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▶ **To cite this version:**

Yu Wang, Nicolas Wilkie-Chancellier, Loic Martinez, Stephane Serfaty. Electrodes geometry and surface waves generation on a quartz disk: experimental study. Acoustics 2012, Apr 2012, Nantes, France. hal-00810949

HAL Id: hal-00810949

https://hal.science/hal-00810949

Submitted on 23 Apr 2012

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ACOUSTICS 2012

Electrodes geometry and surface waves generation on a quartz disk: experimental study

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The elaboration of new soft hybrid materials requires adapted smart sensors. Among the ultrasonic techniques, the use of an AT cut quartz is a solution that allows the complete tracking of the mechanical properties of the material in contact. In order to get a RF wireless excitation of such a sensor in a wide frequency bandwidth, the tuning of the electrodes geometry is determinant as it must be based on closed loops. The aim of the present experimental study is to analyse the role played by the electrodes shape upon the generation of the surface waves. Several electrodes excitation geometries are presented in order to optimize the surface wave focusing at the center of the sensor. The quartz disk is excited by a voltage pulse and the quartz surface is scanned by a laser vibrometer. The surface waves and the transient aspects linked to the electrodes shape borders are analyzed by using the 3D Gabor transform. The observed waves and their generation sources are presented, revealing new insight about the modeling of the sensor electrodes. A comparison with classical electrodes shapes is carried out.

1 Introduction

In recent years there has been considerable interest in the investigations on new soft hybrid materials with the help of specific properties. In particular, a control of the viscoelastic parameters during the material transition has been extensively needed. Our laboratory has presented an ultrasonic technique to measure the viscoelastic parameters of the material during its formation. We have used an AT-cut quartz crystal contacting with the material on one side and with air on the other side for the surface waves generation.

The present paper attempts to study the role played by the electrodes shape of the quartz upon the generation of the surface waves. In this experimental work, the method is to scan the surface of the quartz disk by a laser vibrometer when it is excited by a voltage pulse [1]. The surface waves and the transient aspects linked to the electrodes shape borders are analyzed by using the 3D Gabor transform [2]. In order to optimize the surface wave focusing at the center of the quartz, several electrodes excitation geometries are presented and a comparison with classical electrodes shapes is carried out. The observed waves and their generation sources are also presented, revealing new insight about the modeling of the sensor electrodes.

2 Experimental section

2.1 General

In our experimental study an AT-cut quartz crystal resonator (cut of the crystal relative to the main crystallographic axis is 35.25°) is used because of its frequency stability, its low temperature coefficient [3] and with the purpose to generate thickness–shear vibrations on the quartz surface [4].

The method is to scan the surface of an AT-cut quartz disk by the beam of the Polytec laser Doppler vibrometer (LDV) while the quartz is excited by a voltage pulse generator with a repetition rate of 100 Hz [5]. The experimental setup is illustrated in Figure 1.

The probe laser beam scanning is realised by mounting the quartz on an automated motion control device with two orthogonal linear translation stages.

Two soft springs maintain the quartz disk with the electrodes in opposite positions. This offers the advantage to maintain the disk with nearly free edge conditions.

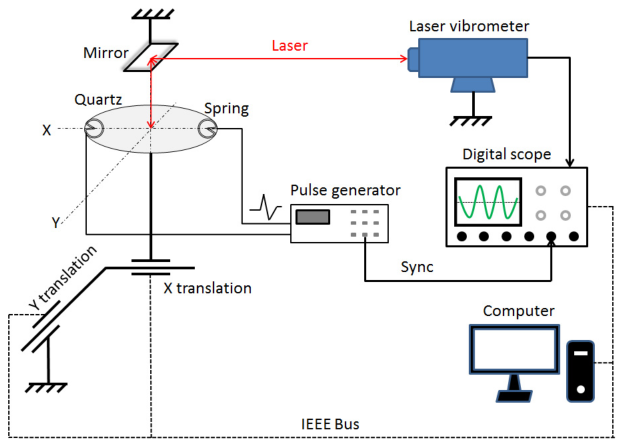

Figure 1: Experimental setup.

2.2 Electrodes with disk geometry

In this part, a standard AT-cut quartz disk is studied. The quartz disk is designed to offer a 6 MHz fundamental frequency with a diameter of 13.8 mm and a thickness of 0.3 mm [1-2] (Figure 2). In order to generate the waves, gold electrodes are deposited on the both surfaces of the sensor. These electrodes are plain disk (5 mm in diameter) located at the center of the quartz disk.

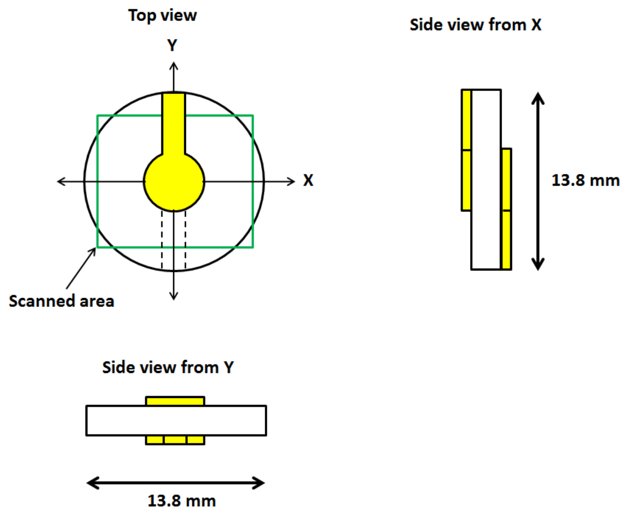

Figure 2: Geometry of the quartz and the electrodes used in the classical experiment [1-2].

In order to perform an accurate study of the surface waves which propagate on the sensor face, the spatial acquisition is performed on 80 by 110 positions rectangular area which included almost all the surface of quartz, with 125 µm steps.

2.3 Electrodes with ring geometry

In this second part, as a similar choice of the AT-cut quartz, a quartz disk with a diameter of 13.8 mm, a thickness of 0.3 mm and a fundamental frequency of 9 MHz is studied (Figure 3).

However the electrodes geometry is complementary. In this case, the whole surface of the quartz disk is deposed by the gold electrodes, except for a circular area of 5 mm in diameter in the center, consequently achieving a kind of ring form electrodes geometry.

This kind of geometry is determinant as it must be based on closed loops in order to get a RF wireless excitation in a wide frequency bandwidth (100 MHz).

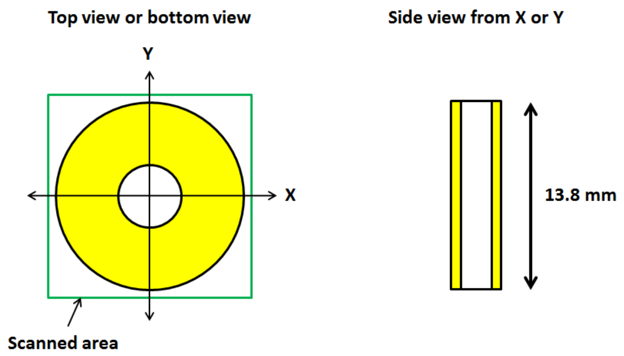

Figure 3: Geometry of the quartz and the electrodes used in the current experiment.

Moreover, the space acquisition is completed over a bigger rectangular area which covers the whole area of the quartz (150 by 150 positions, with 100 µm steps).

3 Results and discussion

3.1 Experimental results : disk geometry

In this section, we refer to the results of the experiment results presented in reference [1] and [2]. Figure 4 illustrates the space-time signals obtained by the laser scanning on the upper surface of the quartz disk with classical disk geometry electrodes. One can note the generation of Lamb waves from the electrodes borders.

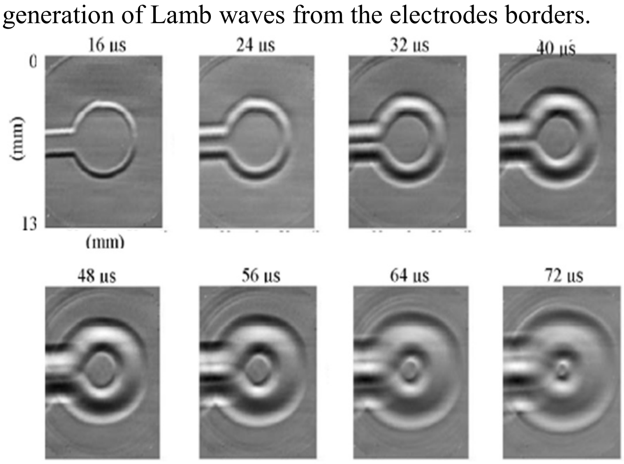

Figure 4: Space-time signals recorded for the sensor with disk geometry electrodes.

3.2 Experimental results : ring geometry

The space-time signals recorded for the sensor with ring geometry electrodes are displayed in Figure 5. The two first snapshots exhibit the generation of surface waves from the ring borders. The outer border generates a wave propagating and focusing toward the centre. The inner border generates two waves: one initially focusing towards the centre, the second one expanding to the outer border.

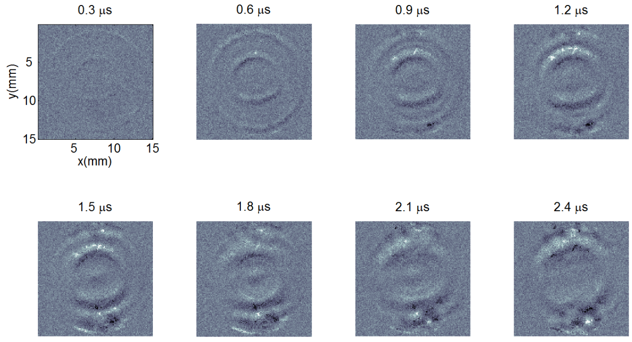

Figure 5: Space-time signals recorded for the sensor with ring geometry electrodes.

These propagating waves are diffracted by the two springs, creating waves rotating along the ring electrodes area.

As the thickness of the quartz disk is finite, the waves are Lamb-like and dispersive. A detailed analysis of the transient behaviour of these waves is to be done through a 3D Gabor transform [6-13].

3.3 Transient analysis using 3D Gabor transform

Figure 6 and 7 show the result of the Gabor analysis wave generation for the two quartz sensors. In the two cases, the waves are generated from the electrodes borders only, propagating downward or upward the center. In the low frequency domain (under 1MHz), the wave-numbers estimated from the Gabor analysis reveals only the Lamb mode A0. Moreover, along one diameter the waves are in phase opposition, revealing a shear movement from the electrodes borders.

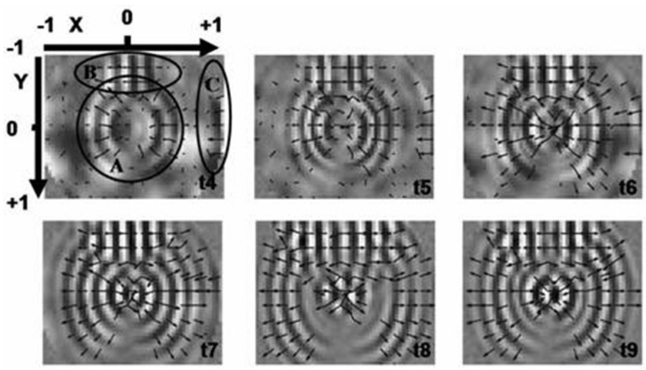

Figure 6: Gabor analysis of the disk electrodes setup for F = 1 MHz.

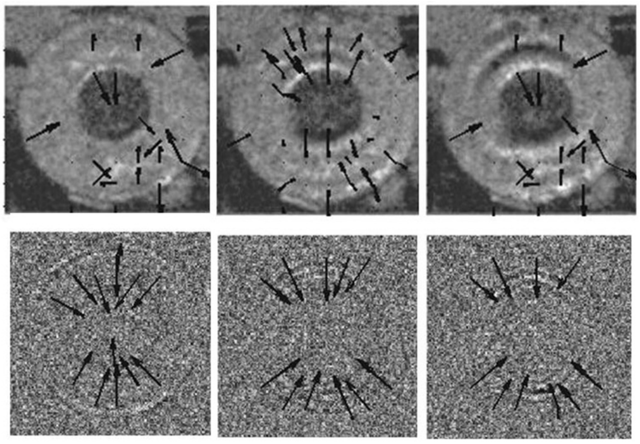

Figure 7: Gabor analysis of the ring electrodes setup. Upper for F=0.8MHz and from left to right for time 0µs, 1µs and 2µs. Lower for F=2.1MHz and from left to right for time 0µs, 1µs and 2µs.

Due the high noise level in the signals from the ring electrodes sensor, a Fourier analysis based on the whole time horizon is presented below.

3.4 Fourier analysis for the ring electrodes

In order to reach a better signal to noise ration, the whole time window is used prior Fourier transform. This has the advantage to measure the wave numbers with a better resolution, but at the cost of losing their time and space localization. Figure 8 presents slices for selected resonance frequencies. Such analysis exhibits the eigenmodes of the sensor disk shape. As the frequencies increase, the wavelength shortens and the complexity of eigenmodes pattern increases.

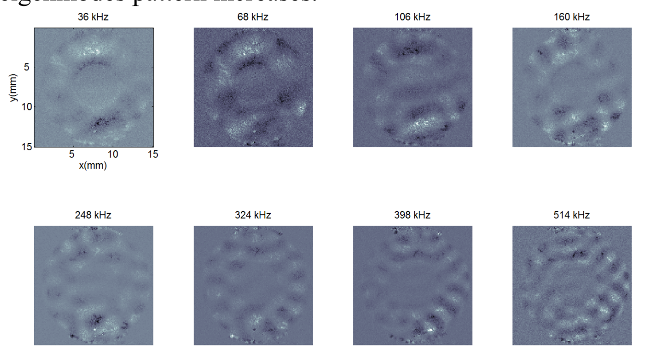

Figure 8: Time Fourier transform for identifying the wave modes in the ring electrode case.

Figure 9 shows the complete 3D Fourier transform in the low frequency range of *[0 kHz - 600 kHz]*. As with the Gabor transform, the A0 mode is followed along the frequency axis. One can note that the wave amplitudes are not isotropic: this reveals that the wave generation favours the spring contact direction.

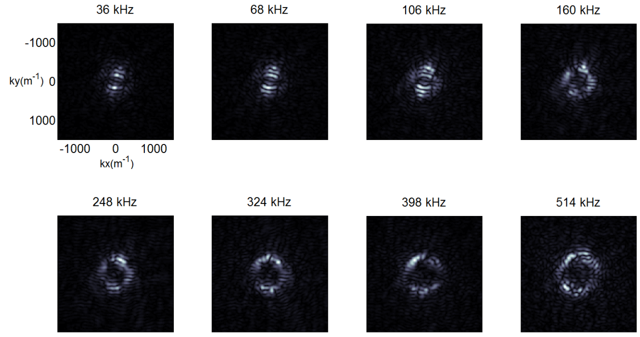

Figure 9: 3D Fourier transform in the range of *[0 kHz-600 kHz]* in the ring electrode case.

Figure 10 displays the 3D Fourier transform in the high frequency range of *[1 MHz - 9 MHz]*. A second surface wave is generated and observed up to the frequency of 9MHz. The measured phase velocity of this wave is close to the shear velocity of the quartz (2903 m/s). One can note a strong anisotropy for this wave, mainly generated along 4 directions.

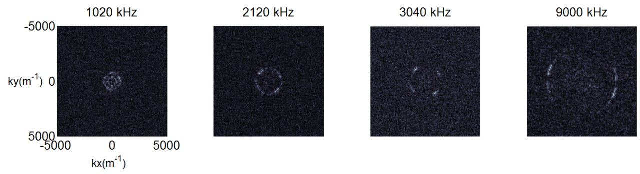

Figure 10: 3D Fourier transform in the range of *[1MHz-9MHz]* in the ring electrode case.

4 Conclusion

In this paper, it is observed that there is a significant generation of the surface waves with the influence of the role played by the electrodes shape. These waves propagate with opposite directions, focusing at the sensor centre, and then diffracts on the maintaining electrodes springs, creating waves rotating along the ring electrodes area. The observed waves and their generation sources are also presented, revealing new insight about the modelling of the sensor electrodes.

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