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PDMS Microchannel QCM Chip Using Embedded Anodized Aluminum Antennas

Tomoya Aoki[1†], Yu Qi[1], Noriyasu Masumoto[1], Fumihito Kato[1], and Hirotsugu Ogi[2]
([1]Dept. Mech. Eng., Nippon Inst. of Tech.; [2]Grad. Sch. Eng., Osaka Univ.)

1. Introduction

The quartz crystal microbalance (QCM) sensor is one of the sensors that can measure reactions between biological molecules such as antigen-antibody reactions in real time and quantitatively evaluate the affinity[1)]. The QCM sensor can detect the change in the mass of the quartz resonator due to the adsorption of substances on the surface of the quartz plate which vibrates in the thickness shear mode as the resonant frequency changes. Because the sensitivity of the QCM sensor is proportional to the reciprocal of the square of the quartz thickness, the sensitivity improves as it becomes thinner[2)]. However, it is difficult to improve the sensitivity of conventional QCM sensors due to the structure of the device. Because metallic electrodes are formed on both sides of the quartz resonator, their inertial resistance increases relatively as the quartz thickness decreases, making it difficult to excite the quartz resonator. Additionally, because temperature characteristics are caused by the difference in the thermal expansion coefficient between the quartz resonator and the metal electrode, it is necessary to the temperature compensation of the measurement cell, which makes the apparatus large. Furthermore, because the quartz resonator is mechanically fixed to the measurement cell in conventional QCM systems, the quality factor deteriorates due to structural damping. To improve these issues, the wireless electrodeless QCM sensor was developed[3)]. This sensor is loaded with a blank AT-cut quartz resonator supported by micropillars in a microchannel made of silicon/glass/silicon multilayer substrate. The quartz resonator is excited by applying electromagnetic waves from the antenna attached to the upper substrate of the sensor chip, and then electric charges generated on the quartz surfaces are detected by the antenna attached to the lower substrate. Because the quartz resonator has no electrodes, a thin quartz plate with a thickness of 10 μm or less can be used, and because temperature compensation is not required, the measurement apparatus can be miniaturized. In addition, because the quartz resonator is loaded in a microchannel constructed of rigid substrates, it will not be damaged during handling. The quartz resonator does not cause structural damping because it is not mechanically fixed in the microchannel. However, when the quartz resonator is loaded in the microchannel and packaged, the fabrication process at several hundred degrees Celsius is required, making it difficult to immobilize proteins such as biomolecules on the surface of the quartz resonator in advance. In this study, to improve this issue, the wireless electrodeless QCM chip in which a quartz resonator is loaded in a microchannel made of silicone resin and packaged at room temperature is fabricated. In addition, by embedding columnar antennas in silicone substrates, the efficiency of transmitting and receiving electromagnetic waves to the quartz resonator is improved.

2. Wireless PDMS-QCM chip with embedded antennas

Figure 1 shows the configuration of the wireless PDMS-QCM chip fabricated by nanoimprint lithography using polydimethylsiloxane (PDMS) which is a silicone resin. This chip consists of five main parts. It is PDMS upper and lower substrates, a pair of columnar antennas, and an AT-cut quartz resonator (2.5×1.7×0.025 mm^3).

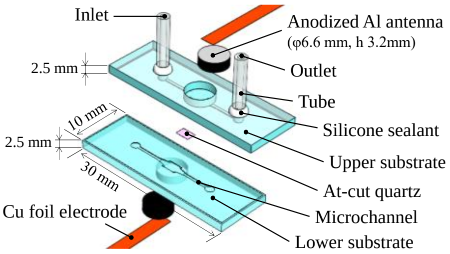

Fig.1 Configuration diagram of the wireless PDMS-QCM chip with embedded antennas.

The wireless PDMS-QCM chip fabricated earlier had columnar embedded antennas with an outer diameter close to the width of the quartz resonator[4)]. Therefore, when connecting signal cables to columnar antennas, the stress acts on them, causing the microchannel to deform. As a result, the resonant spectrum in the solution could be measured, however the resonant frequency change could not be detected even if the solutions with different viscosities were fed into the microchannel. In this study, the diameter of the columnar antennas was changed from φ 2.6 mm to φ 6.6 mm to improve the rigidity of upper and lower substrates so that the microchannels would not be deformed. Using the

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E-mail: kato.fumihito@nit.ac.jp

developed the wireless PDMS-QCM chip, we evaluated whether the difference in viscosity between a glycine-HCl buffer (GHB) solution and ultrapure water (UW) could be detected as the change in resonant frequency. Differences in viscosity also affect the resonant frequency, however it is thought that differences in pH and polarity (i.e., polarizability) greatly affect the electrical boundary conditions and thus the resonant frequency.

3. Experimental

Figure 2 shows experimental configuration for measuring the resonant frequency change in real time while sending the solution. In this experiment, GHB solution, which can release the specific binding between proteins, and UW were used as solutions with different viscosities (η_{Water}: about 1 mPa·s, η_{GHB}: Not disclosed by the manufacturer). GHB solution was injected in the microchannel after confirming that the resonant frequency was in a steady state while sending UW at a flow rate of 0.35 ml/min. After confirming that the resonant frequency rose sharply due to the difference in the solution viscosity and then the slope became gentle, UW was injected. After that, the resonant frequency dropped sharply and then returned to a steady state. The above-mentioned injections of GHB solution and UW were performed twice continuously, and the resonant frequency changes were measured in real-time.

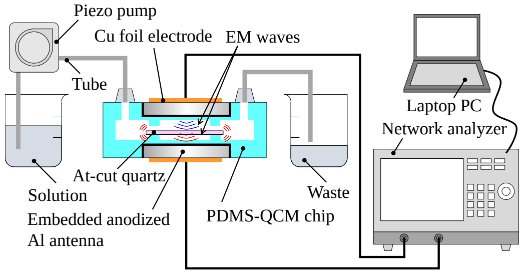

Fig.2 Measurement setup.

4. Results and discussion

In the previously fabricated wireless PDMS-QCM chip, after the signal wires were connected to antennas, even a slight load applied to the antennas caused a large change in the intensity of the spectrum. In the wireless PDMS-QCM chip fabricated in this study, the intensity of the resonant spectrum hardly changed even when a load was applied to the antennas. This improvement was achieved by increasing the outer diameter of the columnar antennas on the newly manufactured chips. Specifically, this was because the microchannel did not deform even when the load acted on the antennas. Therefore, the upper and lower surfaces of the microchannel do not come into contact with the quartz surface due to the deformation of the microchannel. The gap of several hundred μm between the quartz resonator and the microchannel is not blocked, and liquid can be sent. Therefore, when solutions with different viscosities are sent, the frequency change caused by the difference in viscosity can be detected. **Figure 3(a)** shows the result of evaluating the change in resonant frequency caused by the viscosity difference using UW and GHB solution. **Figure 3(b)** shows the frequency fluctuation when UW is sent. The measurement resolution was about 15 ppm. Higher resolution can be obtained by decreasing the flow rate and increasing the number of measurements averaged. After the baseline was obtained by sending UW, when GHB solution was injected, the resonant frequency increased by about 400 ppm. And then, when UW was sent, the resonant frequency decreased by about 350 ppm. After this frequency change, a steady state was obtained, however it changed by about 50 ppm from the baseline when initially sending UW. This baseline change was thought to be due to drift. When GHB solution was injected again, the resonant frequency increased by about 380 ppm. Subsequently, by sending UW, the resonant frequency decreased by about 310 ppm and a steady state was obtained. From the above results, the wireless PDMS-QCM chip embedded with the anodized Al antennas fabricated in this study succeeded in detecting the frequency change caused by the difference in viscosity.

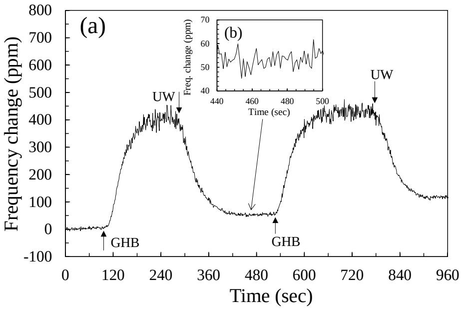

Fig.3 (a) Frequency response when sending solutions with different viscosities and (b) frequency fluctuation.

5. Conclusion

Using UW and GHB solution with different viscosities, the change in resonant frequency was measured in real time. As a result, rapid changes in the resonant frequency due to the viscosity differences were obtained. In the future, we will evaluate the usefulness as a biosensor by measuring reactions between biomolecules in real time.

References

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