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미소 유량 측정을 위한 마이크로 전자 유량 센서의 제작

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Fabrication of a Micro Electromagnetic Flow Sensor for Micro Flow Rate Measurement

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요 약

본 논문에서는 패러데이의 전자기 유도 법칙을 응용한 마이크로 전자 유량 센서를 제작하였다. 마이크로 전자 유량 센서는 열발생이 없고 빠른 응답 속도를 가지고 있고 압력 손실이 없는 장점을 가지고 있다. 전도성 유체가 영구 자석 자장 내의 유로를 통과할 때, 유속에 비례하는 유도 기전력이 발생하게 되는데, 발생된 기전력은 유로 벽에 제작된 전극으로 검출된다. 마이크로 전자 유량 센서는 유로를 가지고 있는 두 장의 실리콘 웨이퍼 기판과 전극, 그리고 두 개의 영구 자석으로 구성되어 있다. 두 장의 실리콘 웨이퍼 기판을 이방성 식각 공정으로 유로를 제작하고, Cr/Au를 증착하여 전극을 제작한다. 제작된 마이크로 전자 유량 센서에 유량을 변화시킬 때, 발생되는 기전력을 측정한다.

ABSTRACT

This paper presents the fabrication of a micro electromagnetic flow sensor for the liquid flow rate measurement. The micro electromagnetic flow sensor has some advantages such as a simple structure, no heat generation, a rapid response and no pressure loss. The principle of the micro electromagnetic flow sensor is based on Faraday's law. If conductive fluid passes through a magnetic field, the electromotive force is generated and detected by two electrodes on the wall of the flow channel. The flow sensor consists of two permanent magnets and a silicon flow channel with two electrodes. The dimension of the flow sensor is 9 mm × 9 mm × 1 mm. The micro flow channel is mainly fabricated by anisotropic etching of two silicon wafers, and the detection electrodes are fabricated by metal evaporation process. The characteristic of the fabricated flow sensor is obtained experimentally. When the flow rates of water with the conductance of 100-200 μS/cm are 9.1 ml/min and 62 ml/min, the generated electromotive forces are 261 μV and 7.3 mV, respectively.

I. INTRODUCTION

The measurement of flow rate is essential in micro fluidic systems such as flow injection analysis systems, micro total analysis systems and liquid dosing systems[1]-[3]. With the development of micromachining, various micro flow sensors have been investigated. There are several types of micro flow sensor[3] such as differential pressure[4]-[5], ion generation[6] and hot-wire anemometry[7]-[8]. These

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micro flow sensors have many advantages such as the fast response, the low power consumption and the measurement of small flow rates. But they have some disadvantages such as the pressure loss, brittleness, the complexity of fabrication, the electrostatic charge generation and the heat generation which affects the sensor output signal due to the exponential temperature dependence of the liquid viscosity.

This paper presents a novel micro flow sensor of which the principle is based on Faraday's law. This micro electromagnetic flow sensor can be integrated into a micro channel without changing the shape of the channel and the flow resistance. The electromagnetic flow sensor is limited to conductive liquids. The micro electromagnetic flow sensor has the advantage of the simplicity in structure over other devices. It needs only two silicon substrates to make the flow channel. Also, it has the advantages such as no heat generation, rapid response and no pressure drop. Moreover, the sensor output is independent of the density, the viscosity, the specific heat, the thermal conductivity and the temperature of the liquid except for the electric conductivity[9].

In this paper, the principle, the structure and the fabrication process of a micro electromagnetic flow sensor are presented. The output characteristic of the fabricated micro electromagnetic flow sensor is obtained experimentally.

II. PRINCIPLE

Fig. 1 shows the schematic diagram of the electromagnetic flowmeter. The liquid flows through a channel between two magnet poles. The electromagnetic flowmeter is based on the Faraday's law of induction[9]. The conductive liquid which is moving in a magnetic field will generate the induced voltage, e proportional to its average velocity, $\bar{v}$ as

$$e = kBD\bar{v} \tag{1}$$

where k, B and D are the proportional constant, the flux density and the diameter of the channel. The direction of B, D, and are mutually perpendicular, respectively. This induced voltage is detected with the electrodes imbedded in the wall of a nonconducting pipe. The volume flow rate of the fluid, Q, in the channel is given by

$$Q = A\bar{v} = \frac{A}{kBD}e \tag{2}$$

where A is the cross-sectional area of the flow channel. The electromotive force is proportional to the flow rate.

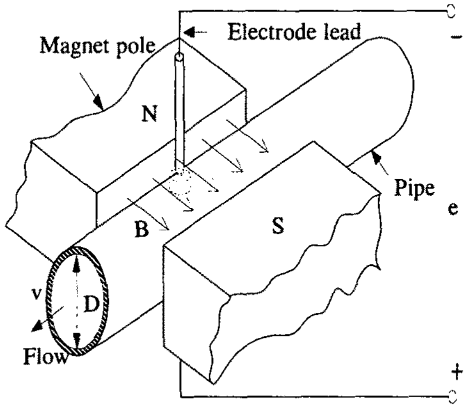


Fig. 1. The principle of the electromagnetic flowmeter.

III. STRUCTURE

Fig. 2 illustrates the structure of the micro electromagnetic flow sensor. The flow sensor consists of two small permanent magnets, one top silicon substrate and one bottom silicon substrate with two Cr/Au electrodes for the detection of the induced voltage. Both substrates are covered with thick silicon oxide for electric insulation. To make a uniform magnetic field, two permanent magnets are attached on both sides of the substrates. The diameter and the thickness of the permanent magnet are 5 mm and 1.5 mm, respectively. And the magnetic flux density between two magnets is about 2500 gauss. Fig. 3 illustrates the cross-sectional view of the channel for the micro electromagnetic flow sensor. The cross-section of the flow channel is hexagonal. The diagonal length is 900 μm and the cross-sectional area is about 0.5 ㎟. The size of the electrode contacting the liquid is 300 μm × 120 μm.

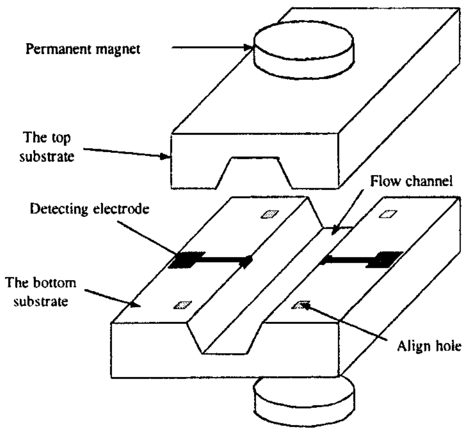


Fig. 2. The structure of the micro electromagnetic flow sensor.

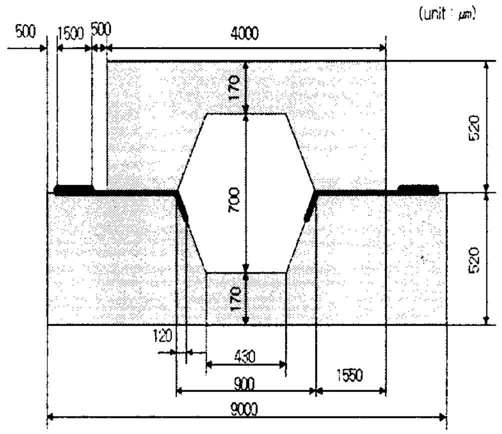


Fig. 3. The cross-sectional view of the channel for the micro electromagnetic flow sensor.

IV. FABRICATION

Fig. 4 shows the fabrication process of the micro electromagnetic flow sensor. The two silicon substrates are fabricated by silicon bulk micromachining. The top substrate is simply fabricated by one anisotropic etch step. To fabricate the bottom substrate one anisotropic etch step and one evaporation step are needed. Fig. 4(a)-(d) show the fabrication process of the top substrate and Fig. 4(a)-(i) show the fabrication process of the bottom substrate.

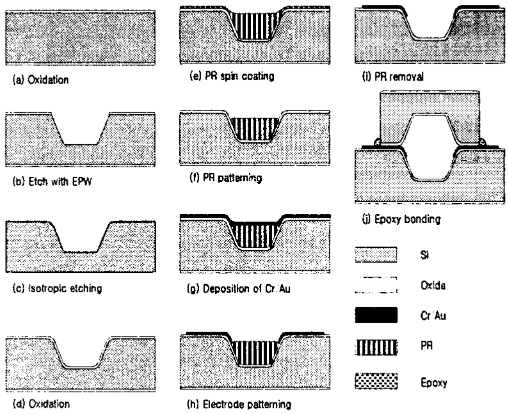
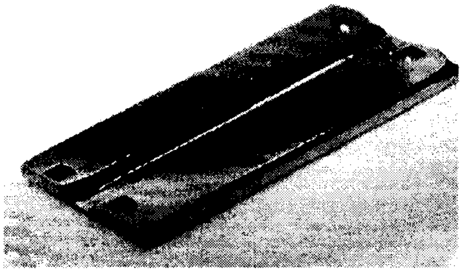
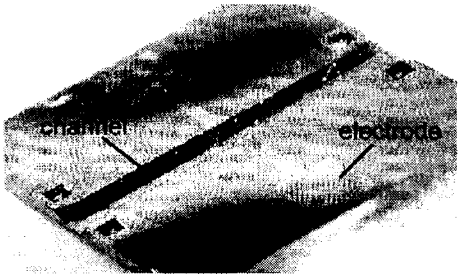


Fig. 4. The fabrication process of the micro electromagnetic flow sensor.

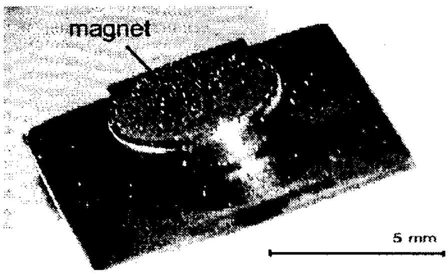
The starting material of the flow sensor is 525 ± 10 μm thick 4 inch n-type <100> silicon wafer. First, a 0.7 μm thick thermal oxide layer for an etch mask is grown. To make a flow channel, the oxide on the front-side of the wafer is patterned by photolithography and the front-side of silicon wafer is etched 350 μm deep with the EPW (Ethylendiamine : Pyrocathecol : D.I. Water = 250 ml : 40g : 80ml) etchant at 115 ± 2 °C. After the residual oxide is removed, the sharp edge of the etched silicon wafer is rounded by a touch-off technique with an isotropic etchant (HNO_3 : CH_3COOH : HF = 75 ml : 30 ml : 9 ml). This rounding prevents the step coverage problem during the evaporation process along the sharp edge of the etched silicon. To insulate the inside wall of the flow channel, 1.0 μm thick thermal oxide is grown. At this time the fabrication of the top substrate is finished. Further steps proceed for the bottom substrate. After the spin coating and patterning of the photoresist, the flow channel is filled with photoresist to deposit Cr/Au layer on the rounded corner of the channel.



(a) The top substrate.



(b) The bottom substrate.



(c) The assembled micro electro-magnetic flow sensor.

Fig. 5. The photograph of the fabricated micro electromagnetic flow sensor.

Then, Cr/Au (500Å / 3000Å) is thermally-evaporated on the bottom layer which is filled with photoresist. For the fabrication of the electrode, Cr/Au layer is patterned by photolithography and photoresist is stripped with acetone. Finally, the epoxy bonding is performed to bond the top silicon substrate and the bottom silicon substrate. Fig. 5 shows the photograph of the fabricated micro electromagnetic flow sensor. Fig. 5(a) and (b) show the top and the bottom silicon substrates, respectively. The photograph of the assembled micro electromagnetic flow sensor is shown in Fig. 5(c).

V. EXPERIMENT RESULTS

The characteristic of the fabricated flow sensor is obtained for large flow rate over 60 ml/min and small flow rate under 10 ml/min. Fig. 6 illustrates the large flow rate measurement system of the fabricated micro electromagnetic flow sensor. Water is pumped by a mechanical pump with a speed controller. The mechanical pump ranges from 60 ml/min to 6000 ml/min. Two capillary tubes are connected to the inlet and the outlet of the fabricated flow sensor with epoxy. The conductivity of the water is about 100-200 μS/cm. A low-pass filter and an amplifier are connected to the electrodes.

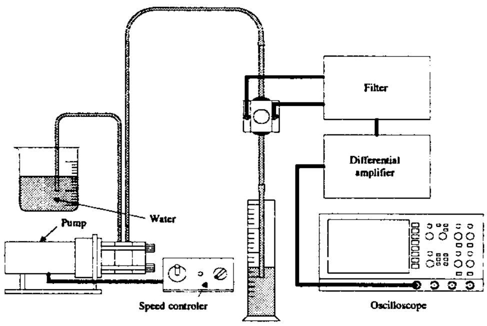


Fig. 6. The measurement system for the large flow rate of the micro electromagnetic flow sensor.

Fig. 7 shows the flow rate vs. the generated electromotive force for various flow rates. The figure does not show that the characteristic of the flow sensor is linear as expected. But, the experimental data can be fitted by a line. When the flow rate increases from 62 ml/min to 153.0 ml/min, the measured electromotive force increases from 1 mV to 7.3 mV, where the voltage means the voltage before the amplification.

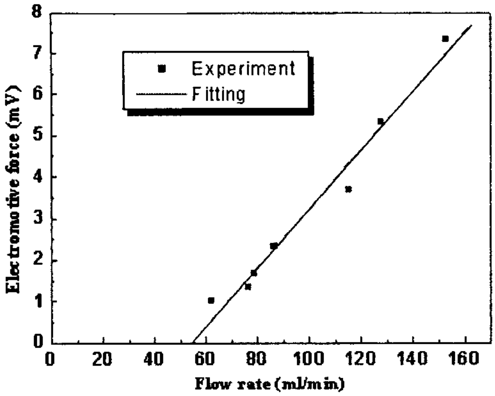


Fig. 7. The plot of the large flow rate vs. the generated electromotive force.

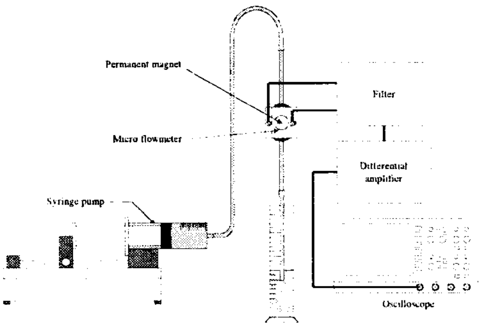


Fig. 8. The measurement system for the small flow rate of the micro electromagnetic flow sensor.

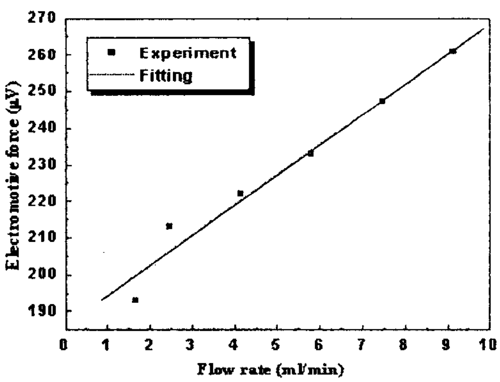


Fig. 9. The plot of the small flow rate vs. the generated electromotive force.

Fig. 8 illustrates the small flow rate measurement system of the fabricated micro electromagnetic flow sensor. Water is pumped with a syringe pump ranging from 1.6 μl/min to 10 ml/min. Fig 9 shows the flow rate vs. the generated electromotive force for small flow rate region and illustrates that a line fits the experimental data properly. When the flow rate varies from 1.7 ml/min to 9.1 ml/min, the measured electromotive force varies from 193 μV to 261 μV.

Ⅵ. CONCLUSIONS

In this paper, a micro electromagnetic flow sensor has been fabricated and tested. The micro electromagnetic flow sensor has simple structure and is simple to fabricate by micromachining technique such as one anisotropic etching, isotropic etching and metal evaporation. The characteristic of the fabricated flow sensor has been obtained for two flow rate regions. One ranges from 1.7 ml/min to 9.1 ml/min and the other ranges from 62 ml/min to 153 ml/min. The experimental data in each region can be fitted by a line, which illustrates the feasibility of the fabricated micro electromagnetic flow sensor. In the near future, the characteristic test will be performed for flow rates ranging from several μl/min to hundreds μl/min by means of improved measurement circuits and technique.

Ⅶ. ACKNOWLEDGEMENTS

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