Single Crystalline Silicon CMOSFETs on Plastic and Their Application to Highly Sensitive Virus Detection System

Seiichiro Higashi[1], Rikiya Sumichika[1], Toru Suehiro[1], Hiroaki Hanafusa[1], and Yoshiko Okamura[2]

sehiga@hiroshima-u.ac.jp
[1]Graduate School of Advanced Science and Technology, Hiroshima University
Kagamiyama 1-3-1, Higashihiroshima, Hiroshima, 739-8530 Japan
[2]Graduate School of Integrated Sciences for Life, Hiroshima University
Kagamiyama 1-3-1, Higashihiroshima, Hiroshima, 739-8530 Japan
Keywords: Flexible electronics, Silicon CMOS, Virus detection device

ABSTRACT

Formation of single-crystalline silicon CMOSFETs on PET has been achieved by meniscus force mediated layer transfer (MLT) with a high yield of 99.97% and N-channel transistors show typical mobility of 529 $cm^2V^{-1}s^{-1}$. A novel application of MLT technology to a virus detection device based on micro-chamber matrix is addressed.

1 Introduction

Fabrication of high-performance devices on plastics is the key technology for highly functional flexible electronics and various semiconductor materials such as organics, oxides and their compound have been proposed. Still, silicon CMOS is the ideal device in terms of circuit operation with high frequency, low power consumption and high reliability. We have proposed meniscus force mediated layer transfer (MLT) to form single crystalline silicon channels on polyethylene terephthalate (PET) and glass substrates and successfully operated transistors based on a process steps described in Fig. 1[1-3]. N- and p-channel transistors show typical mobility of 529 (n) and 191 (p) $cm^2V^{-1}s^{-1}$, respectively, and subthreshold swings of 78.3 (n) and 72.3 (p) mV/dec, respectively. By an optimization of the microstructure for layer transfer, a high transfer yield of 99.97% over 16380 transistors has been achieved. CMOS inverter showed a clear reversal of input signal and a 5-stage ring oscillator was successfully operated with 14.3 MHz as shown in Fig. 2 [4]. In addition, a floating gate memory operation and a hybrid integration of silicon CMOS and perovskite photovoltaic cells have been achieved [5].

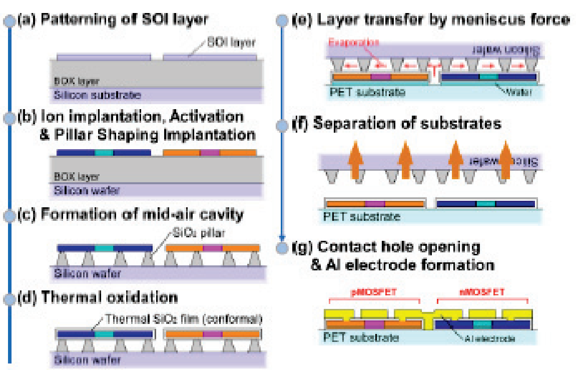

Fig. 1 Process steps to fabricate silicon CMOS on PET substrate based on MLT.

Based on the MLT technology, a new virus detection device has been proposed. In this work, the principle of virus detection and a micro chamber matrix concept will be addressed.

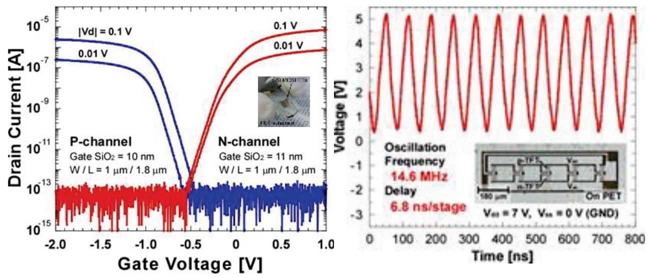

Fig. 2 I_d-V_g characteristics of n- and p-channel transistors (left) and operation waveform of a CMOS ring oscillator on PET (right).

2 Virus Detection Device

2.1 Principle of Virus Detection

The virus detection method most widely used under COVID-19 pandemic is reverse transcription polymerase chain reaction (RT-PCR). This requires thermal cycles to repeat replication of DNA and final detection is done by measuring the intensity of fluorescence. In order to realize virus detection device, electrical screening is required and we have introduced a method called RNaseH-assisted rolling cycle amplification (RHa-RCA) [6]. Based on the present method, virus can be detected with proton (H^+) generation induced by RCA reaction. Generation of H^+ affects pH of the solution, which can be detected by ion-sensitive field effect transistors (ISFETs) by their shift in threshold voltage (V_{th}).

2.2 High Sensitivity Detection by micro-chamber

RHa-RCA is an amplification method without thermal cycles and H^+ are generated continuously by the reaction. However, to achieve a high sensitivity comparable or

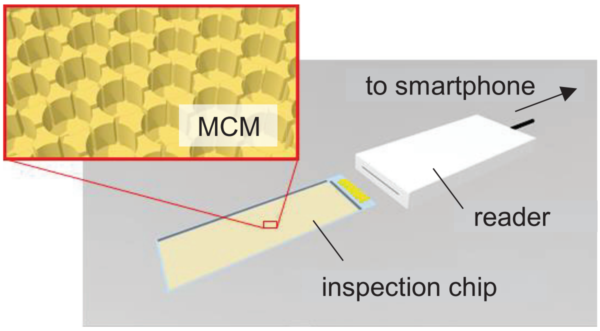

Fig. 3 A schematic diagram of virus detection device based on silicon micro chamber matrix (MCM).

even higher than that of conventional PCR, the authors introduced a micro structure called micro-chamber matrix (MCM) as shown in Fig. 3. MCM is composed of a huge number of small chambers (~20μm in diameter) which divides sample solution to small amount individuals in micro-chamber. Sample solution (saliva) is mixed with RHa-RCA solution and when the RCA reaction takes place with a virus in a chamber, the concentration of H^+ increases abruptly in the specific chambers where viruses exist. ISFETs located in each micro-chamber detect the change in pH by their shifts in V_{th}.

2.3 Virus Detection Circuit

The change in $\mathbf{V_{th}}$ of ISFETs in each micro-chamber is detected by raster scan of ISFET matrix based on the similar operation with active matrix for displays. Figure 4 schematically show the diagram. A specific detection of individual chamber corresponds to counting the number of virus in the sample, which gives very sensitive detection of virus density. Since the time for raster scan of the MCM will be less than 1s, the sensitivity is RCA reaction limited and the size of the micro-chamber should be designed to detect individual RCA reaction with one virus.

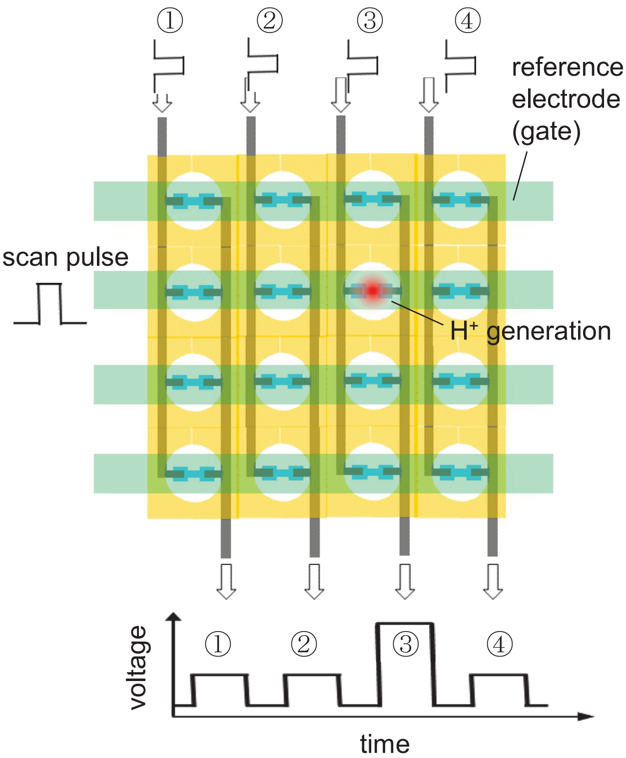

Fig. 4 A schematic diagram of electrical virus detection by raster scan of MCM composed of ISFETs at the cross point..

3 Conclusions

In this study, a new application of single-crystalline silicon CMOS on plastic to virus detection device has been addressed. This will be a new field of flexible electronics for the preparation of future coming new virus pandemic.

Acknowledgements

A part of this work has been supported by Japan Agency for Medical Research and Development (AMED) grant number 22he0422014j0002.

References

[1] K. Sakaike, M. Akazawa, S. Nakamura and S. Higashi, “Fabricating metal-oxide-semiconductor field-effect transistors on a polyethylene terephthalate substrate by applying low-temperature layer transfer of a single-crystalline silicon layer by meniscus force,” Appl. Phys. Lett., **103** (2013) 233510-1.

[2] K. Sakaike, M. Akazawa, A. Nakagawa and S. Higashi, “Meniscus-force-mediated layer transfer technique using single-crystalline silicon films with midair cavity: Application to fabrication of CMOS transistors on plastic substrates,” Jpn. J. Appl. Phys., **54**, (2015) 04DA08-1.

[3] M. Akazawa, K. Sakaike, and S. Higashi, “Formation of silicon-on-insulator layer with midair cavity for meniscus force-mediated layer transfer and high-performance transistor fabrication on glass,” Jpn. J. Appl. Phys., **54**, (2015) 086503-1.

[4] R. Mizukami, T. Yamashita, H. Hanafusa, and S. Higashi, “Single-Crystalline Si-CMOS Circuit Fabrication on Polyethylene Terephthalate Substrate by Meniscus Force-Mediated Layer Transfer,” IEEE J. Electron Dev. Soc., 7, (2019) 943.

[5] T. Hirano, F. Kondo, S. Nagasawa, H. Hanafusa, Y. Mizukawa, and S. Higashi, “Development of high-yield layer transfer process of single-crystalline silicon thin films on plastic substrate and its application to multifunctional device integration,” Jpn. J. Appl. Phys., **59**, (2020) SGGJ02-1.

[6] H. Takahashi, M. Ohkawachi, K. Horio, T. Kobori, T. Aki, Y. Matsumura, Y. Nakashimada, Y. Okamura. “RNase H-assisted RNA-primed rolling circle amplification for targeted RNA sequence detection”, Sci. Rep., **8**, (2018) 7770.