consist of bundles of small glass capillaries (Fig. 8), each of them representing a single collimator with a diameter in the order of a few µm. Its divergence, however, is limited by the angle of X-ray total reflection and is in the order of 0.1°, comparable or a little smaller than for the collimators used up to now. A capillary optic is effective only in connection with a special microfocus X-ray tube needing a relatively small power. The collimator diameter can be chosen, e.g., between 1 and 10 mm. So one has a collimator system, with a constant mean beam direction constant across the whole beam width (Fig. 9). It would be possible to measure blank sizes smaller than the beam size without systematic errors due to the blank positioning. Using larger blanks, the irradiated area could be adapted to the active area of the oscillator.

V. Discussion and conclusions

Higher precision and/or shorter cycle time of the cutting-angle determination are general demands of the producers of quartz blanks. Further developments of the angle-sorting machines based on the Ω-Scan Method must consider these demands. Shorter cycling time can be realized if the statistic errors could be decreased for the present cycle time. This is true as long as it is not limited by the time for the automatic feeding and handling.

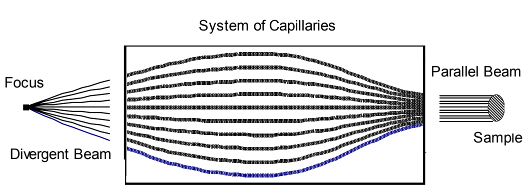

Fig. 8. Polycapillary X-ray optic.

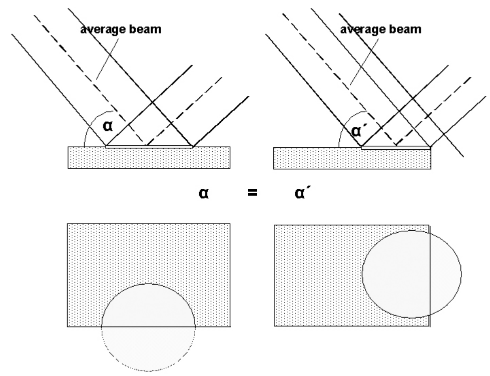

Fig. 9. The effect of cutting off the irradiated area at wrong blank positioning for parallel-beam collimator (polycapillary X-ray optic).
On the left: cutting off parallel to the collimator-detector plane;
on the right: cutting off perpendicular to the collimator-detector plane.

The expected statistic errors when using polycapillary optics cannot yet be realistically estimated because they are applied in connection with low-power microfocus X-ray tubes and, therefore, hardly comparable to the conventional X-ray optical system. Very probably the intensities of the reflections would be essentially enlarged. In connection with reflection-curve widths comparable to the present ones, this would reduce the standard deviations of the Ω-Scan measurements. It must, however, be considered that then the contribution of other factors, e.g., of the homogeneity of the turntable rotation, may be more important. Nevertheless, it seems to be possible to reduce the statistic errors of Ω-Scan measurements, say, by a factor two, using polycapillary optics. However, also the precision of the turntable should be improved in the same time.

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