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BASKET FORCEPS WITH FLOW SENSOR FOR EVALUATING BREATHING CHARACTERISTICS IN SMALL AIRWAY

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ABSTRACT

We developed a basket forceps with a flow sensor for evaluating the breathing characteristics in small airways. The flow sensor, fabricated using mirco-eletro-mechanical systems technologies, was integrated into a guide wire with the basket forceps. The fundamental sensor characteristics, response time and flow rate vs. sensor output curve, were experimentally confirmed. The sensor was successfully fixed to the inside surface of a small tube by using the bending arms of the basket forceps. We confirmed that the breathing properties of a rat were successfully detected with the integrated flow sensor.

KEYWORDS

Flow sensor, Basket forceps, Respiratory, Breathing, COPD

INTRODUCTION

The number of cases of chronic obstructive pulmonary disease (COPD) is increasing rapidly. According to World Health Organization statistics, COPD is ranked as the fourth leading cause of death in the world and is expected to rank third by 2030. The respiratory system consists of numerous levels of bronchi just like a tree, and the lung alveoli are located at the end of diverging bronchi. The alveoli structures gradually collapse due to increasing age, absorbed cigarette smoke, or air-polluting substances in the case of COPD. This means that lesions form at the ends of the diverging bronchi, which are at the opposite end of the mouth. Spirometry is normally used to evaluate the state of this disease. It involves measuring the flow rate at the human mouth. Therefore, evaluating small lesions in the bronchi in the lung system with this measurement method is difficult because it is used to evaluate lesions in the mouth.

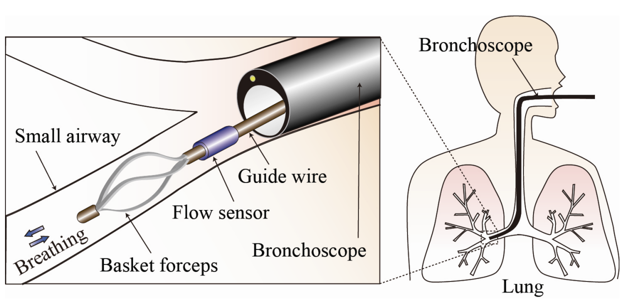

Figure 1: Breathing evaluation by basket forceps with flow sensor in small airway.

To precisely evaluate COPD, micro-electro-mechanical systems (MEMS) technologies have been applied to integrate a thermal flow sensor into the inside surface of a catheter [1-2]. However, a catheter-type flow sensor requires a balloon structure on the tube outside to fix it onto the inside surface of the airway. Thus, it is difficult to apply for measuring breathing in small airways. To overcome this problem, we propose a basket forceps with a flow sensor. The sensor can be fixed to the inside surface of a small airway by using the bending arms of the basket forceps (Fig. 1).

BASKET FORCEPS WITH FLOW SENSOR

Sensor design

A schematic view of a flow sensor assembled onto a guide wire of a basket forceps system is shown in Fig. 2. To shorten the response time, the cavity under the sensor was designed for thermal isolation, as shown in Fig. 2(c). Metal heaters comprised the flow velocity sensor and were formed on a thin polyimide (PI) film. Two heaters were used to detect the flow direction during breathing.

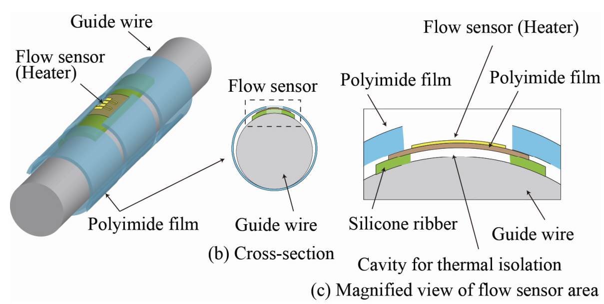

Figure 2: Flow sensor structure on guide wire.

Operation principle

Three principles of thermal anemometry, calorimetric flow sensing and time-of-flight sensing, have been used in miniaturized thermal flow sensing [3, 4]. Hot-wire anemometry sensing was chosen in this study because the flow rate could be measured over a wide range and it had the simplest structure. Hot-wire anemometry (heater) uses its cooling effect of forced convection, enabling changes in flow to be detected. Therefore, the relationship between the electrical energy supplied to a heater in constant temperature mode and the flow velocity u in a low Reynolds number flow can be expressed, as by King [5], as

$$\frac{P}{\Delta T} = G_0 + Ku^n \ , \qquad (1)$$

where P is the electrical energy supplied to a heater and ΔT is the temperature difference between the heater and fluid. Here, G_0, K, and n are constants, and u means the average flow rate. The equation is translated by using the applied voltage to the heater, as below.

$$V^2 = a + bu^n \ , \qquad (2)$$

where V is the applied voltage to the wire, and a, b, and n are constants depending on the geometry of the heater. If the heater is a cylinder shape and infinitely long, n would generally be 0.5. The square of the voltage at the heater is proportional to the nth power of flow velocity.

FABRICATION

The fabrication process of the sensor is shown in Fig. 3. A 7.5−μm-thick polyimide (PI) film (Ube Industries Ltd.) was used as a substrate. The film was first fixed on a glass wafer with 0.5-mm-thick silicone rubber to enable it to be handled in the process. A negative-type photoresist (ZPN1150-90, Zeon Corporation), specially developed for the lift-off process, was put onto the film surface and patterned with UV light to define the shape of the sensor. An Au/Cr film was deposited by sputtering, and patterned by selectively removing the photoresist (lift-off process). The thickness of the Au and Cr was 250 and 10 nm, respectively. The flexible film was manually peeled from the silicone rubber on the glass wafer in an acetone solution. The film sensor was fabricated on a 3-inch wafer, and each sensor was manually cut with a knife.

The fabrication process of the flow sensor on the guide wire is shown in Fig. 4. To form the cavity under the heater for thermal isolation (see Fig. 2(c)), the fabricated flow sensor was placed onto a silicone rubber with a rectangular hole (Figs. 3(a)-(b)). Then, they were assembled onto the guide wire by using an adhesive rubber surface (Fig. 3(c)), and enamel wires were connected onto the pads on the flow sensor for the electrical wiring. Adhesive polyimide film was applied to both sides of both heaters to mechanically fix the film and electrical contact area (Fig. 3(d)). The fabricated flow sensor on the guide wire is shown in Fig. 5. A hand-made plastic basket forceps was also attached to the end of the wire to stimulate arms.

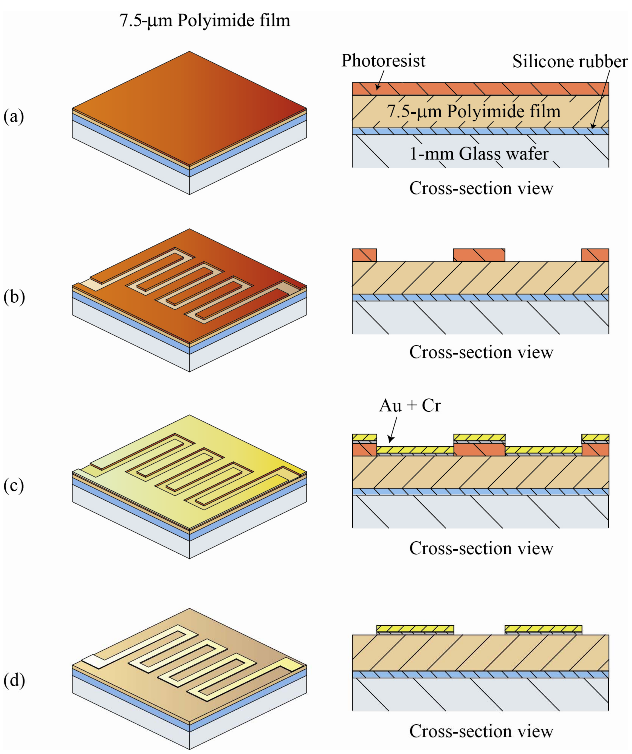

Figure 3: Fabrication of flow sensor.

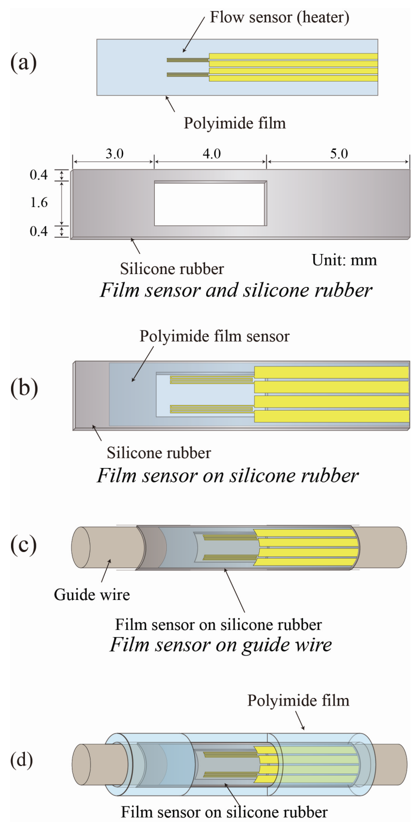

Figure 4: Fabrication of flow sensor on guide wire.

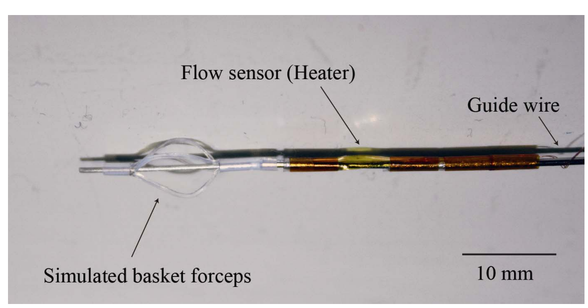

Figure 5: Fabricated basket forceps with flow sensor.

FUNDAMENTAL CHARACTERISTICS

The developed sensor was first inserted into and successfully fixed to the inside surface of the tube by using the bending arms of the basket forceps (Fig. 6). The flow sensor was operated using a constant temperature circuit to shorten the response time. The fundamental sensor characteristics, response time and flow rate vs. sensor output curve, are shown in Figs. 7 and 8, respectively. A sufficient small response time of 93 ms was obtained for measuring breathing. The sensor output against the flow rate obeyed King's law, as shown in Fig. 8.

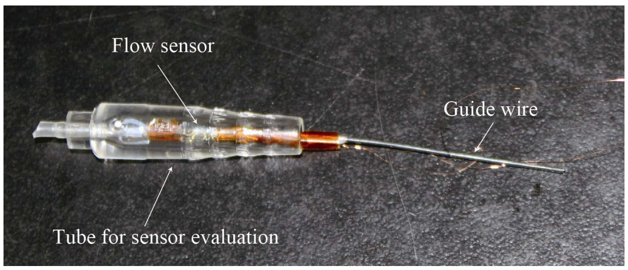

Figure 6: Flow sensor inserted into tube.

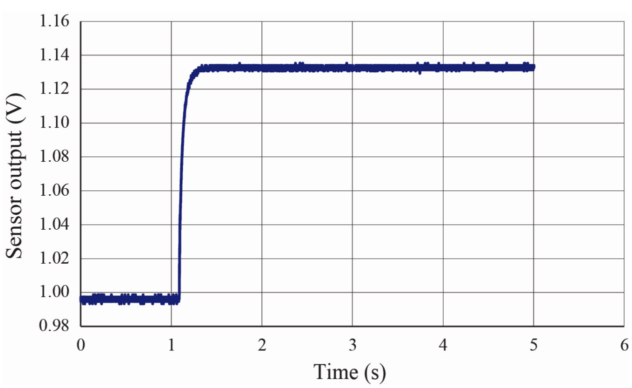

Figure 7: Response waveform of fabricated sensor.

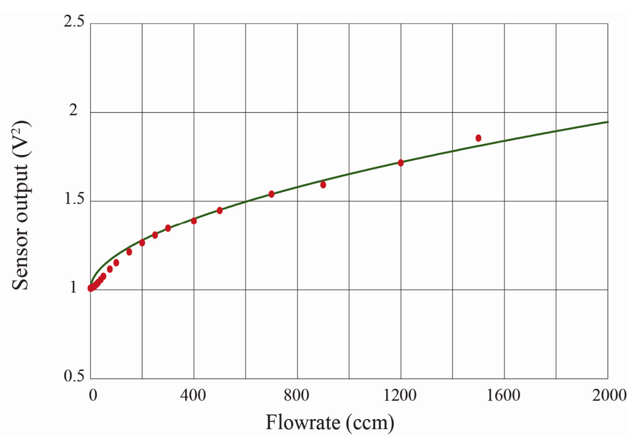

Figure 8: Relationship between flow rate and sensor output.

ANIMAL EXPERIMENT

The developed flow sensor was used to measure breathing in a rat. The experiment was conducted under the regulations set forth by the Nagoya University Animal Experimentation Committee. The developed flow sensor was inserted into the air passage of the rat by applying an adaptor because the diameter of the passage was a little smaller than that of the sensor. The air flow passing through the sensor was directly measured in real time. The waveform showing the breathing of the rat is shown in Fig. 9. The obtained breathing frequency of 1.7 Hz corresponded to the physiological values of the rat.

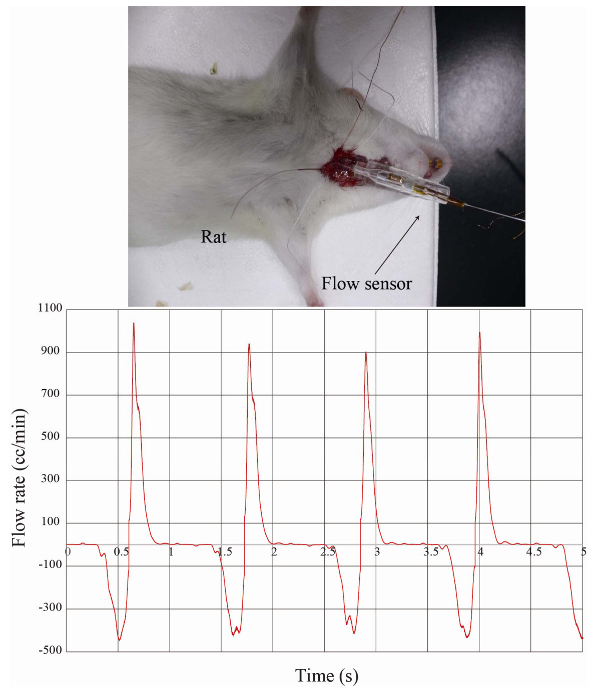

Figure 9: Detected breathing waveform of rat.

CONCLUSION

We fabricated a basket forceps with a flow sensor by applying MEMS technologies. The obtained results are as follows.

(1) A sufficiently small response time of 93 ms was obtained for measuring breathing.

(2) The sensor output against the flow rate obeyed King's law.

(3) The obtained breathing frequency of 1.7 Hz corresponded to the physiological values of the rat.

From these obtained results, we concluded that the developed basket forceps with a flow sensor is applicable for measuring breathing in small airways.

ACKNOWLEDGMENTS

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