Determination of liquid viscosity with microfabricated diaphragm resonating sensors for the biomedical application

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There has been growing interest of an accurate and rapid viscosity monitoring of liquid medium in various fields such as, oil industry, medicine, and food industry [1,2]. Especially, the blood viscosity is essential factor to diagnose and monitor the cardiovascular diseases (hypertension, ischemic heart disease, and acute myocardial infarction). In spite of the importance of blood viscosity information, there is some quite a sure method for measurement of blood viscosity. Recently, because conventional rheometers have some limitation for application in these fields, microresonator-based viscosity measurement technique has been in the spotlight. Microresonators such as, microcantilever, microbridge, or microdiaphragm have been used to probe the viscosity of liquids by measuring the resonant frequency change of microresonators. The resonant frequency of microresonators can be changed by viscosity and density of surrounding liquid.

Here we developed piezoelectric layer-embedded microdiaphragm resonating sensor for liquid viscosity monitoring. With fabricated microdiaphragm sensors, we monitored the resonant frequency change caused by liquid viscosity change when the liquid solutions with various viscosities were injected in the fabricated microdiaphragm sensor included sensing chamber.

We fabricated microdiaphragm resonating sensors with a piezoelectric (PZT) thin film layer. The PZT layer with 2 µm of the microdiaphragm structure allows for the actuating and sensing of microdiaphragm vibration to monitor the resonant frequency without the use of bulky external actuators. The low stress silicon nitride (SiN_x) layer, with a thickness of 1.0 µm, was deposited on the p-doped (100) bare Si wafers using a low-pressure chemical vapor deposition (LPCVD) method. Then, Pt/PZT/Pt/Ta multilayers were then deposited on the SiN_x layer. After the formation of multilayers on the SiN_x surface, the top Pt and PZT layer were etched by an inductive coupled plasma (ICP) etching process. Then, SiO_2 thin film, with a thickness of 0.2 µm, and was deposited and etched so as to form the Au electrical contact pads by lift-off process. Finally, Si was wet-etched using 30 % KOH solution with a backside SiN_x mask layer. Figure 1 showed photograph and SEM image of fabricated microdiaphragm sensors and resonant peak measured by laser Doppler vibrometer (LDV). The width and length of microdiaphragm was 500 µm × 500 µm and thickness of diaphragm was about 3.45µm. The measured fundamental resonant frequencies of fabricated microdiaphragm 185±3 kHz. This result is consistent with the numerical predictions of 183.863 kHz.

In order to prepare the liquid with various viscosities, we mixed DI water and glycerol by controlling the solution volume. The viscosities of DI water and glycerol mixture liquid were 1, 2.43, 8.4, 55.5, and 1413.8 cP. When the liquid with various viscosities injected in sensing chamber, the resonant frequency of microdiaphragms decreased at the lower frequency range due to mass loading effect caused by viscosity change as shown in figure 2. The resonant frequencies of microdiaphragm were 71.5, 67, 64.5, 62.5, 61 kHz during solution injecting with viscosity of 1, 2.43, 8.4, 55.5, 1413.8 cP, respectively. For investigation in the blood viscosity range (under 10 cP), we measured the resonant frequency change of microdiaphragm by liquid with viscosity of 1~8.4 cP. The viscosity sensitivity (resonant frequency change / viscosity change, Fr/cP) was 1.56 kHz/cP for ranging 1 ~ 3 cP and 0.19 kHz/cP for ranging 3 ~ 8.4 cP. This demonstrated that application feasibility of microdiaphragm resonating sensor-based blood viscosity measurement method.

References

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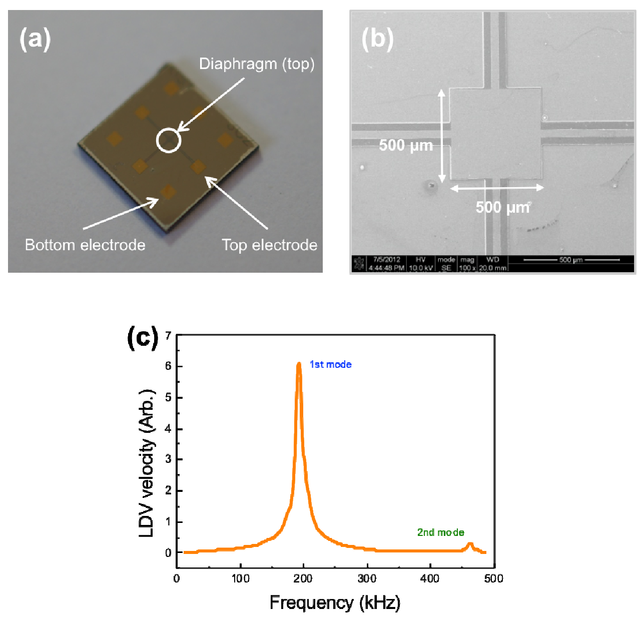

Figure 1. Microfabricated diaphragm sensor and its resonant property. (a) Photograph and (b) SEM image of microdiaphragm sensor, and (c) resonant property of microdiaparagm.

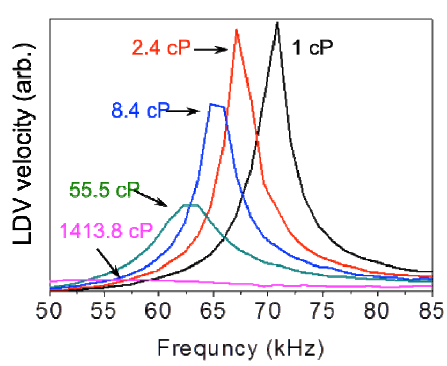

Figure 2. The resonant frequency change of microdiaphragm sensor when liquid with various viscosities injected in sensing chamber.