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Thin quartz resonators as detector element for thermal infrared sensors

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Summary:
In this work, we describe the technology and packaging of a quartz sensor with a thickness of 5 µm. The temperature dependence of the resonance frequency of quartz resonators can be used for thermal radiation sensors. The sensitive element in the form of a bowl or a cantilever is ion beam etched and must be able to vibrate freely. Impedance measurements show the vibration of the 5 µm thick resonators, however highly damped and with a low quality factor.

Keywords: quartz resonator, thermal infrared sensor, ion beam etching, packaging, impedance spectrum

Introduction

Thermal radiation sensors absorb infrared radiation which results in a temperature change in the responsive element. Depending on the used physical effect the change of a physical quantity is usually transformed in a signal voltage, i.e. in pyroelectric sensors.

Quartz resonators on the other hand use the temperature dependence of the resonance frequency of piezoelectric oscillators. Frequency can be measured with great accuracy. These sensors stand out by a high specific detectivity *D** whereby very small radiation fluxes can be detected. Quartz bulk sensors with Y-cut and a thickness of 7 µm achieved a value of $D^* = 9 \cdot 10^7$ cmHz$^{1/2}$W^{-1} [1].

Goal of this work is the improvement of sensor parameters which directly influence the sensitivity like quartz thickness decreasing, thermal conductance between sensor and environment and the absorption coefficient.

Here, we present a technological procedure for manufacturing quartz sensors with a thickness of 5 µm with both plate and beam-like structures.

Manufacturing Technology

Starting point for the fabrication of the resonator devices are quartz wafers with a size of (20 x 20) mm² and a thickness of 500 µm (Quarztechnik Daun GmbH, Daun, Germany). They are thinned down to a thickness of 20 µm by lapping and polishing and cut to chips with a size of (4 x 4) mm². The chips are structured by photolithography followed by depositing thin films or by removing material. Electrode films of NiCr and Au are deposited by thermal evaporation. Structures like bowl-like cavities and trenches are ion beam etched.

In a first step, sensors were build up with unstructured quartz chips after each technology step (lapping, polishing, etching) to investigate their influence on the vibration because the crystal structure may be damaged by processing its surface [2]. However, our measurements showed no influence on the vibration.

After that, two sensor layouts were implemented:

- In the first layout, the front and back electrode form a cross. The sensitive element is the overlapping part where a bowl with a thickness of 5 µm is etched in the chip (Fig. 1a). The sensors are build up on a TO8 holder. A substrate is glued on the holder and the quartz chip is put on silicon rods so that it can vibrate freely (Fig. 2a).
- The second layout consists of a 5 µm thin cantilever which is connected to the thicker frame by a narrow bridge (Fig. 1b). The trench between cantilever and frame keeps the sensitive element thermally isolated. Here, the frame is firmly fixed on a substrate with a deepening in the middle leaving the cantilever versatile (Fig. 2b). This layout has been used successfully for pyroelectric $LiTaO_3$ sensors [3].

Before the 5 µm thin quartz chips were manufactured, the technology had been tried out with 80 µm thick chips.

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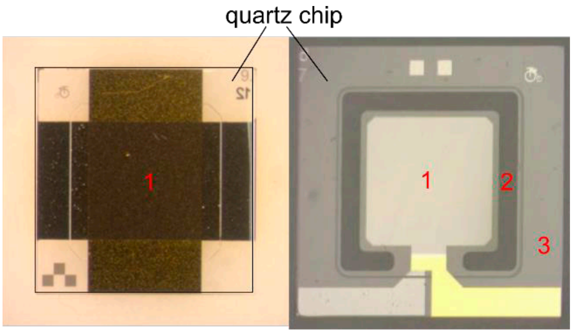
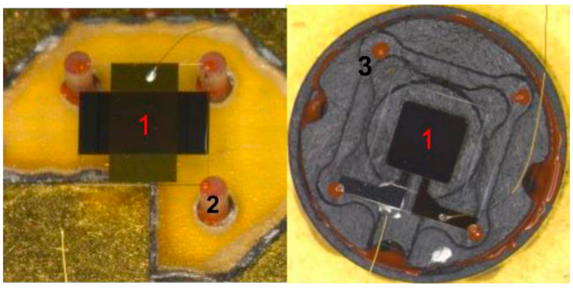


(a) (b)

Fig. 1. Two sensor layouts: a) sensitive element (1) as a bowl and (b) sensitive element (1) as a cantilever with trench (2) and frame (3).



(a) (b)

Fig. 2. Sensor packaging for a) first layout with quartz chip (1) on silicon rods (2) and for b) second layout with quartz chip (1) fixed on substrate (3).

Measurement Results

The fundamental resonance frequency of a quartz crystal vibrating in thickness mode is determined by

$$f_r = \frac{1}{2d}\sqrt{\frac{c}{\rho}}, \qquad (1)$$

where d is the thickness of the quartz plate, c the Young's modulus and ρ the density [4].

Impedance measurements show the resonance frequency and the quartz parameters may be derived from them.

The following results refer to the first sensor layout with the bowl. The impedance spectrum of a sensor with a quartz resonator thickness of 80 µm shows a distinct peak at 25 MHz (Fig. 3a). The sensors with 5 µm thin sensitive elements which corresponds to a frequency of 370 MHz develop only a small and broad peak, however (Fig. 3b). In the latter case, the quartz crystal vibrates highly damped and with a low quality factor.

Measurements with the second sensor layout are going to follow which should improve the vibration amplitude.

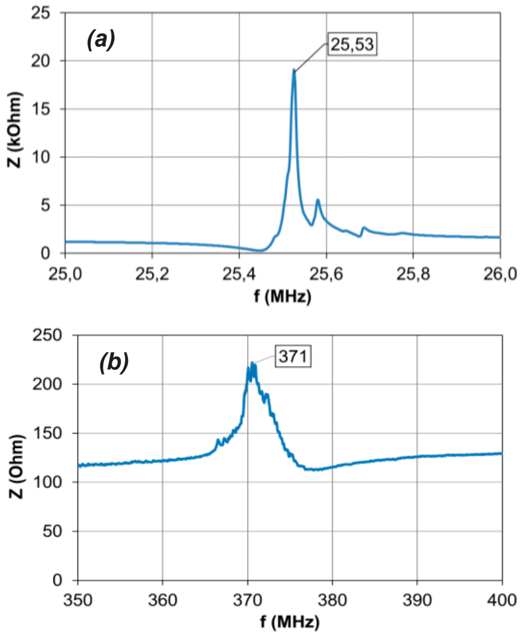


Fig. 3. Impedance spectrum (absolute value of the complex impedance Z) of a quartz resonator with a thickness of (a) 80 µm and (b) 5 µm.

Conclusions

Quartz chips were successfully thinned down to 5 µm by lapping, polishing and ion beam etching. Sensors with two different layouts were build up. 80 µm thick quartz resonators show a strong peak in their impedance spectrum, whereas the vibration of the thin crystals is highly damped. An optimized sensor layout and packaging should improve the vibration quality.

Acknowledgement

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