ACOUSTIC MICROSCOPY APPLIED TO ACOUSTIC RESONATOR CHARACTERIZATION

L. Germain and J.D.N. Cheeke
Dept. de physique, Université de Sherbrooke
Sherbrooke, QC, Canada JIK 2R1

The characteristics of acoustic resonators and the techniques used to characterize the standing wave patterns are described. It is shown that these patterns can be observed by the acoustic microscope in a transmission mode. Results are presented for circular and rectangular transducers showing the effects of supporting mount leads and defects on the vibration characteristics.

INTRODUCTION

Piezoelectric quartz resonators have widespread use in timing devices employed in the audio and RF range. From the ordinary digital watch to precision telecommunication systems, these resonators play an essential role due to their high Q, great temperature stability and relatively cheap cost. Apart from the intrinsic quality of the crystals (inclusions, impurities, dislocations, etc.)[1], the nature of the vibration pattern is an important characteristic of such resonators [2], which directly affects their performance. Although there exist numerous methods for visualising the standing wave patterns in these crystals, all of these methods are indirect in nature and suffer from different limitations. The development of new more direct techniques for observing the acoustic resonances of piezoelectric transducers is thus of considerable fundamental interest and this is the subject of the present communication.

REVIEW OF OTHER TECHNIQUES

A complete description of the vibratory modes from the historical and practical point of view for the case of AT Quartz resonators is given by Bahadur and Parshad [2]. In general, there are a number of different plate modes (extensional, flexural, face shear) and the desired fundamental thickness mode. The basic problem is that in a finite plate, all of these modes as well as anharmonic overtones of the fundamental thickness mode will be excited due to elastic coupling and boundary constraints. These extra modes lead to frequency jumping and parasitic losses which degrade the performance of the device. A considerable body of literature exists, mainly due to Mindlin and coworkers (for a summary, see [2]) in which the frequency and number of modes are calculated for different plates as a function of the aspect ratio (length/thickness).
Most of these modes can be detected experimentally, for example, by the X-Ray technique [3] and in practice it is desired to eliminate them so as to leave only the fundamental thickness mode. Various techniques have been used to suppress undesired modes, principally bevelling and contouring which leads to energy trapping of the fundamental mode in the centre of the plate while the other modes propagate out to the outer region where they are attenuated much as in a waveguide beyond cutoff.

Experimentally, visualisation of the nodes and antinodes in vibrating piezoelectric resonators was first done by Chladni with lycopodium powder [4]; these results were discussed by Lissajous [5] and Lord Rayleigh [6]. This method is mainly of historical interest. Multiple beam interferometry has been used with great success by Tolansky and coworkers [7] on circular discs where the flexural modes are observed as radial modes (diametral lines and concentric circles). The technique gives quantitative access to the local amplitude of the normal displacements. More direct methods measure the local strain and the most successful of these is the X-Ray method [3] where the strain associated with specific crystallographic planes is imaged. This method has been used to study the effects of leads and irregularities in the crystal [8]. Another direct method is to measure directly the local charge polarisation by a point probe [9] where excellent detailed agreement is obtained between theory and experiment. The method is however painstaking and not practical for generalised use, particularly on contoured crystals. Another major technique is scanned electron microscopy which is sensitive to both the local topography and the local potential distribution, usually the former at high magnification ($\geq 2000$) and the latter at low magnification ($\approx 20$) [2]. This technique has been useful in detecting the flexural vibrations outside the electrode area [10] although there is still some discussion on the interpretation of the results [2]. Finally, there have also been measurements by laser techniques [2] and the recent developments in scanned laser microscopy should be particularly interesting in this area.

EXPERIMENTAL SET UP

In the present work, we use a scanning acoustic microscope (SAM) in a transmission type mode [11] with the transducer to be studied as the receiving element. Such a configuration had been suggested earlier for studying transducers [12]; one image was later reported [13] but no interpretation was given. Our actual experimental set up is shown in fig. 1.

The transducers used were $36^\circ$ rotated Y cut LiNbO$_3$ circular disks of 6 mm diameter with a fundamental frequency of 30 MHz. Gold electrodes were deposited on the surfaces in a coaxial configuration with a 3 mm diameter central electrode. The electrical contact on the central electrode was made either by a spring POGO contact (as shown on the figure) or by a small copper wire soldered directly on the electrode.

The SAM used here [14] employed a quartz lens with a 1/16 in. spherical cavity and short RF pulses at 30, 90 or 150 MHz were applied to the transducer. Images were displayed on a high resolution monitor (512 x 512 x 8 bits).

RESULTS

Typical results for the fundamental (30 MHz) and fifth harmonic (150 MHz) are shown in Fig 2. It is important to note here that in these and following images, the center electrode approximately covers the entire field of view.
Fig. 1. Schematic view of the experimental arrangement.

Fig. 2. Images of a circular transducer with POGO contact to the center electrode. (a) 30 MHz, (b) 150 MHz.
We interpret the general form of the images in the following way. A given transducer has a large number of modes, dilatational, shear and flexural, which are all coupled together. At a given frequency, there will be a complex standing wave pattern set up in the crystal when one or several of these modes are excited. The standing wave pattern can hence be observed by scanning the focused beam of the SAM over the face of the electrode so that the response of the transducer is greatest at the position of the antinodes and least at that of the nodes.

Alternatively, images could also be made by using the microscope lens as the receiver, monitoring point by point the studied transducer, now acting as the emitter. Very similar images are obtained for both methods. We thus arrive at two complementary views of the process. When the transducer to be studied is used as receiver, we measure the average potential difference between the electrodes due to contributions from all modes set up by the focused acoustic beam at the point in question. Conversely, when the transducer is used in the generation mode with detection by the lens, we measure the acoustic power emitted from the focal point into the liquid within the lens aperture due to the different modes set up in the vibrating transducer.

In fig. 2, we associate the circular fringes with radial modes and the increase in fringe density with frequency supports this hypothesis. The perturbation of the fringe system due to the POGO spring contact is clearly visible. The method of electrical contact to the central electrode has a marked influence on the image as seen in fig. 3, where the lead is now directly soldered to one edge of the electrode. The position of the soldered joint is clearly seen. For the fundamental, we see that the

![Fig. 3. Images of a circular transducer with a soldered contact to the center electrode. (a) 30 MHz, (b) 90 MHz.](image-url)
Fig. 4. Image of a circular transducer at 150 MHz. The localized defects are believed to be minute air bubbles.

standing wave pattern is drastically altered due to the contact. In a final result for this type of transducer, we often observed localised defects as seen in fig. 4. These are not characteristic of the transducer material and we suspect that they are due to minute air bubbles trapped on the transducer surface.

Due to the threshold voltage used in the imaging system, a simple association of light regions to antinodes and dark regions to nodes can give rise to false conclusions. More quantitative information on the vibration amplitude can be obtained by doing linear sweeps across the electrode surface as shown in fig. 5 for the fundamental. Considerable variations in the amplitude are observed and it is interesting to note that these are considerably reduced for the harmonics.

Similar and rather more quantitative results were obtained for the rectangular transducers. In this case, the two electrodes covered each face of the transducer which was mechanically supported at one end in cantilever fashion. As seen in fig. 6, the fringes are now rectangular and again the fringe density increases with frequency. This change in form of the standing wave pattern with the physical constraints strongly supports our interpretation and rules out any possibility that the fringes are due to some characteristic internal structure of the material, but further experiments are needed to determine whether it is the physical form of the transducer or that of the electrode which determines the nature of the fringes. The fringe density as a function of frequency is shown in fig. 7; the form is approximately parabolic, which would be expected for flexural vibrations [15].

A final example which combines several of the preceding features is shown in fig. 8. The transducer is supported on the lower edge corresponding to the white band in the image. The electrical connection is made on the left hand edge of this strip corresponding to the dark spot in the lower left hand corner. There is a chip near the upper left hand corner and again, the perturbation of the vibration pattern is clearly visible.

Many more experiments are planned in order to render this technique
Fig. 5. Line sweep across a diameter for a circular transducer at 30 MHz.

Fig. 6. Standing wave pattern for a rectangular transducer. (a) 30 MHz, (b) 90 MHz.
Fig. 7. Fringe density as a function of frequency for the transducer of fig. 6.

Fig. 8. Image of a rectangular transducer with a defect on one edge.
more quantitative including the use of line scans across an interesting part of the crystal face. But it is already clear that the technique has an interesting potential for studying the properties of acoustic resonators and of ultrasonic transducers radiating into water.

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