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STROBOSCOPIC TOPOGRAPHY OF QUARTZ RESONATORS WITH SYNCHROTRON RADIATION

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ABSTRACT

Stroboscopic X-ray topography experiments have been carried out with vibrating single crystal AT quartz using the synchrotron radiation of the storage ring DORIS as a pulsed light source. Our results for the first time give insight into the dynamics of dislocations on the nsec time scale.

We report on the first experiments which use the time structure of synchrotron radiation (emitted by the storage ring DORIS) for imaging periodical processes inside single crystals on the nsec scale. Experiments have been carried out at the new topography station at Hasylab, Hamburg. Samples under investigation, in our case AT cut quartz, are brought into the direct beam of the storage ring at a distance of about 34m away from the tangent point. From the Laue pattern behind the crystal several reflections with specially good contrast were chosen for closer investigations.

During most of our experiments the storage ring was operated in the single bunch mode i.e. the synchrotron radiation pulses of 130 psec duration being emitted at intervals of 960 nsec. The electron energy was 3.3 GeV at typically 5 mA current. In order to obtain a stroboscopic image of the acoustic vibrations they had to be synchronized to the frequency of the storage ring. To benefit from resonant amplification we used a biconvex quartz plate with maximum thickness of 2 mm and a radius of curvature of 26.5 mm [1] which in this way was exactly tuned to the frequency of the light source. Synchronization was achieved by means of the output signal of a fast photomultiplier fed by the optical component of the synchrotron radiation which triggered a sine wave generator driving the crystal vibrations. A change of the phase relation between the light pulses of the storage ring and the sine wave generator was accomplished by inserting a variable delay line. The output voltage of the generator was up to 10 V_{pp}.

The basic mode of a circular plane parallel AT-quartz plate is the so called thickness shear mode leading to a sinusoidal displacement of the $21\bar{0}$ net planes which are perpendicular to the crystal surface [1]. Coupled to this fundamental mode more complex modes can occur depending on the boundary conditions. X-ray topography may be used to map the distribution of acoustic vibrations throughout the whole crystal because of enhanced reflectivity from areas of inhomogeneously strained lattice planes, mathematically speaking, where the second spatial derivative of the scalar product $\mathbf{g}\cdot\mathbf{u}$ with reciprocal lattice vector $\mathbf{g}$ and displacement vector $\mathbf{u}$ is non-zero.

Fig. 1 shows half a period of the acoustic wave in a series of topographs taken at phase intervals of $\pi/12 \hat{=} 40$ nsec. Besides the "acoustical" contrast many dislocation images are visible most of them moving in the strain field of the vibration. To our knowledge these are the first experiments which directly image dislocation motion due to ultrasonic waves.

[1] produced by KVG, Neckarbischofsheim.

In order to get better information about the depth in the crystal at which these processes occur, section patterns have been recorded at various positions using a slit of 50 - 60 μm width. The geometry is explained in Fig. 2. The dislocation lines crossing the narrow illuminated section give strong kinematical contrast in the direction of the reflected beam. Thus the distance of the spot from the margins of the section pattern is a direct measure for the depth of the dislocation line in the crystal. Fig. 3 shows such a section pattern for the quartz at rest and at two different phases of the acoustic vibration.

A first analysis gives the following results

1. Imaging of different vibration modes.

   a. The thickness shear mode is imaged by the increased reflectivity at the antinodes of the vibrating net planes which in case of the fundamental mode lie on the surface of the plate leading to a significant enhancement and broadening of the "hot margins" of the section pattern.

   b. The possibility to measure the contrast throughout the depth of the crystal by taking section patterns is especially useful in imaging higher harmonics where the complicated structure of nodes and antinodes is not resolved in pictures taken with full aperture.

   c. Close to a zero crossover of the amplitude secondary modes become visible which in the usual phase integrated topographs [2] are covered up by the basic mode.

2. Movement of dislocations.

   a. The first surprising fact is that the dislocations move at all. Quartz with its covalent bonds is expected to have high Peierls barriers corresponding to critical stresses of $10^{-2}\,\mu$ where μ is the shear modulus. With a Q-factor of 10^5 the resulting shear stress of the acoustic vibration is one order of magnitude lower even at its maximum.

   b. Some dislocations oscillate with such a large amplitude that they exceed sound velocity.

c. Comparing both halves of the acoustic cycle most of the dislocations move in the same direction although the applied stress changes sign.

Further experiments are certainly needed to elucidate the mechanism which is responsible for the strange observations listed above.

The measurements reported here are considered to be pilot experiments to demonstrate the feasibility of stroboscopic topography on a nsec scale. Besides the astonishing results concerning dislocation motion this new technique opens up the possibility to study the coupling of acoustic modes in greater detail compared to usual topography with continuous radiation. Future experiments will deal with the investigation of surface acoustic wave (SAW) devices and acoustic waves in non-piezoelectric crystals.

REFERENCES

[1] R. D. Mindlin, W. J. Spencer, J. Acoust. Soc. Am. 42, 1268 - 1277 (1967).

[2] B. J. Isherwood, C. A. Wallace, J. Phys. D 8, 1827 - 1842 (1975).

FIGURE CAPTIONS

Figure 1. : Stroboscopic topographs of an AT quartz crystal plate covering phase angles of half a period of the thickness shear mode ($10\bar{1}2$ reflection, $\lambda \sim 1.2$ Å, Kodak Industrex type R film, 40 sec exposure time). Phase (time) increases from the top left to the bottom right in steps of $\pi/12$ (40 nsec).

Figure 2. : Geometrical relations between defect position and image in a section pattern. B white beam, S slit, X crystal, D dislocation, F X-ray film, H hot margins, I direct image.

Figure 3. : Section pattern of the quartz crystal, $\lambda \sim 0.5$ Å, $1\bar{2}.2$ reflection; (a) at rest (b) stroboscopically imaged acoustic vibration ($U = 5\ V_{pp}$), $^3/_{16}\ \pi$ (90 nsec) before zero crossover; (c) same as (b) but $^5/_8\ \pi$ (300 nsec) before zero crossover. On the right the dislocation pattern changes entirely. On the left one can trace the path of dislocation movement as indicated for three numbered dislocations.

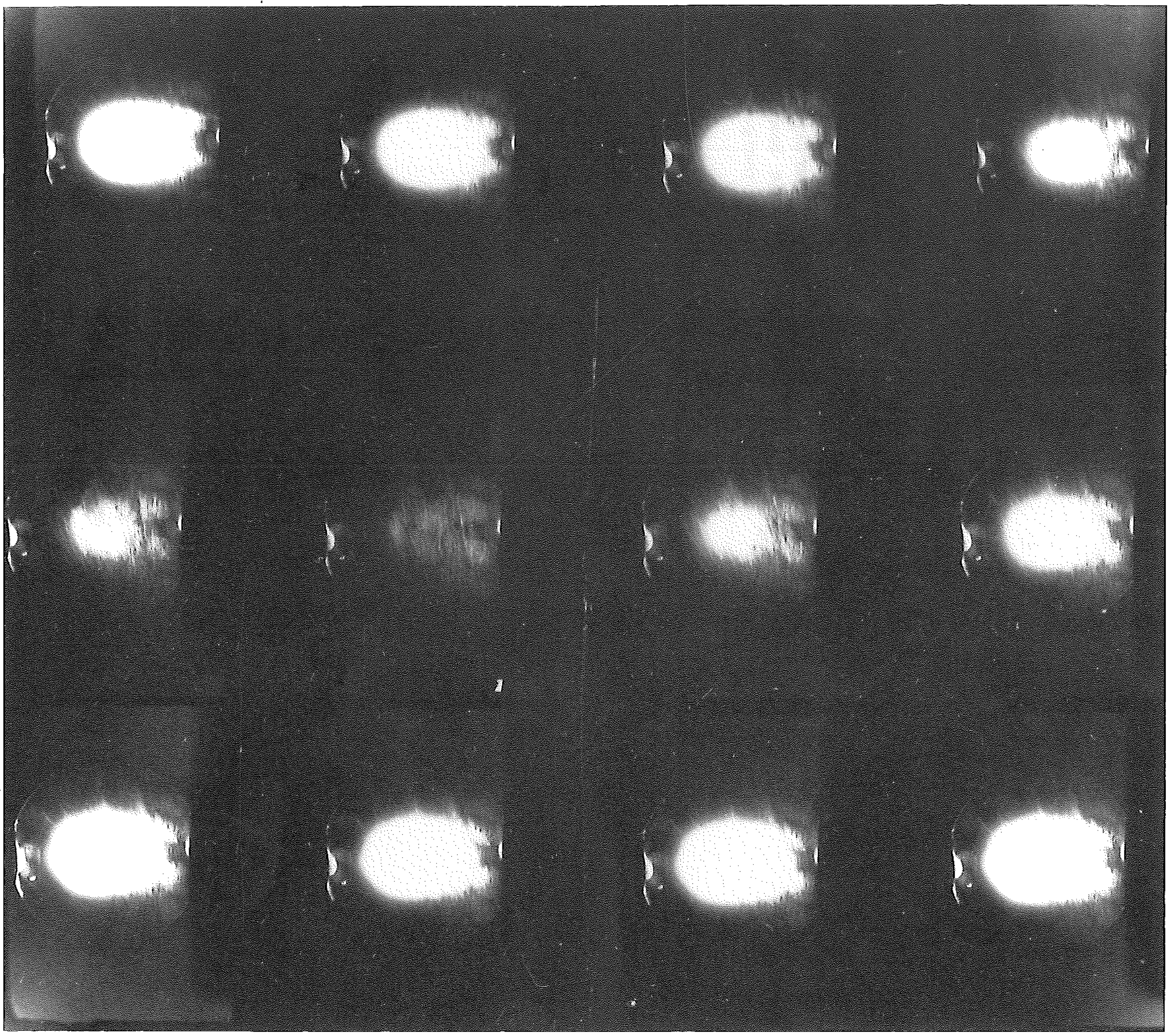

Fig. 1, Glüer, Graeff Möller, 1981

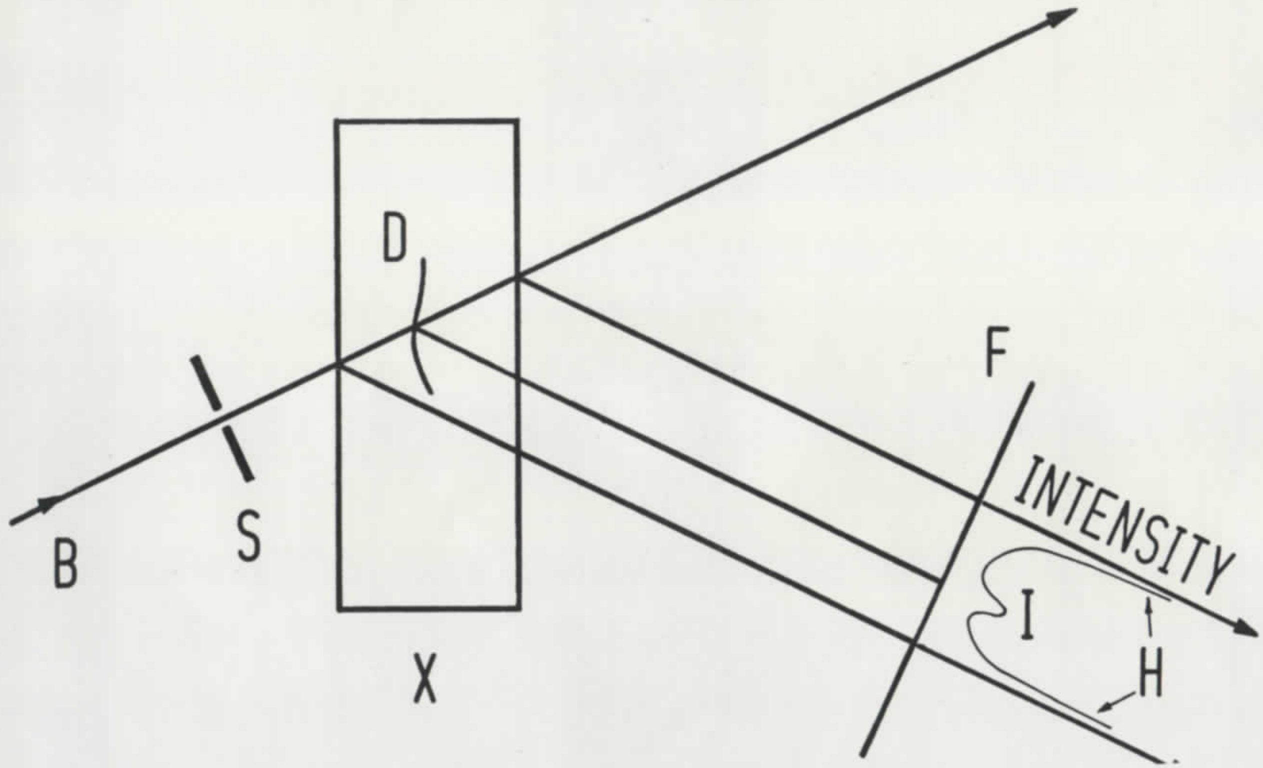

Fig. 2, Glüer, Graeff, Möller, 1981

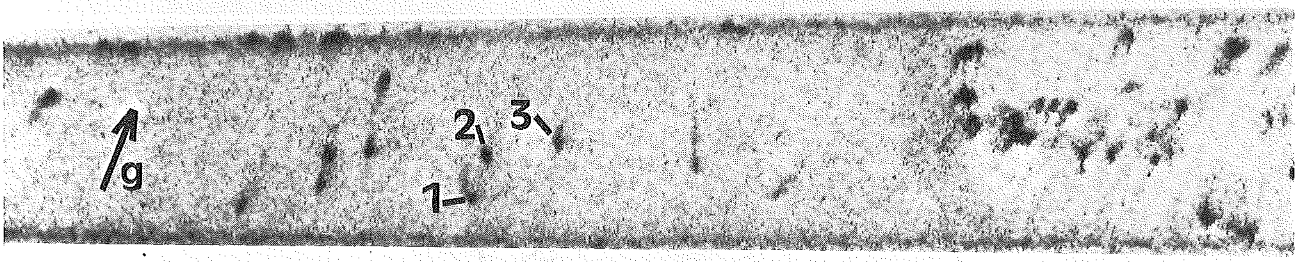

Fig. 3a, Glüer, Graeff, Möller 1981

Fig. 3b, Glüer, Graeff, Möller, 1981

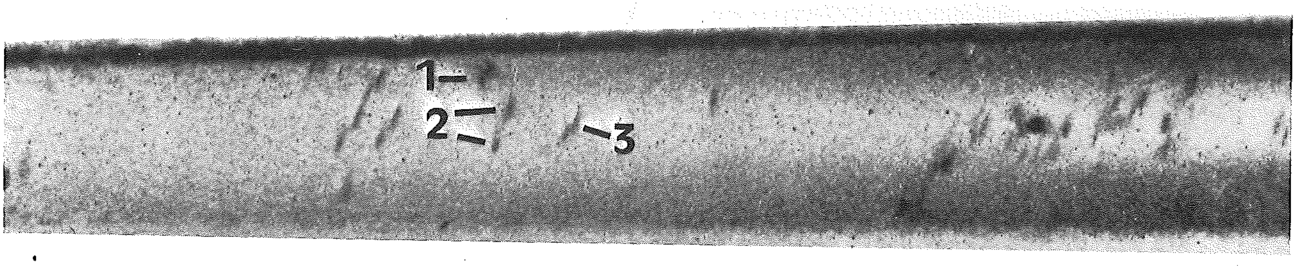

Fig. 3c, Glüer, Graeff, Möller, 1981