A Robust Resistive Fingerprint Sensor

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***Abstract*—**A novel sensing scheme using resistive characteristics of the finger is proposed. ESD problem is more harmful than a capacitive fingerprint sensor in a resistive fingerprint sensor, because the sensor plate is directly connected to the sensing cell. The proposed circuit is more robust than conventional circuit for ESD. The sensor plate and sensing cell are isolated by capacitor. The pixel level simple detection circuit is fully digital operation unlike that of the capacitive sensing cell. The sensor circuit blocks are designed and simulated in a standard CMOS 0.35 μm process. The proposed circuit is more stable and effective than a typical circuit.

***Index Terms*—** Resistive Fingerprint Sensor, ESD, Detection Circuit, VLSI, Ridge, Valley

I. INTRODUCTION

THE recent expansion of trading by INTERNET and the needs to prevent unauthorized usage of private communication and information processing systems open new opportunities to authentication systems. In that sense, a portable fingerprint recognition system, especially a silicon-based sensor system could be an ideal candidate.

The fingerprint sensor is the most important prerequisite in the automatic fingerprint identification system because it decides the resolution of the fingerprint image, the cost and size of the system. Among the various kinds of the fingerprint sensor, semiconductor-based fingerprint sensors are considered most suitable for low-power, small-size and inexpensive system and especially for the portable applications due to the characteristics of the direct contact and the possibility of the single-chip identification system[1-5].

For a decade, CMOS processes have been used to produce fingerprint sensor prototypes. Most of them rely on capacitive coupling between the finger and matrix of small metal plates to detect ridges and valleys on the finger surface. Each plate forms a pixel of the resulting image and requires circuitry to measure the capacitance using either DC [3] or AC [5] signals.

Another sensing scheme using resistive characteristics of the finger is proposed. The resistive fingerprint sensor shows stable performance because it operates fully digitally. A resistive sensing scheme, which assumes the finger as a resistor, is also proposed. Good-quality images could be extracted irrespective of the finger-condition. Compared to the capacitive and thermal sensors, the skin resistivity method leads to a simpler pixel circuit while showing good sensitivity. The sensing scheme has a high sensitivity and a simple circuit structure for the restricted pixel area below a sensor metal. Some papers have proposed a sensor circuit where the property of human skin to conduct electricity is exploited to read fingerprints[1][2][6].

However, those detection circuits of above results are weak in electrostatic discharge(ESD). A direct-contact semiconductor fingerprint sensor suffers from ESD problem. A number of techniques have been used to prevent it. In a resistive fingerprint sensor, this problem may be more harmful than a capacitive fingerprint, sensor, because the sensor plate is directly connected to the sensing cell. Energy from a static discharge can be coupled to an electronic circuit in three ways: By direct conduction, by capacitive coupling and by inductive coupling[7].

Direct conduction occurs when the discharge current flows directly through the sensitive circuit. This often results in damage to the circuit. Capacitive and inductive couplings occur when there is a discharge to a nearby object and the resulting fields are coupled to the susceptible circuit. Therefore, the direct conduction from a sensor plate to the gate of the transistor in a resistive sensing scheme may cause actual damage to the transistor.

In this paper, a new resistive sensing scheme is analyzed in view of the durability. A novel sensing

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scheme using resistive characteristics of the finger is proposed. The proposed circuit is more robust than conventional circuit for ESD.

The paper is divided as follows: section II presents the overall architecture of the sensor while section III followed by conclusions focuses on the proposed detection circuit blocks and simulation results, namely the pixel and the reading circuit.

II. SENOR ARCHITECTURE

In a resistive sensing scheme, finger can be modeled as a resistor if it is connected to a sensor electrode directly as shown in Fig. 1. This resistor-like characteristic of the finger can be used as another fingerprint sensing scheme. In other words, the potential of the sensor plate should be the same with that of the finger skin if the ridge is in contact with the sensor plate. But that of the sensor plate is maintained if it is under the valley of the finger and is not contacted to the finger skin. It is simpler than that of the capacitive sensing scheme. The potential of finger skin is assumed as ground potential. This is guaranteed by the fact that a lattice-like wall connected to the ground surrounds the sensor plate and discharges the charge of finger. As this wall covers the whole sensor surface, some parts of fingerprint must be connected to the ground.

Skin resistivity varies from one person to another and depends also on skin humidity and mechanical pressure applied on the sensor. A skin resistivity varies from 1 MΩ to 8 MΩ in dry conditions. A resistivity of 100 KΩ has been measured in the case of humid skin. Therefore, the detection circuit must be able to detect skin resistivity varies from 100 KΩ to 8 MΩ[2][6].

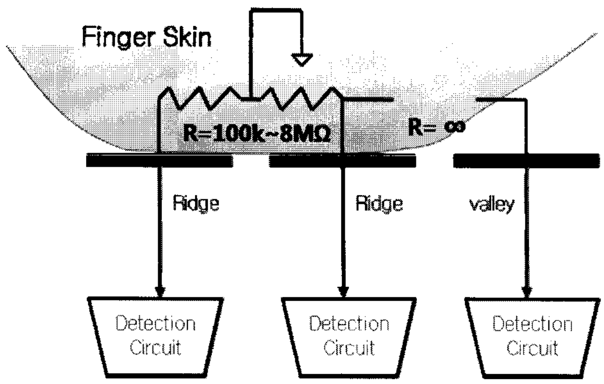

Fig. 1 Resistivity sensor principle scheme

Fig. 2 shows a conventional resistive fingerprint sensing scheme[1]. The diode D1 and D2 are connected to the sensing node in Fig. 2. These diodes provide limited over-voltage path to the ground or power. Although those methods above are useful in ESD protection, a fundamental problem comes from the direct conduction.

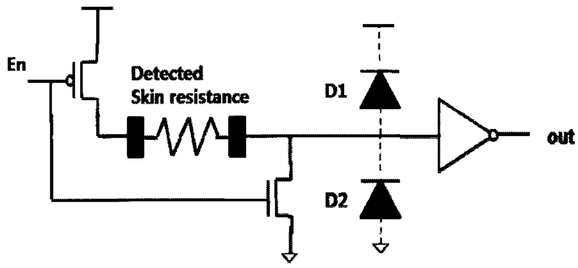

Fig. 2 Typical resistive fingerprint sensing scheme

The detection circuit of Fig. 2 must be more durable for ESD. The first step in designing a sensor to be immune to ESD is to prevent the direct discharge current from flowing through the susceptible circuits. In order to divert the ESD current from sensitive circuits, a ground-wall surrounding the sensor plate is used. Moreover, all the rows except an active row in the sensor array are connected to the ground and make another path of the ESD current.

A resistive fingerprint sensing scheme is expanded to a new sensing cell which does not introduce a direct path from a sensor plate to the gate of the transistor. A conceptual diagram of the new sensing cell is depicted in Fig. 3. Now, the sensor plate is not directly connected to the input of the inverter but the capacitor C2 is between them. R is the finger skin resistance in a ridge and Cp is an expected parasitic capacitance.

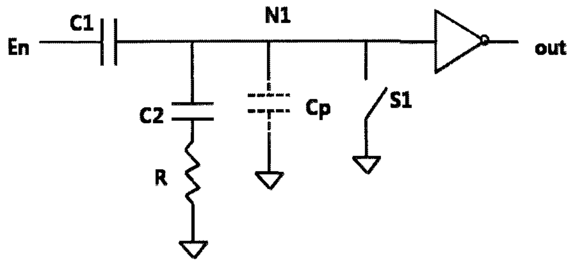

Fig. 3 Proposed sensing scheme

First, the node N1 is precharged to ground via the switch S1 and the enable signal En is in the ground state. Second, the node N1 is floated as the switch S1 turned off. Now, en is triggered to high state. If the sensor plate is contacted with the finger of the ground potential, the triggering signal affects to the node N1. The floating node N1 is given as follows;

$$VN1.ridge = \frac{C1}{C1+(C2+Cp)} VDD \quad (1)$$

While if the finger is not in contact with the sensor plate, C2 does not affect the node N1. Therefore,

$$VN1.valley = \frac{C1}{C1+Cp} VDD \quad (2)$$

Here, VN1.ridge means the node N1 voltage in a ridge (contact) condition and VN1.valley means the node N1 voltage in a valley(non-contact) condition. If VN1 is larger than Vth of the inverter, the output becomes low and if VN1 is smaller, the output becomes high. Therefore, the extraction of the finger pattern is made possible. The voltage difference between a ridge and valley is

$$VN1.valley - VN1.ridge = \frac{C1\ C2}{(C1+C2+Cp)\ (C1+Cp)} VDD \quad (3)$$

In this scheme, the actual capacitor C1 is not necessary to be very large. Several decades femtofarads is enough to propagate the triggering signal because the parasitic capacitance Cp is also order of several decades femtofarads. Because the parasitic capacitance Cp below the sensor plate reduces the voltage difference between a ridge and valley, it gives a limitation in the operating range of the inverter Vth and becomes an important factor in fingerprint sensor's image quality decline. Therefore, we need a circuit methodology to remove parasitic capacitance Cp.

III. DETECTION CIRCUIT DESIGN

Fig. 4 shows the proposed resistive fingerprint sensing architecture of Fig. 3. The unit sensor pixel includes one sensor metal plate and detection circuit block. The detection circuit block is located below a sensor metal. A resistivity sensing scheme has a high sensitivity and a simple circuit structure for the restricted pixel area below a sensor plate. Here, the components of the capacitors are as follows:

C1; the actual capacitance

C2; the capacitance between metal3 plate and metal4 plate for sensor plate of 0.35μm1P, 4M process.

Cp; the parasitic capacitance of the node N1 below the metal3.

This paper adopts unity-gain buffer(BUF) for removing the parasitic capacitance Cp. The role of BUF is tracking the voltage of the node N1. Therefore, the voltage difference between Cp terminals is almost 0V and we can remove the influence of Cp.

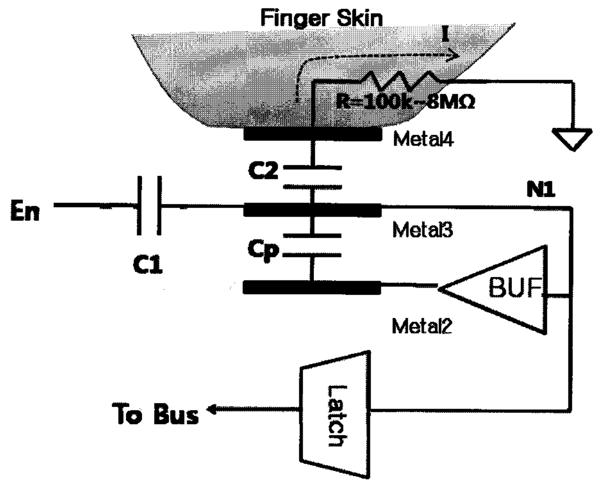

Fig. 4 Proposed sensor architecture

The area of the each sensor plate is 58μm x58μm, which is small enough to be implemented in the unit sensing cell for a 423dpi sensor[3]. The pixel pitch is 60μm. The values of C2 and Cp are 86fF in 0.35μm typical CMOS process, respectively. Here, we simply assumed Cp as the capacitance between the metal2 plate and the metal3 plate, which is the largest possible value of Cp. The optimized actual capacitance C1 is 20fF.

Fig. 5 shows the proposed resistive fingerprint sensing scheme. C1 is the actual capacitor by PMOS for an effective layout area. Fig. 6 shows the timing diagram of the detection circuit and Fig. 7 is BUF circuit for eliminating the influence of Cp.

In the precharge mode, the node N1 is precharged to ground via the NMOS M1 and the precharge signal PC is in the VDD state. In the evaluation mode, the node N1 is floated as the MOS switch M1 turned off. Now, PC is triggered to low state. If the sensor plate is contacted with the finger of the ground potential, the triggering signal affects to the node N1. That means ridge of a finger skin. In fact, the node N1 may not be precharged to VDD if the resistance of finger skin is very small as the case of the wet finer. However, this does not introduce an error in this scheme because the node N1 is finally discharged to the ground in the evaluation phase. Because the resistance of a dry ridge is larger than its of a wet ridge, Ts is larger than its of a wet ridge. Ts means time from low state of PC to high state of the inverter input signal di. In a valley, the inverter output signal di is always low because of an extremely large resistance.

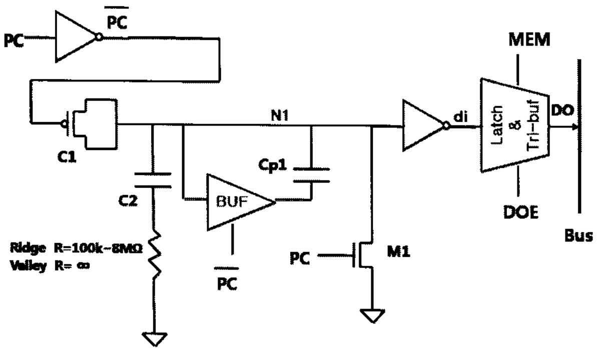

Fig. 5 Detection circuit

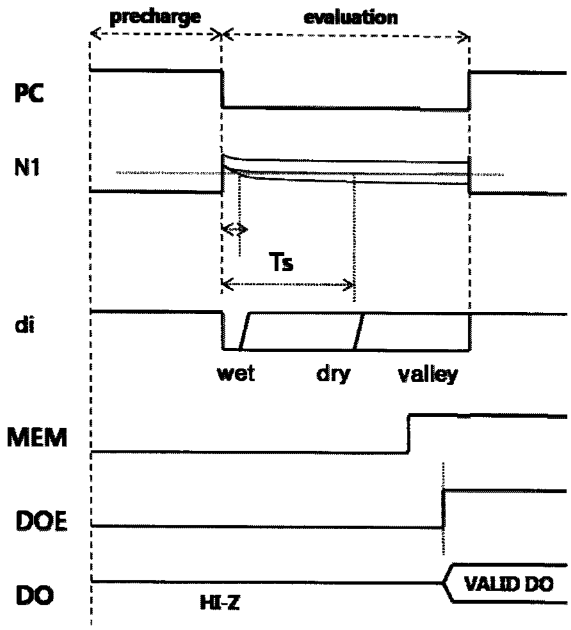

Fig. 6 Timing diagram

Furthermore, this effect can be used as the discriminator between the wet and dry finger. The point of the cell operation is that it is fully digital operation unlike that of the capacitive sensing cell. Although the latched inverter is for sensing the change of N1, it is different from the comparator in that VN1 is not stuck on any analog voltage but eventually discharged to the ground. Only the discharging time varies. There is no need of tuning the reference voltage of the comparator to obtain images of good quality. Therefore, the resistive fingerprint sensor is more stable in its operation than the capacitive fingerprint sensor.

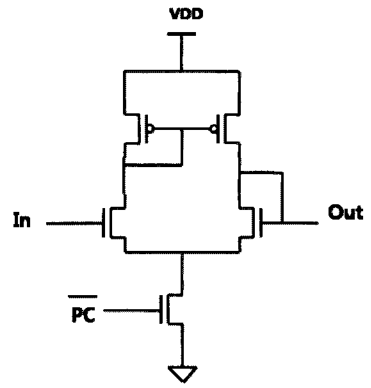

Fig. 7 Unit-gain buffer(BUF)

In the proposed resistive fingerprint scheme, gray scale can be obtained from the resistance of the finger. The resistance of the finger skin is varied from a few KΩ to a few MΩ according to the dryness of the finger. This variation of the resistance results in the variation of the time Ts required for the discharge of the node N1 in Fig. 5. This is because the RC time constant determines the speed of the discharge and the capacitance of the node 1 is fixed and same for all sensing cells. The resistance of the contact point between the sensor plate and the finger is determined by the area, which the skin covers. Apart from the difference of the resistivity between the wet and dry finger, the wet finer covers the sensor plate more completely than the dry finger and have a small resistance. Here, the change of the output voltage is given by;

$$V(t)=VDD \exp(-t/RC) \quad (4)$$

Therefore, the time at which the response has dropped to the logic threshold voltage Vth of the inverter is given as follows, which is a linear function of R.

$$T=RC \ln(VDD/Vth) \quad (5)$$

HSPICE simulations were performed on the whole sensing circuit. Fig. 8 shows a simulation result of detection circuit in a ridge and valley condition. The node N1 voltage is discharged slowly because of the big dry ridge skin resistance. The node N1 voltage VN1 is saturated on 1.1V in a wet and dry ridge condition. Sensing time Ts is about 230ns in a dry ridge. Fig. 8 also shows a simulation result of detection circuit in a valley condition. The VN1 is 2V because of open circuit.

△VN1 is simulated as 1.9V using the above values in 3.3V supply voltage condition, which is large enough to charge the state of the inverter. Consequently, this scheme is more robust to the ESD problem than the previous resistive sensing scheme . The size of the sensor plate is 58x58 μm^2 and the pitch of unit cell is 60μm, which provides a resolution of 423dpi.

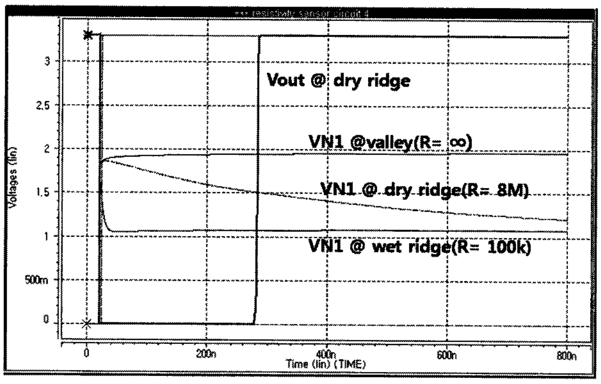

Fig. 8 Simulation result
(Condition: 3.3V, 0.35μm typical CMOS process)

IV. CONCLUSIONS

A novel fingerprint sensor based on the principle of skin resistivity variation due to a ridge and valley of the fingertip contacting a metal tip has been presented. A novel circuit scheme is proposed to solve the serious ESD problem. ESD problem is more harmful than a capacitive fingerprint sensor in a resistive fingerprint sensor, because the sensor plate is directly connected to the sensing cell. The proposed circuit is more robust than conventional circuit for ESD. The sensor plate and sensing cell are isolated by capacitor. The simple and effective detection circuit is designed. The detection circuit is composed of sensing inverter, latch, precharge transistor, switching transistor and BUF. The BUF improve the voltage difference between a ridge and valley by removing the influence of the parasitic capacitance below metal3.

HSPICE simulations are performed with the model file of the CMOS 0.35 μm process and have shown the proper functionality. The voltage difference between a ridge and valley is simulated as 1.9V in 3.3V supply voltage, which is large enough to charge the state of the inverter. Sensing time Ts is 230ns. Consequently, this scheme is more robust to the ESD problem than the previous resistive sensing scheme . The size of the sensor plate is 58 x 58 μm^2 and the pitch of unit cell is 60μm, which provides a resolution of 423dpi. The image identification algorithm is under development and full chip implementation will be the topic of a future paper.

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