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Fundamental Study of Magnetic Drive Micropump for Integration of Quartz Crystal Microbalance Sensor
水晶振動子センサ集積化における磁気駆動型微小ポンプの基礎的研究

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1. Introduction

The Commercial Quartz Crystal Microbalance (QCM) sensors have the gold electrodes on both surfaces of the thin quartz oscillator. The quartz oscillator can be excited in thickness shear vibration because it is a piezoelectric material. The QCM sensor is the mass detection sensor, and so can detect the mass adsorbed on the quartz surface quantitatively as the resonance frequency change. It is important to find out serious diseases such as cancer and diabetes at an early stage, and various biosensors are used for early detection. When the cancer occurs in the body, the specific protein is secreted from the disease part. Therefore, if this protein can be detected with high sensitivity, early treatment becomes possible. One candidate for the sensor which allows detection of the specific protein with high sensitivity is the QCM biosensor. In the recently, the wireless-electrodeless QCM biosensor, which has the high-frequency quartz oscillator, which is supported by the micro-pillars without fixing mechanically, packaged in the microchannel made of poly(dimethylsiloxane) (PDMS), was developed.[1)] However, the thin quartz oscillator inside the sensor chip is easy to break, when connecting with the feed-pump or other equipment, because the sensor chip is fabricated with PDMS which is the flexible silicone resin. Therefore, the integration of the QCM biosensor chip and feed-pump is absolutely required. In recent years, the micro-electro-mechanical systems (MEMS) technology has developed and the studies of integration with various sensors into a chip have been investigated. For example, the thing which integrated MEMS and heaters to warm has been already developed. For example, Lab-on-a-Chip (LOC) is the prime example.[2)] However, there is no study that integrates the QCM sensor and feed-pump. Accordingly, we carried out fundamental study on micro feed-pump for integration of the PDMS QCM biosensors chip in this research.

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2. Magnetic drive micropump

The device to be developed is the micro feed-pump which rotates the resin-made rotor by the neodymium magnet and an electromagnet to obtain liquid transfer force. We are planning to combine between the PDMS biosensor chip and micro feed-pump directly by the surface activated bonding. The micro feed-pump in this study features the structure in which the neodymium magnets are embedded in the resin-made rotor without using a motor. The electromagnets installed outside the feed-pump sequentially changes the polarity and rotates the resin-made rotor. The micro feed-pump without pulsation can be realized by adopting such the structure and driving principle. In addition, the large torque can be obtained by making the neodymium magnet away from the center of the resin-made rotor.[3)] **Figure 1** shows the schematic of the micro feed-pump integrated with the PDMS biosensor chip. The micro feed-pump has a height of 30 mm, width 30 mm, and depth 30 mm. And the inner diameter of the solution supply tube is 2 mm. The acrylic resin is applied as the base material.

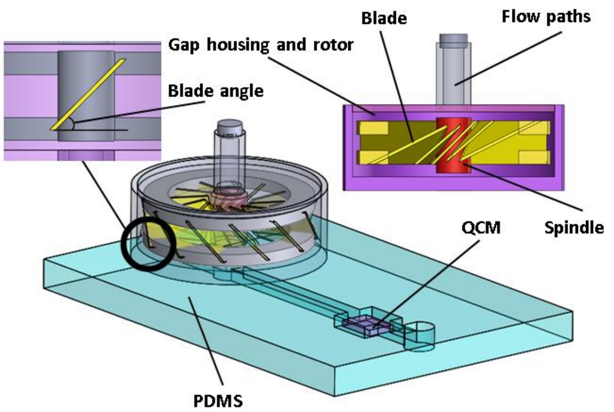

Fig. 1 The structure of solution feed-pump integrated with PDMS QCM biosensor chip.

3. Simulation

In order to design the micro feed-pump, the simulation was performed using the fluid analysis software (SolidWorks, Dassault Systemes, S.A.)

with the gap between the resin-made rotor and housing, the blade angle, and the spindle diameter as parameters. Assuming that the fluid is water, the following values were used as material characteristics. The viscosity is 1.002 mPa・s, the kinematic viscosity is 1.004 mm^2/s, and the density is 0.9982 g/cm^2. As the boundary condition, the simulation was performed assuming that the inside of feed-pump is the rigid wall (i.e., immovable object). However, the boundary condition was not applied to the rotor with several blades. The rotation speed of the resin-made rotor was set at 100 rpm. In this simulation, the flow rate and pressure at the fluid outlet were calculated. At first, the gap between the resin-made rotor and housing was calculated, because the principal purpose is the miniaturization of the feed-pump (**Fig. 2**).

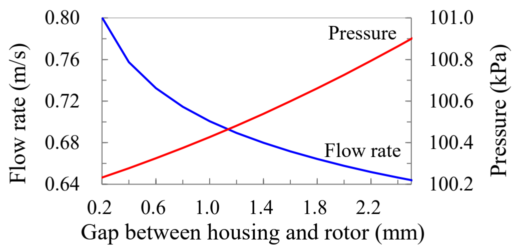

Fig. 2 Relationship between the gap and flow rate, and pressure.

Subsequently, the relationship between the blade angle and resin-made rotor was calculated considering the results in **Fig. 2** (**Fig. 3**).

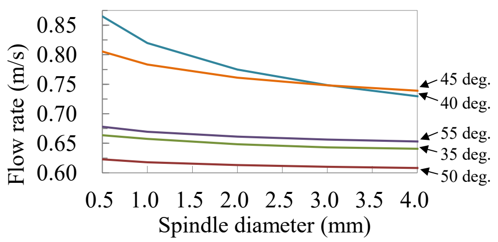

Fig. 3 Relationship between the spindle diameter and flow rate, and blade angle.

Finally, the relation between the spindle diameter and the flow rate, and also between the spindle diameter and the liquid pressure, at the blade angle of 45 degrees were calculated (**Fig. 4**).

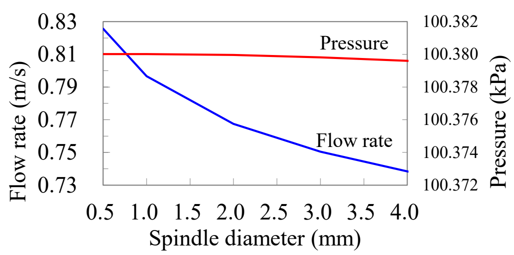

Fig. 4 Relationship between the spindle diameter and flow rate, pressure.

4. Results and Discussion

Figure 2 shows that the narrower the gap, the less the stagnation of the fluid and the higher the flow rate. Although the flow rate increases as the gap is narrow, the gap was decided to 0.8 mm considering that the resin-made rotor parts are manufactured by the 3D printer. Based on this gap, the blade angle was decided to 45 degrees from the relation between the spindle diameter and blade angle in **Fig. 3**. This is because the flow rate is realized stable and high value at 45 degrees of the blade angle, even if the manufacturing tolerance of the spindle diameter is large. The spindle diameter was decided to be 2.5 mm from the perspective of smooth fluid transfer and precision in manufacturing parts considering results in **Fig. 4**.

5. Conclusion

We proposed the magnetic drive micro pump for the integration of the PDMS QCM biosensor chip, and then decided better gap between the rotor and housing, blade angle, and spindle diameter through the fluid analysis. Based on the results in this study, we will manufacture small feed-pump, combine with sensor chip by the direct bonding, and then evaluate the integrated chip.

Acknowledgment

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