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Development of Wireless Quartz Crystal Microbalance Sensor with Antenna-Embedded PDMS Microchannel

アンテナ埋め込み型 PDMS 微細流路有する無線駆動水晶振動子センサの開発

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1. Introduction

The quartz crystal microbalance (QCM) is a mass detection sensor that detects mass loading due to the adsorption of the target substance on the surface of the quartz oscillator as the change in resonance frequency. Because the sensitivity of QCM is inversely proportional to the square of the quartz thickness, the sensitivity can be increased as the quartz thickness becomes thinner. However, as the thickness becomes thinner, the mass of the attached metallic electrodes for exciting the quartz oscillator increases relatively, and as a result, deteriorating the mass sensitivity of the QCM sensor. Consequently, the thickness of the quartz oscillator used in commercially available QCM is about 60-330 μm. Therefore, to achieving even higher sensitivity, the wireless QCM operated by the electromagnetic wave (EM-wave) have been developed.[1, 2] The wireless QCM is characterized by a structure in which a thin quartz oscillator (30 μm or less) is packaged in the microchannel fabricated by the semiconductor micro fabrication and supported by the micropillars. Because the wireless QCM has no electrodes on the quartz surface and does not mechanically fix the quartz plate, a thin quartz oscillator can be used. As a result, the wireless QCM has achieved higher sensitivity than the commercially available products. In addition, the wireless QCM made of silicone resin (polydimethylsiloxane (PDMS)), which was inexpensive and fabricated by a low-temperature process, was developed, and shown to be useful as a biosensor.[3] However, because the wireless PDMS-QCM has the thin laminated structure of the silicone resin, it has low rigidity and requires a thickness of about 3 mm. Therefore, the distance from the antennas for transmitting and receiving the EM-waves to the quartz oscillator had to be about 1.5 mm, and as a result, the efficiency in transmitting and receiving was low. Accordingly, its operation was limited in gasses, and it was difficult to adopt the wireless PDMS-QCM in the solutions. In order to address this issue, in this study, we propose a wireless PDMS-QCM, in which the antennas are embedded in the PDMS layer to achieve effective transmission and reception of the EM-waves near the quartz oscillator.

2. QCM with Antenna-Embedded Microchannel

Figure 1(a) shows the schematic diagram of the wireless PDMS-QCM chip in which the electrodes (antennas) are embedded in the PDMS substrates. A thin quartz oscillator (t= 25 μm) was loaded into the PDMS microchannel, and the vicinities of the four corners of the quartz plate were locally supported by the micropillars. **Figure 1(b)** shows the cross-section of the wireless PDMS-QCM chip. The embedded electrodes were made of aluminum, and the surfaces of the electrodes were anodized for the purpose of improving corrosion resistance. However, each surface of the embedded electrode exposed at the upper or lower surface of the wireless PDMS-QCM chip had the aluminum part bared.

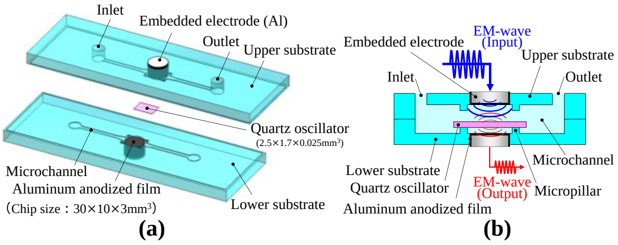

Fig. 1 Schematic diagram of wireless PDMS-QCM chip: (a) Chip configuration, and (b) chip cross-section.

The quartz oscillator was excited by applying the EM-wave to the upper embedded electrode using the network analyzer. In addition, the electric charge excited on the surface of the quartz oscillator which vibrates at a resonant frequency, was detected wirelessly via the lower embedded electrode. Because the electrodes were embedded in the PDMS substrate, EM-wave can be applied from the vicinity of the quartz oscillator and the electric charge can be detected, therefore the wireless operation can be

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performed more effectively than conventional PDMS-QCM chip.

3. Device Fabrication

The mold to form the microchannel was fabricated by nanoimprint lithography (NIL) using the epoxy photoresist (SU-8, MicroChem) (**Fig. 2(a)**). The PDMS (Silpot 184, Dow) prepolymer was injected into the mold, and degassed in the vacuum desiccator (**Fig. 2(b)**). At this time, the columnar electrode parts were placed at the microchannel where the quartz oscillator was going to be installed (**Fig. 2(c)**). Thereafter, the hot plate was used to prebake at 80 °C, and then the oven was used to cure PDMS at 85 °C (**Fig. 2(d)**). After the cured PDMS was peeled off from the mold, it was cut to the chip size and the quartz plate was placed in the microchannel (**Fig. 2(e)**). The plasma cleaner was used to excite the functional groups on the bonding surfaces of the upper and lower PDMS microchannel substrates by performing the plasma treatment for 5 minutes (**Fig. 2(f)**). The upper and lower PDMS microchannel substrates were directly bonded via the hydrogen bond by superposing them at room temperature (**Fig. 2(g)**), and the solution did not leak during liquid transfer. After that, the dehydration reaction proceeds by the heat treatment, the covalent bonds are formed at the bonding interface via the oxygen atoms, and the bonding strength can be significantly improved.

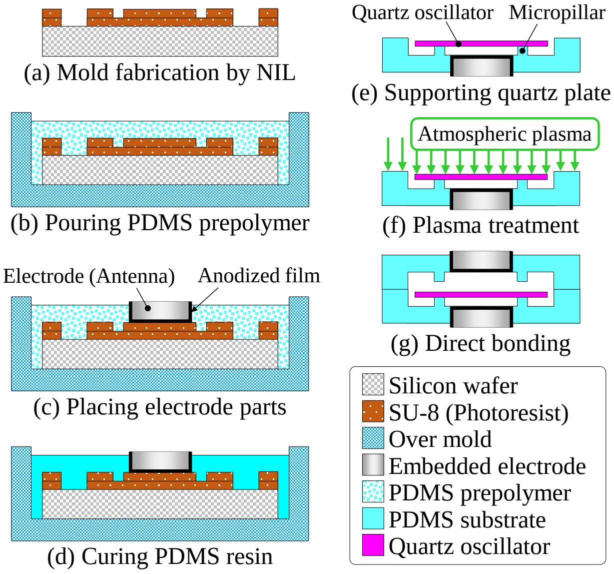

Fig. 2 Fabrication steps of wireless PDMS-QCM chip.

4. Results and Discussion

The board-type network analyzer (custom-made, Advantest) was used to measure the resonance spectrum of the wireless PDMS-QCM chip. **Figure 3(a)** shows the resonance spectrum measured in the atmosphere, and the quality factor (Q-factor) was about 11,400. On the other hand, **Fig. 3(b)** shows the resonance spectrum when the distilled water (DW) was injected in the microchannel, and the Q-factor was about 890. The conventional wireless PDMS-QCM chip without the embedded electrodes required a gap of about 1.5 mm from the copper foil antennas for transmitting and receiving the EM-waves to the quartz oscillator. Therefore, the transmission and reception efficiency of EM-waves using the small network analyzer was low, and it was difficult to measure the resonance spectrum with the chip filled with DW in the microchannel. As a result, the large device capable of transmitting and receiving high-power EM-waves was required. Because the electrode-embedded wireless PDMS-QCM chip fabricated in this study could transmit and receive the EM-waves near the quartz oscillator, the resonance spectrum could be measured even when the microchannel is filled with the DW.

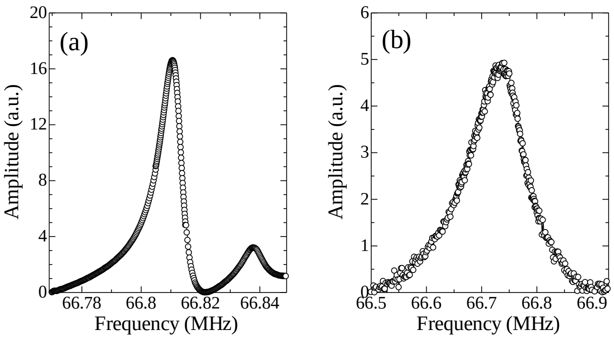

Fig. 3 Resonance spectra: (a) In atmosphere, and (b) in distilled water.

5. Conclusion

For the electrode-embedded wireless PDMS-QCM chip, we succeeded in obtaining the resonance spectrum with distilled water filled in the microchannel using the small network analyzer. This chip is capable of cost reduction and can be fabricated with the low temperature process; therefore, it is expected to greatly contribute to the development of wireless QCM in the future.

Acknowledgment

This study is partially supported by the Amada Foundation Grant Number AF-2018030-B3 and JSPS KAKENHI Grant Number 21K04896.

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