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SAW pressure sensor on quartz membrane lapping

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The fabrication of SAW quartz-based pressure sensors has received a strong interest for many years, yielding various development using either delay lines or resonators. However, most approaches have been developed exploiting quartz machining along standard chemical or mechanical etching, rarely compatible with batch processes as used for Micro-Electro Mechanical Systems (MEMS). In this work, we propose a temperature/pressure sensor fabricated on compound Quartz/Silicon substrates obtained by Au/Au bonding at room temperature and lapping/polishing of Quartz. This approach allows for a collective and accurate production of sensors, the sensor sensitivity being controlled by the membrane thickness and diameter.

As the pressure is intricately connected with temperature, an objective estimation of this parameter requires accurate temperature measurements as well. As a consequence, the proposed sensor combines a reference resonator designed to be temperature compensated (AT, X cut of quartz) together with a resonator which propagation direction is chosen according the targeted temperature coefficient of frequency in order to give access to a linear differential temperature measurement. In addition, a third resonator with propagation axis along X is placed at the right center of a circular membrane. When the membrane is bent by pressure effects, the corresponding resonance frequency drifts linearly, allowing for another differential pressure measurement. Hence, with three resonators, one can easily demonstrate the unambiguous determination of temperature and pressure at once.

Until now pressure sensor based on SAW with quartz material are unity processed. This process allows us a collective manufacturing of sensors. We start by seal the quartz wafer with the silicon substrate using the thin gold layer. This process yields an homogeneous and high quality bond. It is subsequently thinned and polished to an overall thickness of 100 microns. Aluminum electrodes are deposited on the quartz to achieve three SAW resonators.

Process flow based on collective manufacturing is now developed. Electrical responses of SAW resonators are done. Results show the operability of the sensors and the responses are conformed to the design. Electrical test under pressure is currently under development.

1 Introduction

The fabrication of SAW quartz-based pressure sensors has received a strong interest for many years, yielding various development using either delay lines or resonators. However, most approaches have been developed exploiting quartz machining along standard chemical or mechanical etching, rarely compatible with batch processes as used for Micro-Electro Mechanical Systems (MEMS). In this work, we propose a temperature/pressure sensor fabricated on compound Quartz/Silicon substrates obtained by Au/Au bonding at room temperature and lapping/polishing of Quartz. This approach allows for a collective and accurate production of sensors, the sensor sensitivity being controlled by the membrane thickness and diameter

In the first part, the device is presented with is conception. In the second part, sensor manufacturing and clean room process are detailed. In the third part, electrical results is presented and discussed.

2 Sensor description

The sensor consists of a clamped quartz membrane that is free to move and suspended over on a bulk micromachined silicon wafer. Act of the pressure on a circular membrane where is put an acoustic wave resonator induces inhomogeneous stress and changes the resonance frequency and the quality factor of the resonator.

The SAW resonator is placed in the center of a membrane, which is the most high strain area. The IDTs

(Inter Digital Transducer) are designed to generate Rayleigh waves at 433MHz.

To model the behavior of surface acoustic wave under inhomogeneous stress, a specific model was developed in our team. Perturbation method allows us to determine strain frequency shift expected in function of chosen quartz cut as shown in figure 1.

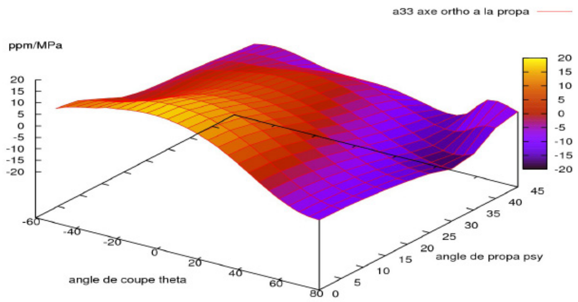


Figure 1: Strain frequency shift in function of chosen quartz cut.

Model allows us to determine the local stress (1), the mean stress (2) and the frequency shift (3). The frequency shift expected, with this model, is linear with applied pressure.

$$\sigma_r(p) = \frac{p}{8}\frac{6}{h^3}\left(R^2(1+\nu) - r^2(3+\nu)\right)z \quad (1)$$

$$\sigma_{res,r}(p) = \frac{1}{L_{res}d}\int_{-h/2+d}^{-h/2}\int_{0}^{R_{res}}\sigma_r(p)dzdr \quad (2)$$

$$\Delta f(p) = \sigma_{res,\theta}(p)S_{\alpha_{33}} + \sigma_{res,r}(p)S_{\alpha_{11}} \quad (3)$$

As the pressure is intricately connected with temperature, an objective estimation of this parameter requires accurate temperature measurements as well. As a consequence, the proposed sensor combines a reference resonator designed to be temperature compensated (AT, X cut of quartz) together with a resonator which propagation direction is chosen according the targeted temperature coefficient of frequency in order to give access to a linear differential temperature measurement. In addition, a third resonator with propagation axis along X is placed at the right center of a circular membrane. When the membrane is bent by pressure effects, the corresponding resonance frequency drifts linearly, allowing for another differential pressure measurement. Hence, with three resonators, one can easily demonstrate the unambiguous determination of temperature and pressure at once.

The structure of such device is showed in figure 2.

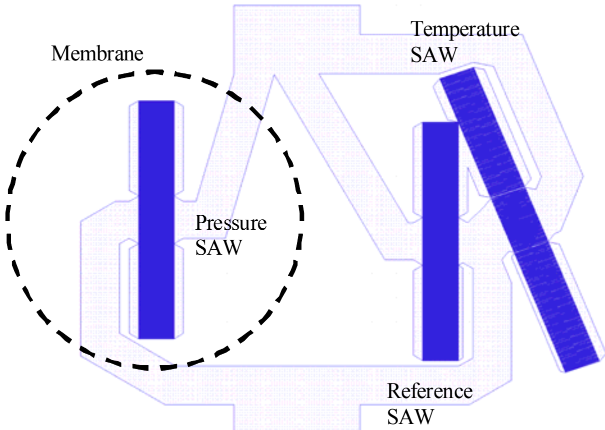


Figure 2: Structure of the device

3 Process Flow

Until now pressure sensor based on SAW with quartz material are unity processed. This process allows us a collective manufacturing of sensors as shown in figure 3.

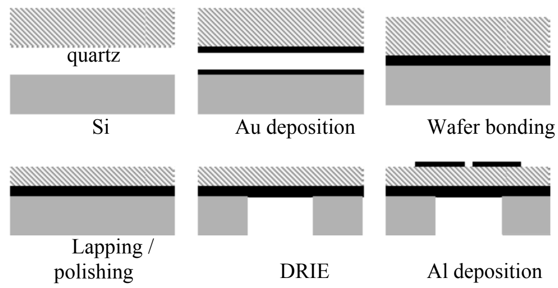


Figure 3: Process Flow

3.1 Bonding

We based our process on the bonding of two wafers. In this approach, we use optical polished surface to facilitate the bonding of the wafers. We start by a chromium and a gold thin layers deposited by sputtering on both quartz and silicon wafers. The quartz wafer is then bonded onto the silicon substrate using the thin gold layer with a thickness of 200 nanometers into an EVG wafer bonding machine as shown in figure 4. During the bonding process, we heat the material stack at a temperature of 30° C and we apply a pressure of 65 $N.cm^{-2}$ to the whole contact surface. We restrict the temperature at the temperature near the final temperature of the device use. It is due to the fact, the silicon and quartz material have different dilation coefficient temperature. To achieve the bonding, we use the time of the process to improve it.

Figure 4: Wafer Bonder EVG

This process yields a homogeneous and high quality bond. The reliability of the bonding is analyzed by ultrasonic non-destructive testing. The bonded wafers are immersed in a water tank and inspected by transmission method. The figure 5 presents photography of the bench. Two focalized transducers are used as emitter and receiver. They are manufactured by SONAXIS and have 15 MHz central frequency, 19 mm active diameter and 30 mm focal length. The beam diameter at focal distance at -6dB is about 200µm.

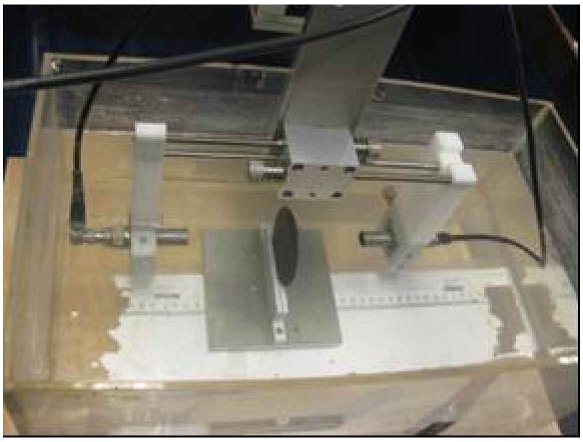


Figure 5: Ultrasonic characterization bench

This good lateral resolution permits to detect very small defects. The principle of the method is based on the measurement of the received amplitude that depends on the variation on the acoustic impedance of the two wafers. If the bonding presents a default at the interface between the two wafers, a dust or an air gap in most of cases, the reflection coefficient of the incident wave is then nearly 1. The amplitude of the received wave is then altered. The figure 6 shows a C-Scan of silicon/quartz wafer bonding characterization. The red color corresponds to bonded surfaces, the white color to saturating signal when the ultrasonic beam is in a membrane or outside the wafer, blue and green to bonding defects.

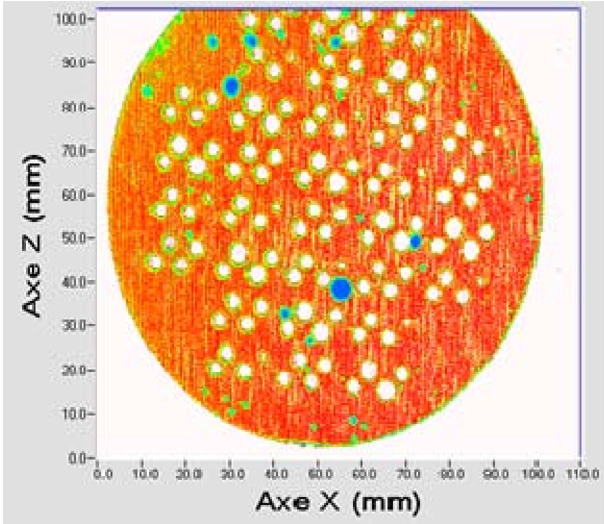


Figure 6: Characterization of the bonding

This method presents three major advantages:

- The control of the bonding can be made during the polishing steps without destruction; or the control can be done at the end of the process, indeed, the different layers obtained by sputtering do not disturb the measure.
- There is no limitation of the temporal resolution of the transducers with the wafers thickness as in pulse-echo method.
- The analysis of the ultrasonic echoes is very simple because only the amplitude of the first detected signal is measured.

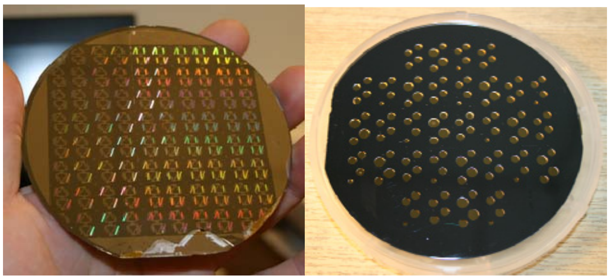
3.2 Lapping/polishing

It is subsequently thinned by lapping step to an overall thickness of 100 microns. The lapping machine is shown in figure 7. We use abrasive solution of silicon carbide. We can control the speed of the lapping by choosing the speed of rotation, the load on the wafer, the rate of flow or the concentration of the abrasive. It is then followed by a micro-polishing step. This step uses other abrasive solution with smaller grain.

Figure 7: SOMOS lapping/polishing machine

End of the process flow

We continue with a Deep RIE to etch silicon to form membranes. To do that, we use aluminum mask of 100nm thickness obtained by lift-off. Aluminum electrodes are deposited on the quartz to achieve three SAW resonators. The figure 8 shows the final wafer aspect.



(a) (b)

Figure 8: (a) SAW resonators (wafer stack top side), (b) Membranes (wafer stack back side)

4 Electrical characterization

The electrical characterization was done with a ROHDE&SCHAWARZ vector network analyzer. We characterize SAW resonators on reflection.

We start on ambient temperature without pressure to have references. The figure 9 shows these electrical results.

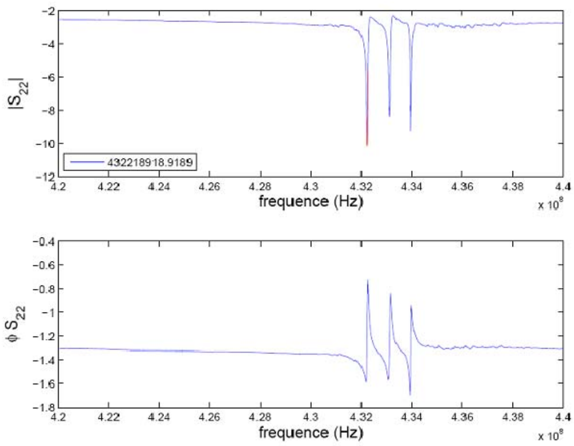


Figure 9: Electrical results

We use a pressure bench to apply relative pressure on the devices. We characterized device between 1 to 4 bars. The figure 10 shows frequency variation due to pressure variation on the membrane of the device for the three SAW resonators.

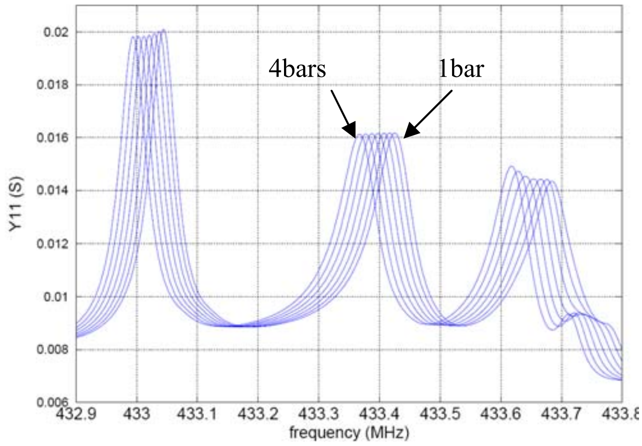


Figure 10: Frequency variation of all SAW resonator vs pressure variation

The figure 11 shows frequency variation due to pressure variation on the membrane of the first resonators. We obtained a frequency shift of 17kHz/bar. As predicted, shift frequency dependency is linear.

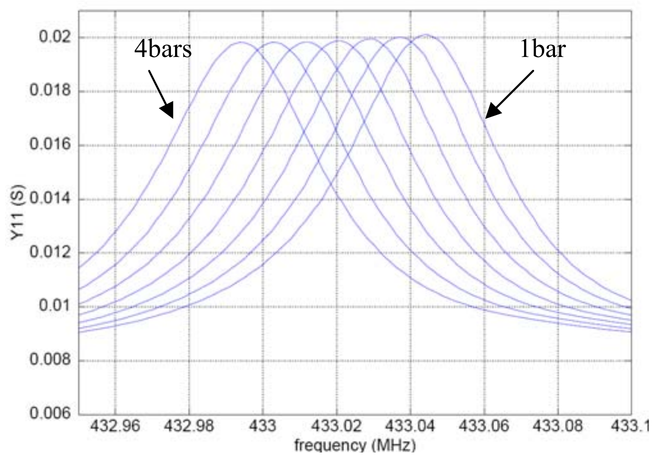


Figure 11: Frequency variation of the first picks of resonance vs pressure variation

Conclusion

We present in this paper a collective manufacturing to obtained membrane based on the lapping/polishing of a bonding wafer. This approach allows us a freedom on the choice of the membrane nature. In our case, we use quartz to manufacture SAW resonator with frequency resonance around 433MHz as expected by conception. We also show the frequency variation due to stress in the membrane due to pressure.

Acknowledgements

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