Temperature Sensor employing Ring Oscillator composed of Poly-Si Thin-Film Transistors: Comparison between Lightly-Doped and Offset Drain Structures

Jun TAYA, Kazuki KOJIMA, Tomonori MUKUDA, Akihiro NAKASHIMA, Yuki SAGAWA, Tokiyoshi MATSUDA, Nonmembers, and Mutsumi KIMURA, Member

SUMMARY We propose a temperature sensor employing a ring oscillator composed of poly-Si thin-film transistors (TFTs). Particularly in this research, we compare temperature sensors using TFTs with lightly-doped drain structure (LDD TFTs) and TFTs with offset drain structure (offset TFTs). First, temperature dependences of transistor characteristics are compared between the LDD and offset TFTs. It is confirmed that the offset TFTs have larger temperature dependence of the on current. Next, temperature dependences of oscillation frequencies are compared between ring oscillators using the LDD and offset TFTs. It is clarified that the ring oscillator using the offset TFTs is suitable to detect the temperature. We think that this kind of temperature sensor is available as a digital device.

Key words: temperature sensor, ring oscillator, poly-Si, thin-film transistor (TFT), lightly-doped drain structure (LDD), offset drain structure

1. Introduction

Poly-Si thin-film transistors (TFTs) have been widely applied to flat-panel displays (FPDs) [2], such as liquid-crystal displays (LCDs) [3] for not only computer monitors and mobile displays but also light valves in data projectors [4], organic light-emitting diode displays (OLEDs) [5], and electronic papers [6]. Because display properties of the liquid crystals [7], [8] and organic light-emitting diodes [9], [10] have temperature dependences, it is required to compensate them by controlling driving conditions. Actually, discrete temperature sensors are prepared near the LCDs for light valves, and the temperature dependences of the liquid crystals are compensated. However, because the temperatures have spatial distributions on the FPDs, it is required to measure the temperatures at several points and compensate the temperature dependences locally point by point.

Therefore, we proposed a temperature sensor employing off-leakage currents of poly-Si TFTs to measure the temperatures at several points [11]–[13]. However, it was needed to equip analog voltage sensing circuits, which are fairly complicated circuits and difficult to be integrated on the FPDs using poly-Si TFTs. Therefore, we proposed a temperature sensor employing a ring oscillator composed of poly-Si TFTs [14]. Although ring oscillators have been utilized to evaluate transistor characteristics [15]–[17], we believe that this was the first report to apply a ring oscillator to a temperature sensor.

Incidentally, TFTs with lightly-doped drain structure (LDD TFTs) are indispensable to reduce off-leakage currents and avoid characteristic degradation [18]–[24]. However, TFTs with offset drain structure (offset TFTs) can be simultaneously fabricated without any additional fabrication process. Therefore, as for n-type TFTs, we are very interested in which is suitable for a temperature sensor. On the other hand, as for p-type TFTs, because offset TFTs do not work at all, only LDD TFTs are used.

Again, we will propose a temperature sensor employing a ring oscillator composed of poly-Si TFTs. Particularly in this research, we will compare temperature sensors using LDD and offset TFTs. First, temperature dependences of transistor characteristics will be compared between the LDD and offset TFTs. It will be confirmed which have larger temperature dependence of the on current. Next, temperature dependences of oscillation frequencies will be compared between ring oscillators using the LDD and offset TFTs. It will be clarified which is suitable to detect the temperature.

2. LDD and Offset TFTs

First, the top-gate, coplanar, solid-phase crystallized (SPC), n-type and p-type, LDD and offset poly-Si TFTs are fabricated [25], [26]. Figure 1 shows the fabrication processes and device structures of the LDD and offset TFTs. These fabrication processes are standard processes for mass production. An amorphous Si film is deposited on a quartz substrate using low-pressure chemical vapor deposition (LPCVD) of SiH4 and crystallized using furnace annealing in N2 ambient to form a poly-Si film. A SiO2 film is grown using thermal oxidation in O2 ambient and another SiO2 film is stacked using chemical vapor deposition (CVD) to form a gate insulator film. The quality of the poly-Si film is improved using post annealing at 1000°C for 1 h. A metal film is deposited and patterned to form gate electrodes. Photoresists are patterned using photolithography as implantation masks, and phosphorus and boron ions...
are implanted, whose dose densities are $5 \times 10^{11} \text{cm}^{-2}$, to form LDD regions. Photoresists are patterned again, and phosphorus and boron ions are implanted, whose dose densities are $2 \times 10^{15} \text{cm}^{-2}$ and $1 \times 10^{15} \text{cm}^{-2}$, respectively, and activated using furnace annealing to form source-drain regions. The edge locations of the gate electrodes are apart from those of the source-drain regions. LDD TFTs are fabricated when the LDD regions are formed there, whereas offset TFTs are fabricated otherwise. As written above, offset TFTs can be simultaneously fabricated without any additional fabrication process. The poly-Si film thickness ($t_s$) and gate insulator film thickness ($t_i$) are 54.0 nm and 33.7 nm, respectively. The gate width ($W$) and gate length ($L$) are 50 μm and 4 μm, respectively, and the LDD length ($L_{\text{LDD}}$) and offset length ($L_{\text{Offset}}$) is 1.0 μm and 1.5 μm.

Next, the temperature dependences of the transistor characteristics are compared between the LDD and offset TFTs. Figure 2 shows the temperature dependences of the transistor characteristics. Here, the relationships between the drain current ($I_{ds}$) and gate voltage ($V_{gs}$) are shown when the drain voltage ($V_{ds}$) is fixed at 5 V and the temperature ($T$) is varied from $-20^\circ \text{C}$ to $100^\circ \text{C}$, where the vertical axes in the graphs for $L_{\text{LDD}}$ or $L_{\text{Offset}} = 1.5 \mu \text{m}$ are the same as those for $L_{\text{LDD}}$ or $L_{\text{Offset}} = 1.0 \mu \text{m}$ and omitted, and the relationships between $I_{ds}$ and $T$ are also shown when $V_{gs}$ and $V_{ds}$ are equal to 5 V for the n-type LDD, n-type offset, and p-type LDD TFTs. The subthreshold swing ($S$), threshold voltage ($V_{\text{th}}$), and field effect mobility ($\mu$) of the n-type self-aligned TFT, which are not shown in this paper, are 0.279 V·dec$^{-1}$, 1.03 V, and 67.3 cm$^2$·V$^{-1}$·s$^{-1}$, respectively, and those of the p-type self-aligned TFT are 0.215 V·dec$^{-1}$, −3.68 V, and 43.7 cm$^2$·V$^{-1}$·s$^{-1}$, respectively [14].

Fig. 1 Fabrication processes and device structures of the LDD and offset TFTs.
It is confirmed that the offset TFTs have larger temperature dependence of the on current. The mechanisms why the LDD TFTs have smaller temperature dependence of the on current and the offset TFTs have larger one are as follows. In the case of the LDD TFTs, because the parasitic resistances of the LDD regions are sufficiently low, $I_{ds}$ is mainly determined by the channel resistances. Although $\mu$ has certain temperature dependence, because the carrier densities of the channel regions are governed by $V_{gs}$, $I_{ds}$ does not change so much [27]. On the other hand, in the case of the offset TFTs, because the parasitic resistances of the offset regions are considerably high, $I_{ds}$ is mainly determined by the
parasitic resistances. Because the offset regions are intrinsic semiconductors and the carrier densities strongly change with $T$, $I_d$ also changes with $T$ very much. Incidentally, it is difficult to quantitatively measure the parasitic resistances of the offset regions because the parasitic resistances next to the channel regions seem quite different from those in the isolated intrinsic semiconductor patterns owing to the physical behavior.

3. Ring Oscillators

Next, ring oscillators composed of poly-Si TFTs are fabricated. The ring oscillators generate spontaneous oscillations, which are subject to the transistor drivability. Figure 3 shows the circuit diagram and microscope photograph of the ring oscillator. Here, static-type ring oscillators consist of the circularly connected odd stages of CMOS inverters, which are composed of the n-type LDD and offset TFTs with $W = 20 \mu m$, $L = 5 \mu m$, $L_{LDD} = L_{off} = 1.0 \mu m$ and p-type LDD TFTs. The supply voltage ($V_{dd}$) is applied, the output signal ($V_{out}$) is strengthened using the pickup circuit and observed using a high-impedance FET probe, and the oscillation frequency ($f$) is measured. It seems that $f$ is mainly dependent on the on currents of the LDD and offset TFTs. Therefore, we expect that $f$ is dependent on $T$.

Finally, the temperature dependences of $f$ are compared between ring oscillators using the LDD and offset TFTs. Figure 4 shows the temperature dependence of $f$. Here, the relationships between $f$ and $V_{dd}$ are shown when $T$ is varied from $-10^\circ C$ to $100^\circ C$ for the ring oscillators using LDD and offset TFTs. The temperature sensitivities of $f$, which are defined as the ratios between the increase of $f$ from $T = -10^\circ C$ to $100^\circ C$ and $f$ at $T = 10^\circ C$ for $V_{dd}$ =
10 V, \( f = 100^\circ \text{C} \) \(-f = -10^\circ \text{C}\), are also calculated, which are 0.39 and 2.68 for the ring oscillators using LDD and offset TFTs, respectively.

It is found that the ring oscillator using the LDD TFTs has little temperature dependence of \( f \), whereas that using the offset TFTs has larger temperature dependence of \( f \) owing to the larger temperature dependence of the aforementioned on current. Although we currently have only the ring oscillator composed of the offset TFTs with \( L_{\text{offset}} = 1.0 \, \mu m \), we suppose that the ring oscillator composed of the offset TFTs with \( L_{\text{offset}} = 1.5 \, \mu m \) has the comparable or higher sensitivity. In any case, it is clarified that the ring oscillator using the offset TFTs is suitable to detect \( T \). Because the temperature dependence of \( f \) is excellently smooth, the detection of \( T \) can be extremely precise. The aforementioned sensitivity of 2.68 corresponds to the change of 2.44 \% in \( f \) per the change of 1\( ^\circ \text{C} \) in \( T \), which is a sufficient sensitivity for controlling the driving conditions of the display devices. We think that this kind of temperature sensor is available as a digital device.

4. Conclusion

We proposed a temperature sensor employing a ring oscillator composed of poly-Si TFTs. Particularly in this research, we compared temperature sensors using LDD and offset TFTs. First, temperature dependences of transistor characteristics were compared between the LDD and offset TFTs. It was confirmed that the offset TFTs have larger temperature dependence of the on current. Next, temperature dependences of \( f \) were compared between ring oscillators using the LDD and offset TFTs. It was clarified that the ring oscillator using the offset TFTs is suitable to detect the temperature. We think that this kind of temperature sensor is available as a digital device. Generally, digital devices are superior to analog devices from the viewpoint of the outward signal operation. It is enough to equip digital pulse counter circuits, which are very simple circuits and easy to be integrated on the FPDs using poly-Si TFTs.

Acknowledgments

We thank Y. Hiroshima and M. Miyasaka of Seiko Epson. This work is partially supported by a collaborative research with Seiko Epson, grant for research facility equipment for private universities from the Ministry of Education, Culture, Sports, Science and Technology (MEXT), grant for special research facilities from the Faculty of Science and Technology of Ryukoku University, and MEXT-Supported Program for the Strategic Research Foundation at Private Universities.

References


[20] G. Usami, Y. Nogami, T. Yajima, M. Yamagata, T. Satoh, and H. Tango, “Hot-carrier degradation and electric field and electron con-


Jun Taya received the B.E. degree in Electronics and Informatics from Ryukoku University in 2012. He had been working on temperature sensors composed of poly-Si TFTs.

Kazuki Kojima received the B.E. degree in Electronics and Informatics from Ryukoku University in 2014. He had been working on temperature sensors composed of poly-Si TFTs.

Tomonori Mukuda received the B.E. degree in Electronics and Informatics from Ryukoku University in 2013. He had been working on temperature sensors composed of poly-Si TFTs.

Akihiro Nakashima received the B.E. and M.E. degrees in Electronics and Informatics from Ryukoku University in 2008 and 2011, respectively. He had been working on temperature sensors composed of poly-Si TFTs.

Yuki Sagawa received the B.E. degree in Electronics and Informatics from Ryukoku University in 2009, and M.E. degree in Material Science from Nara Institute of Science and Technologies in 2011. He had been working on chemical sensors and temperature sensors composed of poly-Si TFTs.

Tokiyoshi Matsuda received the B.S., M.S., and Ph.D. degrees in Science from Osaka University in 1997, 2000, and 2003, respectively. He joined the University of Sao Paulo as a postdoctoral researcher, Kochi University of Technology in 2004, and Ryukoku University in 2011. He has been working on the research and development of oxide materials for TFT applications.

Mutsumi Kimura received the B.E. and M.E. degrees in Physical Engineering from Kyoto University in 1989 and 1991, respectively, and the Ph.D. degree in Electrical and Electronic Engineering from Tokyo University of Agriculture and Technology in 2001. He joined Matsushita Electric Industrial Co., Ltd. in 1991, Seiko Epson Corp. in 1995, and Ryukoku University in 2003. He has been working on TFT characteristic analysis, TFT simulator development, TFT-OLED development, and their advanced applications.