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Design and Characteristics of a MEMS Human Body Hardness Sensor Aimed to Diagnosis of Lesion Size

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Abstract

In this study, design of MEMS hardness sensor using "reference plane" structure is theoretically analyzed and demonstrated with experimental results. Hardness measurement not affected by contact force instability is realized by proper design of the device structure. Fabricated devices were evaluated, and contact force dependence was drastically removed by 96.6% using our reference plane concept (i.e. very stable to the contact force change). Shore A hardness scale was obtained in the range from A1 to A54. Through the experiment, detection of hardness corresponding to the human organs has been successfully demonstrated.

1. Introduction

Information of hardness is very important to identify a lesion site like organs in a medical practice. Under endoscopic surgery, hardness sensor of millimeter size order is necessary, since the doctor cannot directly touch to the organs of a patient. In addition, contact force between sensor and measuring objects is difficult to control in the operation. Therefore, dependency of hardness signal on the device contact force should be minimized. In MEMS field, various hardness sensors have been developed and reported [1-2]. However, most of hardness sensors need to control the contact force. Thus, we have developed MEMS hardness sensor with reference plane which is possible to measure hardness even under unstable contact forces [3]. In this study, theoretical model of stabilizing effect of the reference plane is established first, and its effectiveness is confirmed with experimental results.

2. Device Configuration and Detection Principle

Figure 1 shows configuration of our hardness sensor device. The reference plane has important role to detect hardness stably under unstable contact forces. Detecting the indentation-height with the piezoresistive circuit, the hardness (Shore A scale) can be calculated precisely even for soft materials like organs. Measuring the indentation-height from the reference plane to the object, the hardness such as Shore A index can be quantified for soft objects like human organs. Air pressure is applied to diaphragm on the initial state of the device. If the touching object is very hard, the indentation-height from the reference plane to the object becomes very small as shown in Figure 2 (a). On the other hand, indentation-height increases as the touching material gets softer as illustrated in Figure 2 (b). The reference plane is very helpful to detect the indentation-height to the object. Laying the reference plane area around the contact tip, dependence of hardness signal on the contact force can be much reduced. Most of the contact force is applied to the reference plane area, and the contact tip can extract only the indentation height including the hardness information.

$$\frac{F_{tip}}{F_{contact}} = \frac{A_{tip}}{A_{tip} + A_{plane}} \qquad (1)$$

The contact force dependence of the signal (Fcontact / Fcontact) is expressed to the area ratio between the contact-tip (Atip) and the reference plane (Aplane). Decreasing the contact-tip area, the contact force dependence is decreased.

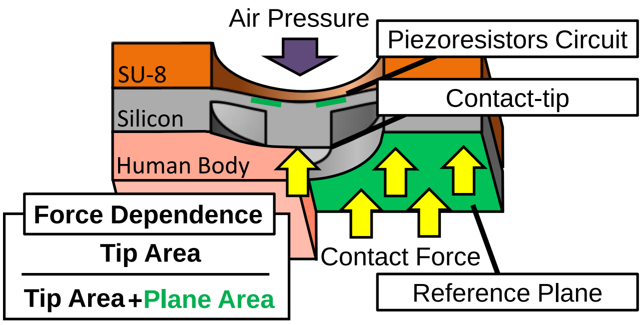
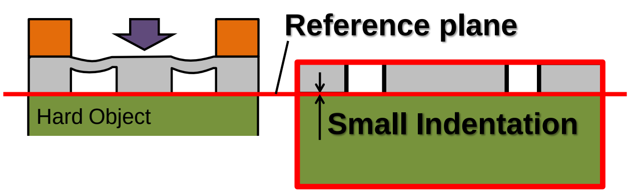
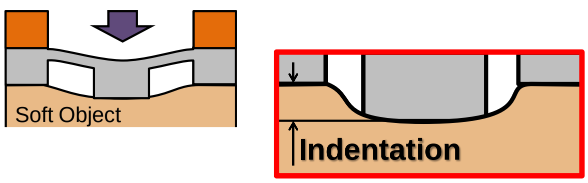


Fig. 1 Conceptual diagram of the tactile sensor with detection ability of human body hardness.



(a) Hardness measurement with hard material.



(b) Hardness measurement with soft material.

Fig. 2 Measurement principle of hardness using the silicon reference plane structure.

3. Device Fabrication and Evaluation

Figure 3 shows a design of the hardness sensor chip. The Chip size is 2.3mm × 2.3mm, the diaphragm diameter is 1mm, and the contact-tip diameter is 0.4mm. The area ratio in the sensor is 1:40. This means the contact force dependence is reduced to 2.5%. Figure 4 shows photographs of a fabricated MEMS hardness sensor.

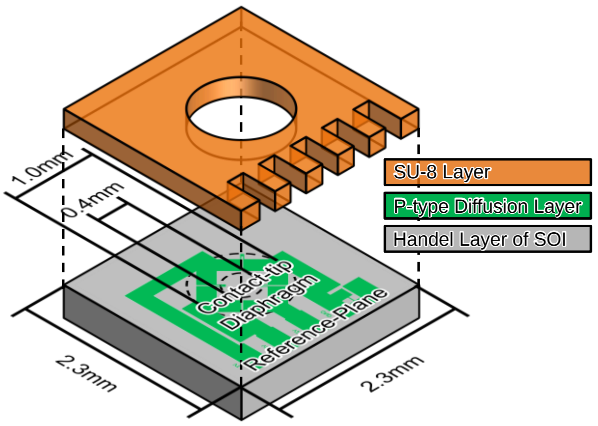


Fig. 3 Design of the MEMS human body hardness sensor.

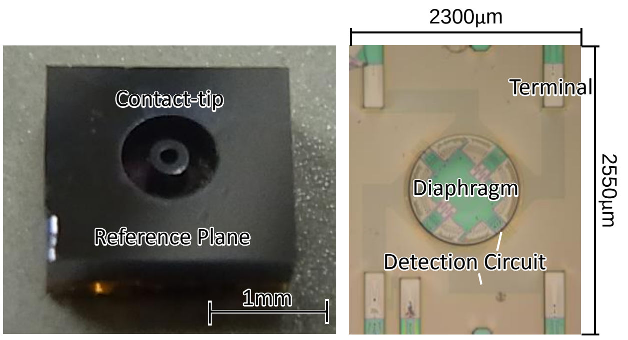


Fig. 4 Photograph of a fabricated backside contact type tactile sensor with silicon contact-tip and reference plane.

Figure 5 shows the relationships between signals of the fabricated sensor and contact forces in the range below 5N. Since the sensor has the reference plane around the contact-tip, their signals are almost saturated in the range of over 0.2 N. In the experiment, the contact force dependence is reduced to 3.4% on average thanks to the plane. This is a close value to the above theoretical value of 2.5 %.

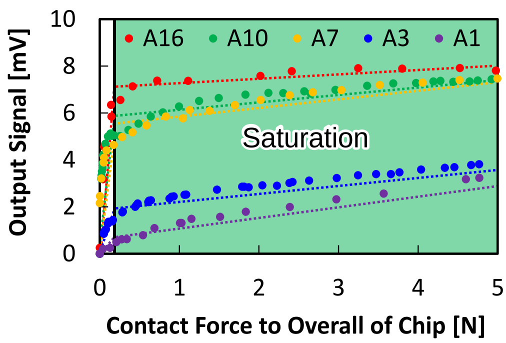


Fig. 5 Measured relationship between the output signal and contact force from the measured objects.

Figure 6 shows the relationship between the output signal at a 0.2N contact force and hardness of the reference objects in the range from A1 to A54. The hardness sensitivity of the measured device is 462μV/HS/V. The minimum detectable hardness in this experiment is less than muscle (4HS). This result corresponds to the ability to identify the lesion site of human organs.

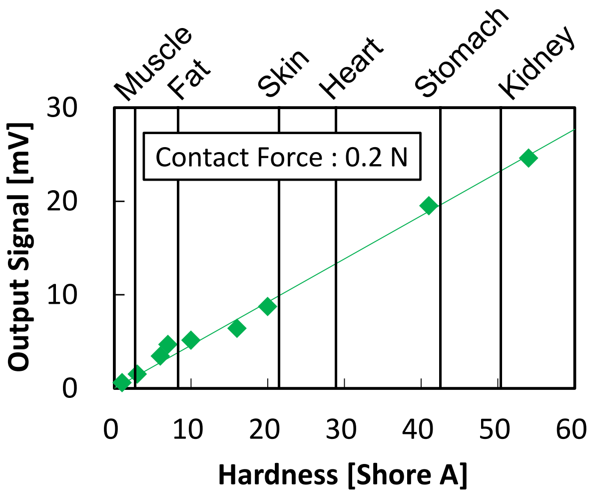


Fig. 6 Measured relationship between the output signal and Shore A hardness of the measured samples. Annotation on plot is hardness of each human organ.

4. Conclusions

In this study, design of MEMS hard-ness sensor using "reference plane" structure was theoretically analyzed and demonstrated with experimental results. The contact force dependence of hardness signal was modeled by area ratio of the contact-tip and the reference plane. Fabricated devices were evaluated, and contact force dependence was drastically removed by 96.6% in the contact force range below 5N using our reference plane concept (i.e. very stable to the contact force change). Shore A hardness scale was obtained in the range from A1 to A54. Through the experiment, detection of hardness corresponding to the human organs has been successfully demonstrated.

Acknowledgements

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