J-2-03

Extended Abstracts of the 2018 International Conference on Solid State Devices and Materials, Tokyo, 2018, pp555-556

Simplified and Disposal CMOS Chip Fabrication for Biomedical Application

T. Tabei[1], T. Sato[1], T. Meguro[1], K. Okada[1], S. Yamada[1], Y. Amemiya[1], S. Yokoyama[1], A. Nakamura[2], H. Murakami[2], S. Nishimura[3], K. Miyao[3], S. Makihira[3], R. Shimizu[3], R. Mihara[3], and M. Furuse[3]

[1] Research Institute for Nanodevice and Bio Systems, Hiroshima University
1-4-2 Kagamiyama, Higashihiroshima 739-8527, Japan
Phone: +81-82-424-6265 E-mail: tabei@hiroshima-u.ac.jp
[2] National Institute of Technology, Kurume College
1-1-1 Komorino, Kurume, Fukuoka 830-8555, Japan
[3] National Institute of Technology, Oshima College
1091-1 Komatsu, Suo-Oshima, Oshima, Yamaguchi 742-2193, Japan

Abstract

To realize disposal system-on-a-chip biosensor for biomedical application, a short turnaround CMOS fabrication technology is proposed. Temperature measurements by using CMOS ring oscillator fabricated by the proposed technology are demonstrated.

1. Introduction

Micro and nanoscale biosensors have been extensively studied for advanced biomedical applications such as temperature sensor [1] and antigen-antibody reaction sensor [2]. Development of system-on-a-chip (SoC) combining these sensors and CMOS circuits is important for simplifying medical examination as shown in Fig. 1. To develop a disposal SoC biosensor, it is desirable that the CMOS circuits are low cost and simple structure. However, studies for integration of biosensor and signal processing circuits on a single chip [3] are not standard yet because of its complex fabrication process.

For the purpose of realizing simplified and disposal system-on-a-chip biosensor with CMOS-based signal processing circuits, a short turnaround CMOS fabrication technology is proposed, and characteristics of fabricated devices are verified. In this study, temperature measurements by using the ring oscillator fabricated by the proposed technology are demonstrated.

2. Materials and Methods

Figure 2 shows a schematic of CMOS transistors fabricated in this study. Major characteristics of our devices are that (1) active regions are formed merely by wet etching of field-oxide film, (2) a single layer of aluminum is used for both gate electrodes and interconnects, and (3) there is no interlayer-dielectric film.

The fabrication process of CMOS devices is as follows. Active regions are formed by etching field-oxide film of 500 nm thick with hydrofluoric acid. N-well regions are formed by phosphorous ion implantation and 1150°C annealing for about 13 hours. N^+ regions for source/drain of n-channel MOS transistor are formed by implantation of arsenic ions, and p^+ regions of p-channel MOS transistors are formed by BF^{2+} ions. Gate oxide film is set to 16-nm thick. Contact holes are formed by wet etching with hydrofluoric acid. Aluminum layer is sputtered for both gate metal and metal wiring, and patterned by wet etching. All lithography were done by digital micromirror device based maskless lithography system. Fabrication time is significantly reduced to be only 4 days.

Temperature dependence of the oscillation frequency of ring oscillators constructed by CMOS inverters are investigated by manual probe system while varying temperature of wafer table from 25.1°C to 40.1°C.

3. Results and Discussion

Figure 3 shows an optical microscope image of part of the CMOS chip fabricated by the proposed technology. They are fabricated on the p-type silicon substrate with the resistivity of 8-12 Ω-cm. Typical properties of drain current vs. drain voltage characteristics for fabricated n-channel and p-channel MOS transistors are shown in Fig. 4. Threshold voltages of n- and p-channel transistor are 0.72 V and -0.9 V, respectively. Figure 5 shows the input and output characteristics of the fabricated CMOS inverter, indicating normal operation.

The fabricated ring oscillator consists of three stages of CMOS inverters followed by one stage of inverter as buffer. Channel width/length of n- and p-channel transistors in the ring oscillator are 25/12 and 50/12 μm, respectively. The absolute value of the threshold voltage of both n- and p-channel transistors are 1.09 V. In this sample, the impurity concentration in the channel was adjusted so that the threshold voltages of n- and p-channel transistors were same value. Figure 6 shows the obtained oscillation waveform of the ring oscillator. Oscillation frequency is 27.9 MHz at a temperature of 25.1°C for power supply voltage V_{DD} = 5 V, indicating normal operation. Figure 7 shows temperature dependence of oscillation frequency for the ring oscillator. It is confirmed that oscillation frequency decreases when temperature T increases. This reason is because that the decrease of carrier mobility by increasing temperature cause the decrease of drain current, and then increase of charging and discharging time of gate capacitance. It is known that, carrier mobility at high temperature is proportional to $T^{-3/2}$ due to phonon scattering, but at low temperature it is proportional to $T^{3/2}$ due to ionized impurity scattering. From Fig. 7, obtained oscillation frequency is proportional to $T^{-1.01}$. Since oscillation frequency is proportional to carrier mobility, obtained result suggests that the variation of oscillation frequency is mostly due to the phonon scattering. These characteristics of ring oscillator can be applied to body temperature measurement, etc.

3. Conclusions

Short turnaround CMOS fabrication technology to realize disposal system-on-a-chip for biomedical application is developed. Ring oscillators constructed by CMOS inverters were fabricated, and temperature measurements by using them were demonstrated. Proposed technology is suitable for fabricating disposal chips for biomedical application. In the future we are planning to measure the body temperature by using wireless chips.

References

[1] T. Ishikawa et al., Proc. of 25th Sensor Symp. 2008, 417-420.
[2] S. Yamatogi et al., Jpn. J. Appl. Phys., 2009, 48, 04C188.
[3] B. Y. Lee et al., Lab Chip, 2010, 10, 894–898.

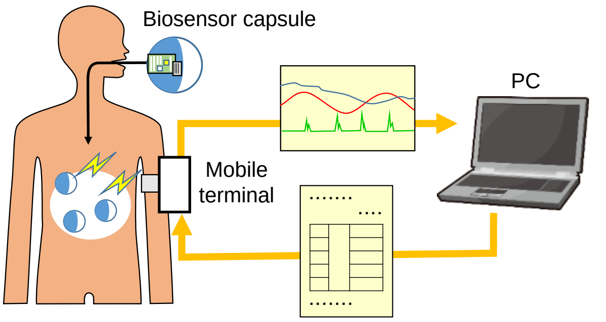

Fig. 1 An example of disposal biosensor for medical examination.

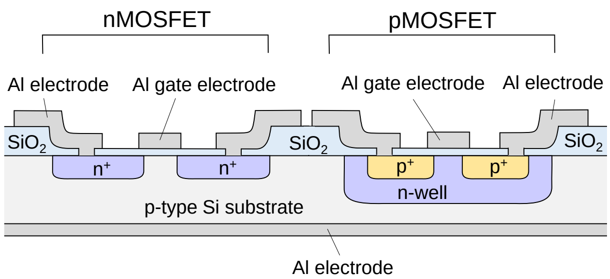

Fig. 2 Schematic structure of CMOS transistors.

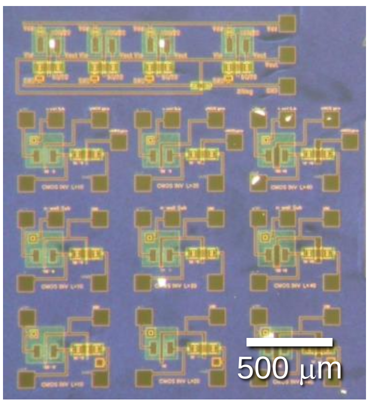

Fig. 3 Optical microscope image of part of the fabricated CMOS chip.

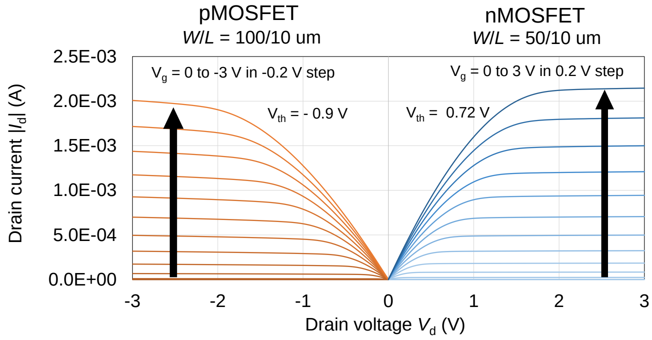

Fig. 4 Drain current ($|I_d|$) vs. drain voltage (V_d) characteristics for fabricated n-channel and p-channel MOS transistors.

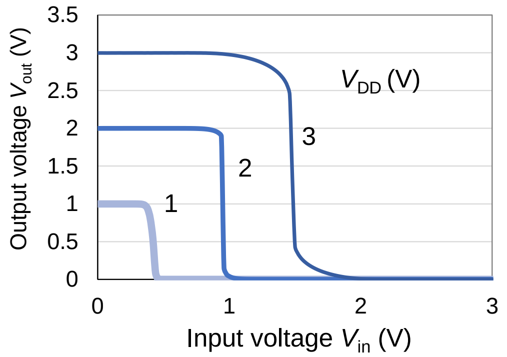

Fig. 5 Input and output characteristics of CMOS inverter.

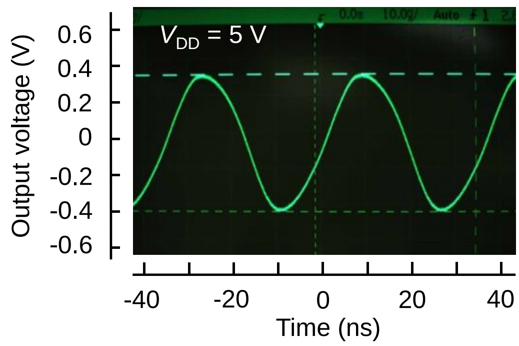

Fig. 6 Oscillation waveform of fabricated ring oscillator with three CMOS inverters.

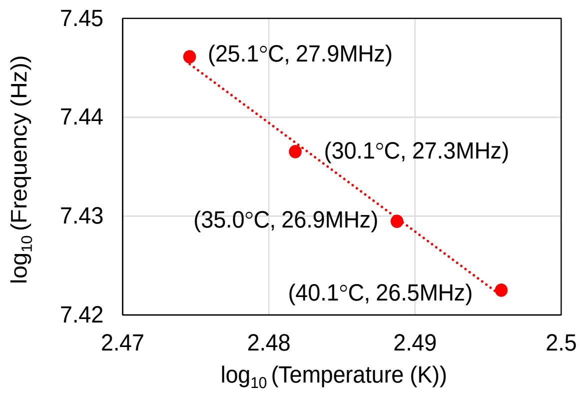

Fig. 7 Temperature dependence of oscillation frequency for the fabricated ring oscillator.