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Wireless MEMS Quartz Crystal Microbalance Sensor Chip Fabricated by Wafer-Level Packaging Process

ウェハレベルパッケージプロセスにより製作した無線駆動MEMS 水晶振動子センサチップ

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1. Introduction

The quartz crystal microbalance (QCM) is a mass detection type sensor, and it is widely used for real-time, label-free, and quantitative analysis for biomolecular reactions.[1)] The mass sensitivity of the QCM is inversely proportional to the square of the thickness of the quartz-crystal oscillator.[2)] Therefore, as the thickness of the quartz crystal oscillator becomes thinner, the sensitivity significantly increases. Commercially available QCMs have metal electrodes on the oscillator surfaces, for excitation and detection of the vibrations, and the quartz crystal oscillator is mechanically fixed in the measurement cell. Therefore, they contain several issues from the perspective of further increasing sensitivity. Specifically, the metal electrodes show much larger thermal expansion coefficients and temperature coefficients of velocity, deteriorating the temperature stability of the oscillator. The electrodeless QCM has been then developed to improve these issues.[3-5)] We proposed to fabricate the wireless-electrodeless QCM by micro-electro mechanical systems (MEMS) technology and nanoimprint lithography technology (NIL). These QCMs show original structures; a thin quartz crystal oscillator is supported by the micropillars without mechanically fixing it in the microchannel made of glass-silicon-glass substrates or siloxane resin. The quartz crystal oscillator is excited by the electromagnetic wave applied from antenna located outside the QCM chip via the inverse piezoelectric effect. At the same time, the electric potential generated via the piezoelectric effect on the surface of the quartz crystal oscillator is detected by another separeted antenna.

The prevous MEMS QCM chip was packaged manually, so that the thickness of the oscillator is limited to be about 10 μm or larger. Therefore, in this study, in order to further increase the sensitivity of electrodeless QCM, we propose a revolutional MEMS process to package thiner quartz crystal oscillator in the microchannel without involving manual processes. In establishing this technology, we focused on the wafer-level package (WLP) process in MEMS technology.

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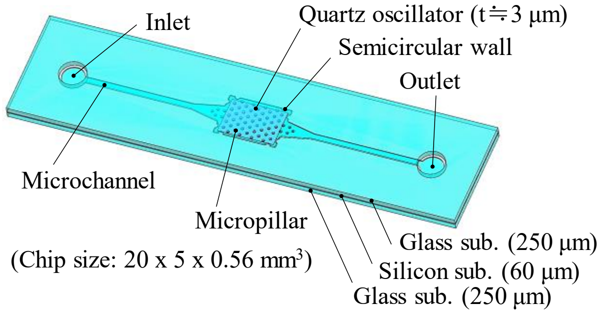

Fig. 1 Schematic of wireless MEMS QCM chip.

2. MEMS QCM and Fabrication

Figure 1 shows the electrodeless MEMS QCM chip fabricated by WLP. The electrodeless MEMS QCM chip is composed by the glass substrate (250 μm), which forms the upper microchannels, and a multilayer substrate of bounded 60-μm silicon substrate and (60 μm) and 250-μm glass substrate, which forms the lower microchannels. A single chip dimensinos are 20 mm in length, 5 mm in width, and 0.65 mm in thickness. The dimensions of the quartz crystal oscillator which are 2.5 mm in length, 1.7 mm in width, and 3 μm in thickness. In the microchannel, we form several micro pillars by etching glass and silicon substrates, which lightly support the quartz crystal oscillator. **Figure 2** shows the WLP process steps we propose: (a) The AT-cut quartz crystal substrate is bonded to a silicon substrate via a resin adhesive layer, and the the quartz crystal substrate is polished to a desired thickness by chemical mechanical polishing (CMP). (b) The resist mask is formed on the quartz substrate by the photolithography. (c) The quartz crystal substrate is processed into a desired oscillator shape by the dry etching. Thereafter, the resin adhesive layer is removed by the oxygen plasma ashing process. (d) The resist mask is removed. (e) The photosensitive polyimide is made, and it is cured by heat treatment. (f) The polyimide layer is patterned into a desired shape on the quartz crystal substrate by the photolithography. The polyimide patterns are used as the adhesive parts and the sacrificial layer. (g) The quartz crystal substrate and the upper glass substrate with through holes are bonded at the micropillar surfaces via the polyimide patterns. (h) The silicon substrate is removed by the dry etching. (i) Thereafter, the resin adhesive layer is removed by the oxygen plasma ashing process. (j) The lower channel substrate (composed of the silicon and glass substrates) and the glass substrate (with the quartz crystal oscillators bounded on the micro pillars) are bonded by the anodic bonding method. (k) Finally, the polyimide sacrificial layer is removed by flowing the removal solution in the microchannel.

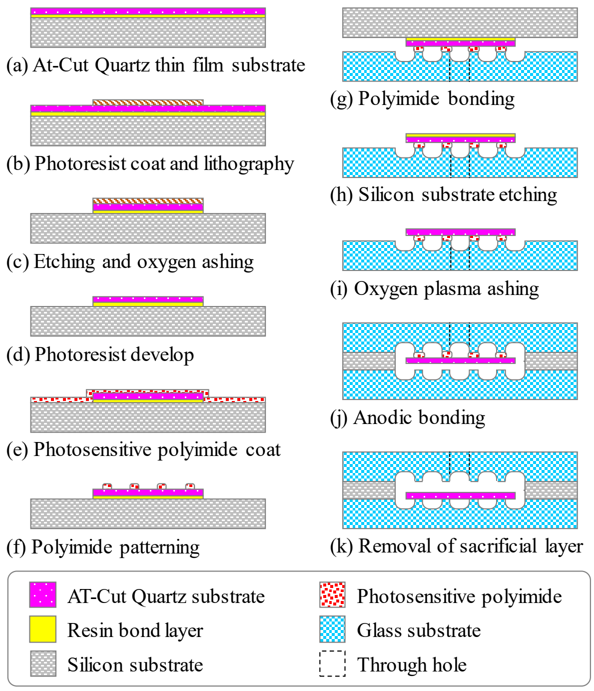

Fig. 2 Wafer-level package process steps using polyimide sacrificial layer.

3. Results and Discussion

Because the polyimide shows excellent heat and corrosion resistance, it is generally used as a permanent film in the MEMS process. Therefore, removal after patterning has never been assumed. However, in this study, we focused on the characteristics that polyimide can withstand high temperature (400-450 °C) applied at anodic bonding and can be used as the adhesive between substrates, and we used the polyimide as the sacrificial layer. We have found that the polyimide can be removed by using a specific basic solution. **Figure 3** shows an example of the resonance spectrum when operating the wireless MEMS QCM chip fabricated by WLP.

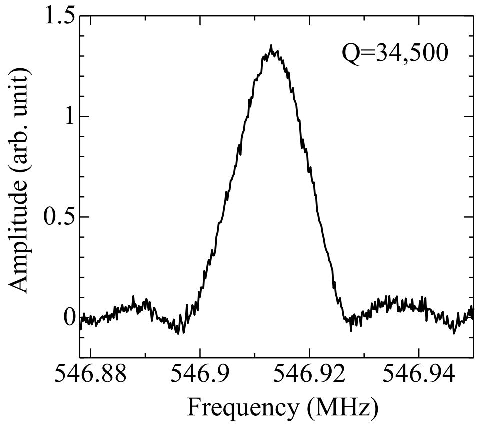

Fig. 3 Resonance spectrum of wireless MEMS QCM chip in the atmosphere.

The Q-factor in the atmosphere at the fundamental resonance frequency near 550 MHz exceeds 30,000. This result indicates that the wireless MEMS QCM chip fabricated by WLP has great possibility of high sensitivity and high resolution measurements.

4. Conclusion

We proposed the WLP process using the polyimide sacrificial layer, and succeeded in fabricating the wireless MEMS QCM chip with 3 μm AT-cut quartz resonator, showing the fundamental resonance frequency of about 550 MHz. It was found that a high Q-factor, exceeding 30,000, can be obtained in the atmosphere as a result of evaluating the resonance characteristics by the wireless operation. The WLP process established in this study is a revolutionary fabricating technology for mass production of the wireless MEMS QCM chip.

Acknowledgment

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