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Fabrication of a low leakage current type impedance sensor with shielding structures to detect a low water content of soil for slope failure prognostics

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ABSTRACT

A low-leakage-current-type impedance sensor chip with shield structures has been fabricated. The low limit detection of soil-water-content measurement was improved compared with that of the other semiconductor-type sensors. The shield structures were fabricated under the impedance sensor areas. To measure the weak signal current eliminated by the leakage current, we proposed a new operation circuit to separate the leakage current. Our sensor was able to measure low water content of 10% or less. The sensor could detect the change of water content in the slope of mountain when it rained.

1. Introduction

Natural disasters of rainfall-induced slope failure and soil fall happen all over the world. Those disasters may cause serious damage to peoples' lives and their houses [1]. Wired sensors, a tilt sensor [2] and a GPS sensor, which can detect the start of soil sliding, are useful for facilitating the announcement of an evacuation signal just before the slope failure. When a risk of slope failure can be detected before the occurrence of the actual slope failure, evacuees can be given enough time to evacuate. Therefore, a prediction of the slope failure is needed. Some groups have been studying ways to monitor water content in soil [3–5]. When the water content in soil is increased, the soil frictional force is decreased, and the soil weight is increased. The measurement of the water content is thus capable of detecting dangerous levels of the slope of the mountain.

The water content sensor has several types of measurement methods which are tensiometers [6–8] to measure suction force, and electrical impedance sensors which are mainly capacitance-measurement-type sensors [9–11], TDR type sensors [12–16], and electrical-conductivity-type sensors [17,18]. The electrical impedance measurements of soil have advantages of long-term determination and that the measurements have no need a periodical maintenance. Our group has been studying a miniaturized impedance sensor fabricated by Si LSI technology [18,19] for measurement of soil water content. This sensor, which is inexpensive and compact, has the advantage that it is easier to install into the soil than other sensors [20], and succeeded in monitoring the soil moisture change of the mountain slope corresponding to rainfall for two years [21,22]. However, the sensor had difficulty measuring low-level soil water contents smaller than 20%. To detect the amount of water volume change in soil, the sensor needed to measure the low-level water content. In this study, we propose to fabricate a new sensor chip with a shield structure to cut-off the leakage current, and to ensure that the sensor could achieve low-level soil water content measurement.

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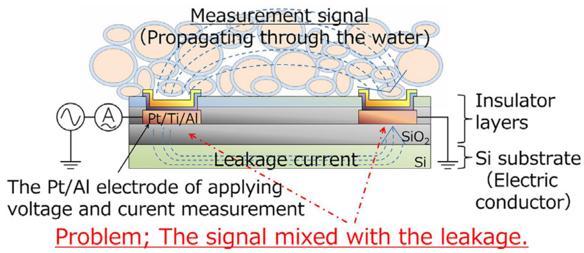

Fig. 1. A cross-sectional view of our previous sensor chip.

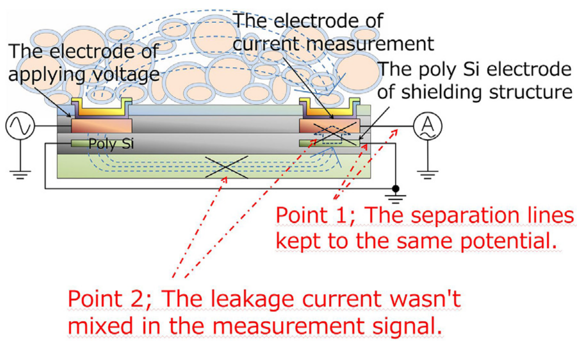

Fig. 2. A cross-sectional view of a proposed sensor chip.

2. Proposal of failure mechanism and fabrication of a new sensor chip

2.1. Conventional sensor chip and failure mechanism

In previous work, the sensing electrodes, which were Pt/Ti/Al structures, were deposited on an insulator layer SiO_2 on Si substrate. Applying alternating voltage and measuring current had been performed on the same electrode, as shown in Fig. 1. The opposite electrode had been connected to ground level. In this case, the current signal becomes the resultant current, which includes with the leakage current through the Si substrate and the measurement signal current propagating through the water in soil. When the water content in soil is small, the measurement signal current was smaller than the leakage current. We had attempted to reduce the leakage current by increasing the thickness of the insulating film, but a large error occurred in the measurement in soil of 20% or less. Since it was not desirable to make the film thickness thicker than this, it was difficult to detect the change in the measured current of the soil with low moisture content in the previous sensor chip.

2.2. Proposal of a new structure for measurement in soil with small water content

To detect the signal current without the leakage current, a new sensor chip was proposed. A cross-sectional view of the proposed sensor chip is shown in Fig. 2. The first of the changes is the connecting point of the current measurement. The electrode for current measurement changed from the applying-voltage electrode in Fig. 1 to the ground-level electrode in Fig. 2. The second change was the addition of a shielding electrode composed of a poly Si structure under the current measurement electrode. In order to mount the pH sensor and the temperature sensor between the electrodes, the size of the shield electrode is somewhat larger than that of the Pt electrode. Specifically, the length of the Pt electrode is 3.9 mm, the width is 0.9 mm, whereas the length of the shield electrode is 3.94 mm, the width is 0.93 mm. The shielding electrode was connected to ground. In this case, the shielding and current measurement electrodes separated the lines and kept the same voltage level as ground. By setting the same potential, the current did not flow between the electrodes. Therefore, the leakage current was not mixed into the signal current. When the previous sensor chip had measured small water content, which is less than 20%, the measurement current had been dominated by the leakage current. In contrast, the proposed sensor chip was expected to measure the signal current without leakage current.

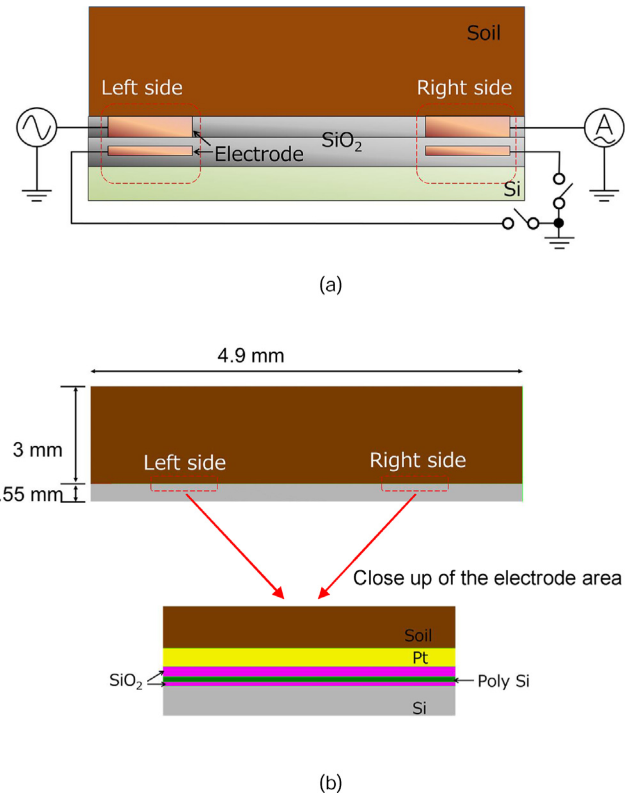

Fig. 3. Simulation model for electric field simulator.
(a) Basic cross-sectional view.
(b) Drawing using the simulator.

2.3. Electric field simulator verification

In order to confirm that the proposed method is correct, a verification was carried out using an electric field simulator, ElecNet, Infolytica Corporation. Fig. 3(a) shows a cross-sectional view when the proposed sensor is inserted into the soil, used for the simulation. Fig. 3(b) shows the drawing using the simulator. The current density between the electrodes at that time is shown in Fig. 4.

The experimental conditions were as follows: the dielectric constant of the soil was 4, the dielectric constant of the insulating film (SiO_2) was 3.9, the dielectric constant of the substrate (Si) was 12, a sinusoidal wave of 250 mVp-p was applied to the metal electrode on the left side, and a 0 V was applied to the right electrode. When the shielding electrodes were not connected to ground, the leakage current entered the Pt electrode from the right side, as shown in Fig. 4(a). In contrast, when the shielding electrodes were connected, the leakage current did not come into the Pt electrode, as shown in Fig. 4(b).

From this result, it can be confirmed that proposed method was able to successfully suppress the leakage current that was flowing in the conventional method. Therefore, the proposed method is effective.

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