

Scanning Electron Microscopy Imaging of Acoustic Wave Fields Distribution in QCM

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Received: 30 August 2019 /Accepted: 15 October 2019 /Published: 30 November 2019

Abstract: The acoustic properties of QCM microbalances based on a $\text{La}_3\text{Ga}_5\text{SiO}_{14}$ crystal (LGS) were studied using scanning electron microscopy technique. Scanning electron microscopy method in the low-energy secondary electron emission mode makes it possible to visualize the distribution of the acoustic wave field in the QCM (distribution of nodes and antinodes of standing bulk acoustic wave in crystal) in the real time mode.

Keywords: $\text{La}_3\text{Ga}_5\text{SiO}_{14}$ crystal, Scanning electron microscopy, Bulk acoustic waves, QCM, Microbalance.

1. Introduction

Usually, electrical measuring methods are used to analyze the functioning of acoustoelectronic devices based on surface and bulk, traveling and standing acoustic waves. It should be noted that these methods do not allow analyzing the process of propagation of acoustic waves in solids. For the analysis of acoustic fields in solids, it is advisable to use the methods of scanning electron microscopy (SEM) [1-3] and X-ray topography [4-6], which allows to visualize the acoustic wave fields distribution both on the surface and in the volume of crystals. These methods make it possible to measure the acoustic wavelengths, to determine the direction of propagation of the acoustic signal and power flow angles, to investigate the acoustic wave fields interaction with crystal structure defects.

The purpose of this work was to study the distribution of the acoustic wave field in QCM

microbalance using the scanning electron microscopy method.

2. Scanning Electron Microscopy Imaging of Acoustic Wave Fields: Experimental Set-Up

The SEM method in the mode of secondary electron recording was used as an experimental technique for visualization of the bulk acoustic waves excitation and propagation in QCM microbalance since only the low energy secondary electrons with energy of $\sim 1\div 3$ eV are sensitive to the electric field which accompanies the propagation of acoustic waves in piezoelectric materials. The acoustic waves were rendered visible in a JEOL JSM-840 scanning electron microscope with an accelerating voltage $E_0=1\div 3$ kV and a probe current $I_0=6\times 10^{-9}$ A. The use of high accelerating voltage is not possible, because the

insulating substrate would be highly charged and thus bring about a distortion of the image because of the deflection of the primary electron beam and the change in the secondary electron emission from the crystal surface.

For visualization of acoustic wave propagation in solids, it is possible to use two different modes of SEM method. In the first one, it is possible to use the SEM in the stroboscopic mode with high-frequency modulation of the electron beam with the frequency of acoustic wave. Under this condition, the electron beam is in phase synchronization with acoustic wave and secondary electron emission from the surface is defined by the electric field, which accompanies the propagation of acoustic wave in piezoelectric materials [1]. In the second case, which is more handy (it is not necessary to use the special stroboscopic techniques), the high-frequency modulation of the low energy secondary electrons is defined by a stationary electrostatic interference field formed above the crystal surface in the process of interaction between the varying electrostatic field of acoustic wave and the component, normal to the crystal surface, of the electromagnetic radiation field of QCM-electrodes. The electromagnetic and acoustic waves are mutually coherent, since they are excited by the same source (QCM-electrodes) and with the same frequency. Since the wavelength of electromagnetic wave is large than the wavelength of acoustic wave (~five order of magnitude), the period of the stationary interference field is equal to the wavelength of acoustic wave. Under these conditions, the low energy secondary electrons are modulated by the stationary electrostatic interference field. In our investigations to visualize the acoustic waves in QCM we used the second method [2-3].

SEM method was used to study of the process of bulk acoustic wave excitation in QCM based on $yx\ell/+50^\circ$ -cut of a $\text{La}_3\text{Ga}_5\text{SiO}_{14}$ crystal (Fig. 1).



Fig. 1. QCM microbalances.

Different types of electrode materials (Au and Ir) were used. Usually bulk acoustic waves (BAW) are

excited in QCM not only at resonance excitation frequency, but also at some another frequencies due to accuracy of QCM fabrication, QCM surface curvature accuracy, location and structure of metal electrodes on the surface of QCM.

3. SEM Imaging of Acoustic Wave Fields in QCM Microbalances

Fig. 2 shows the amplitude frequency response (AFR) S11 of QCM with Au-electrode based on transverse BAW. It seen that resonance excitation frequency is $f_0=6.0072$ MHz, while the frequency of antiresonance is $f=6.0150$ MHz. Fig. 2 also display the different excitation frequencies due to the precision of QCM fabrication. At $f=6.1210$ MHz QCM excited the transverse BAW, that propagates along axis x .

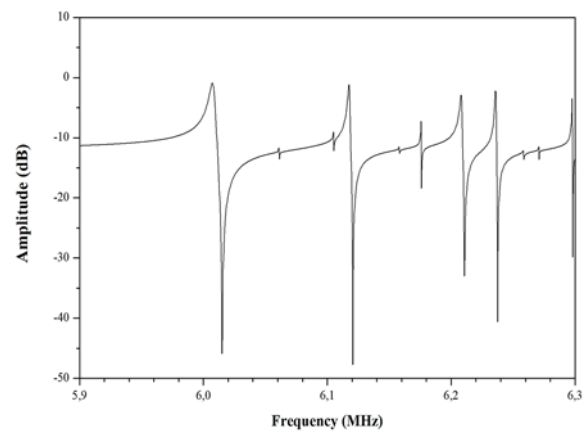
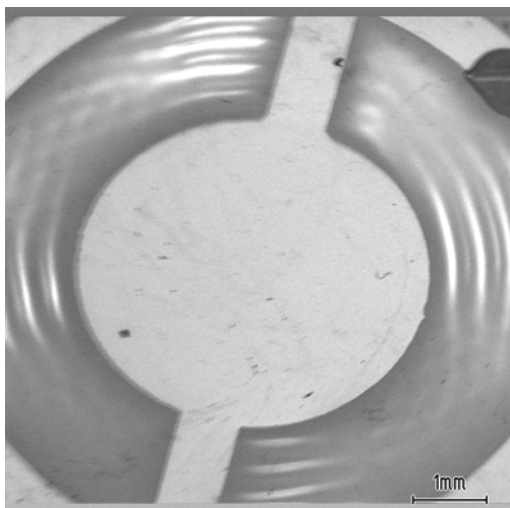


Fig. 2. AFR S11 of QCM with Au-electrodes.

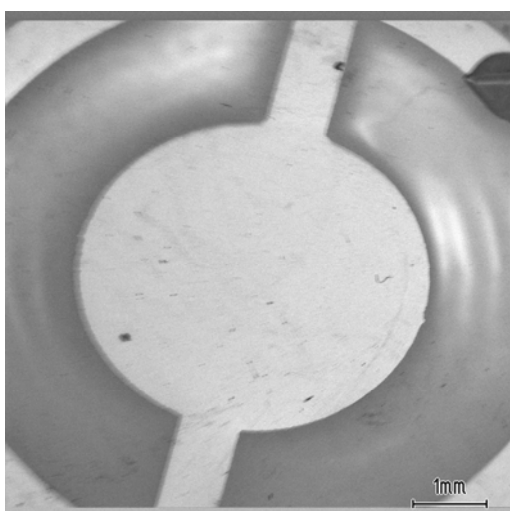
Fig. 3 demonstrated the SEM images of BAW excited in QCM microbalance at different excitation frequencies. At $f_0=6.0072$ MHz Fig. 3(a) shows the resonance excitation mode of transverse BAW, that propagates along axis x . Fig. 3(b) shows the BAW distribution in QCM at antiresonance conditions of $f=6.0150$ MHz. The distribution of BAW in nonresonance mode at $f=6.1210$ MHz is shown in Fig. 3(c). Thus, the SEM method is very simple method to study the operation of QCM based on bulk acoustic wave.

Fig. 4 shows the amplitude frequency response S11 of QCM with Ir-electrode based on transverse BAW. It seen that resonance excitation frequency is $f_0=5.9980$ MHz. AFR at Fig. 4 also demonstrates the different excitation frequencies due to the precision of QCM fabrication (undesirable parasitic modes). At $f=5.9980$ MHz QCM excited the transverse BAW that propagating along axis x .

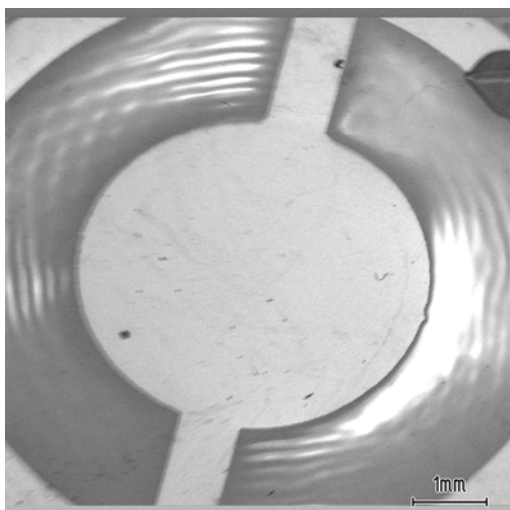
Fig. 5 shows the SEM images of BAW excited in QCM microbalance with Ir-electrodes at different excitation frequencies. At $f_0=5.9980$ MHz Fig. 5(a) display the resonance excitation mode of transverse BAW, that propagates along axis x . Fig. 5(b) shows the BAW in nonresonance mode at $f=6.1045$ MHz.



(a)



(b)



(c)

Fig. 3. SEM images of BAW in QCM with Au-electrodes excited at resonance excitation frequency $f_0=6.0072$ MHz (a), $f=6.0150$ MHz (b), $f=6.1210$ MHz (c).

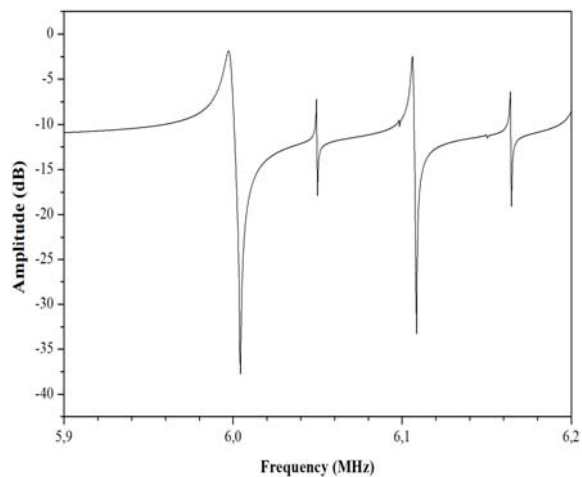
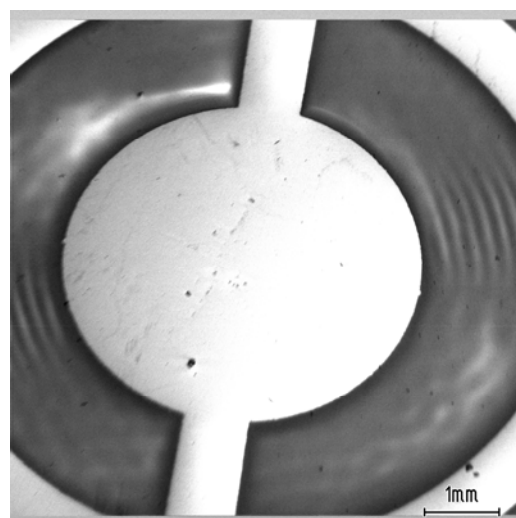
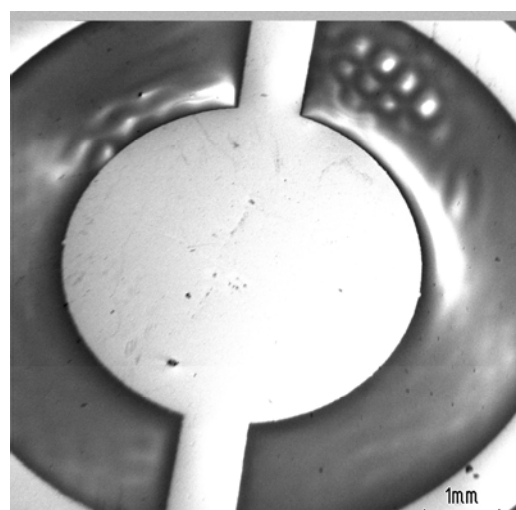


Fig. 4. AFR S11 of QCM with Ir-electrodes.



(a)



(b)

Fig. 5. SEM images of BAW in QCM with Ir-electrodes excited at resonance excitation frequency $f_0=5.9980$ MHz (a), $f=6.1045$ MHz (b).

Distribution of acoustic wave field in QCM strongly depends on crystal and electrodes forms while the resonance excitation frequency depends only from crystal thickness.

Fig. 6 shows the result of SEM investigation of QCM operated at more high frequency. Fig. 6(a) demonstrates the distribution of resonance excitation

mode of transverse bulk acoustic wave in QCM at resonance excitation frequency of $f_0=22.0247$ MHz. Figs. 6(b)-(c) demonstrates the parasitic modes of transverse acoustic waves in QCM excited at $f=22.1064$ MHz and $f=22.1529$ MHz, respectively. In this case the transverse acoustic waves propagates along axis x.

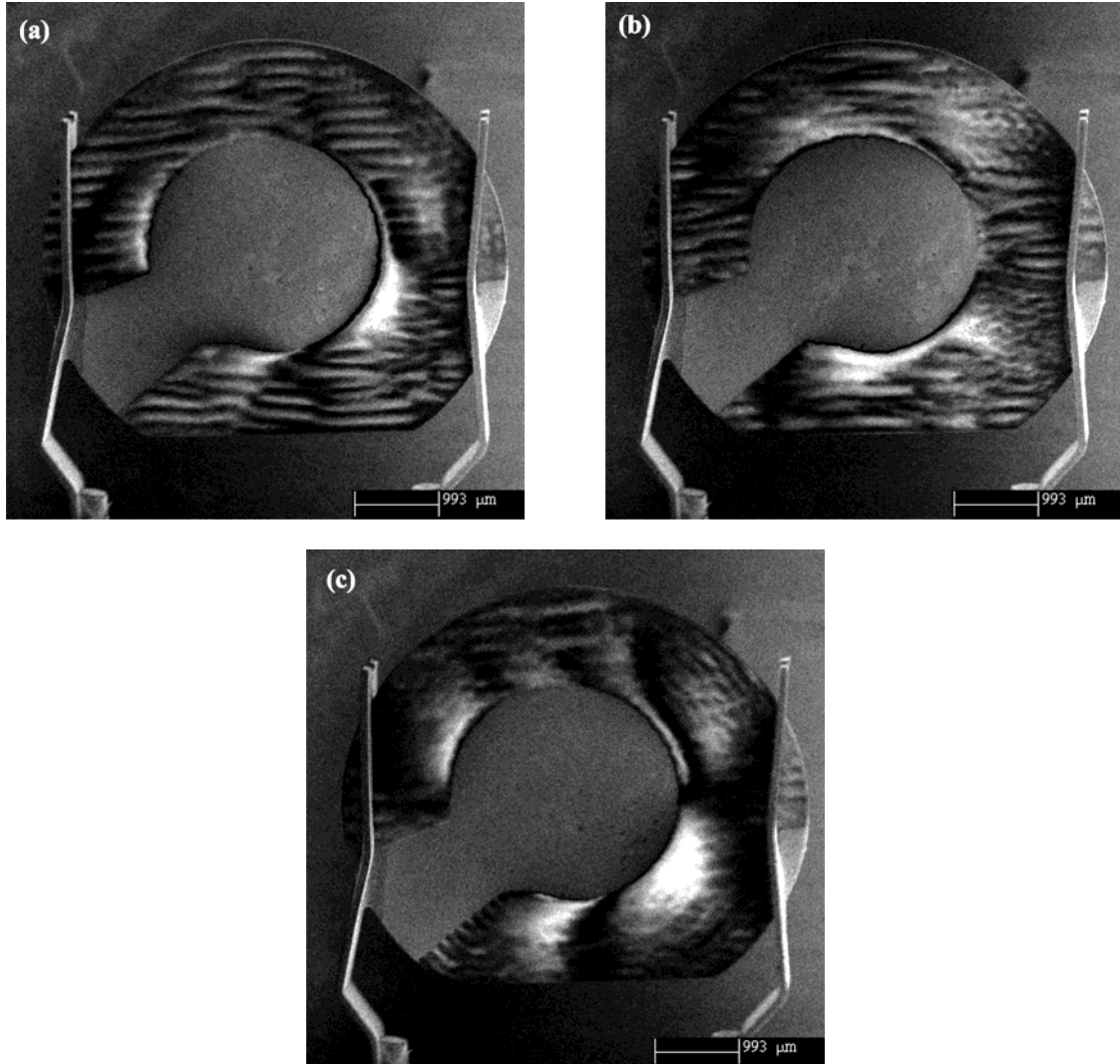


Fig. 6. QCM based on $yx/+/50^\circ$ -cut of a $\text{La}_3\text{Ga}_5\text{SiO}_{14}$ crystal: (a) resonance excitation frequency $f_0=22.0247$ MHz, (b) $f=22.1064$ MHz, (c) $f=22.1529$ MHz.

4. Conclusions

We demonstrate the real possibility to use the scanning electron microscopy method for visualization and controlling of acoustic wave fields in QCM microbalance. It is shown, that SEM method is very fast and useful method for investigation of acoustoelectronic devices.

The only drawback of the SEM method is that it is impossible to observe the image of acoustic waves under the metal electrode, which is an equipotential surface.

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Published by International Frequency Sensor Association (IFSA) Publishing, S. L., 2019 (<http://www.sensorsportal.com>).

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