**Paper 53-3** has been designated as a Distinguished Paper at Display Week 2018. The full-length version of this paper appears in a Special Section of the *Journal of the Society for Information Display (JSID)* devoted to Display Week 2018 Distinguished Papers. This Special Section will be freely accessible until December 31, 2018 via:

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Authors that wish to refer to this work are advised to cite the full-length version by referring to its DOI:

**10.1002/jsid.648**

# IGZO-TFT Technology for Large-screen 8K Display

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## Abstract

*We succeeded in G8 factory for mass production of IGZO-TFT for the first time in the world. The initial TFT process was an ES type TFT, but now we are mass producing CE type TFTs. And, its application range is smartphones, tablets, PCs, monitors, TV and so on. In particular, due to recent demands for high resolution and narrow frame, our IGZO display has been advanced in technology development with GIP (Gate driver In Panel). In this paper, we report development combining low resistance technology and the latest IGZO-TFT for large-screen 8K display.*

## Author Keywords

IGZO; Oxide TFT; large-screen 8K; high resolution; low resistance; 120Hz driving; single Data-line structure

## 1. Introduction

IGZO material was introduced by Kimizuka et al. in 1985 [1]. And ever since the application of a-IGZO to TFT was reported by Hosono's group in 2004 [2], many groups worldwide had reports on the studies and developments of IGZO. We have mass-produced IGZO-LCDs since 2012, the first time in the world.

As shown in Fig.1, at the G8 factory, the initial TFT process was an ES type TFT in 2012, as the first generation (IGZO1). Then, it was evolved to the second generation (IGZO2), as the display resolution was also evolved from 300ppi to 400ppi. CE type TFT was evolved as the third generation (IGZO3), and then the fourth generation (IGZO4). In each generation, we have made capacitance reduction (ES-type→CE-type), mobility increase and reliability improvement [3][4][5]. IGZO display has been advanced in technology development with GIP (Gate driver In Panel).

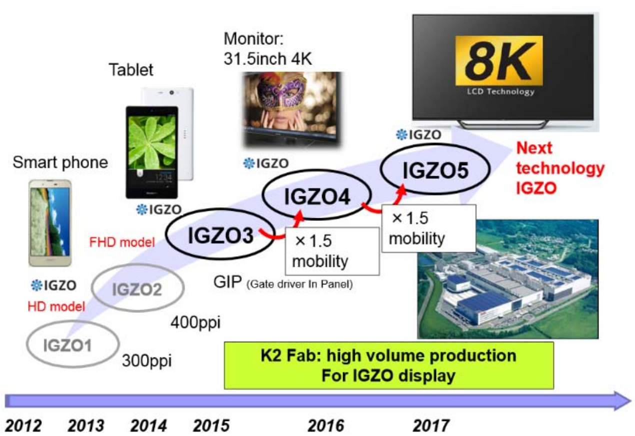


**Figure 1.** IGZO evolution.

As the latest IGZO process, we developed the fifth generation (IGZO5). Novel-TFT (IGZO5) achieves higher mobility, more than 2 times as high as IGZO2-TFT, and its mobility is 15 cm2 / Vs. It satisfies TFT static characteristics and long-term reliability, especially optimized for GIP.

On the other hand, in recent years, the display resolution has advanced from 100 ppi to 400 ppi or more for high resolution due to the market demand. Narrow display frame request from the market is not limited. The narrow frame has been applied from small displays like smartphones to PCs like 2 in 1 PC and tablet. The PC display with 2mm or less is required at about 15 inch display. So the IGZO display has advanced for narrow frame with GIP. Especially, at the G8 mother factory, IGZO-TFT is optimized for GIP circuit for small to medium size display (about 5 to 20 inch display). It has been developed and produced so that the long-term reliability of the GIP has high performance from low frequency to high frequency, low temperature to high temperature (including vehicle standard conditions).

As a demand for high performance display, a display of 8K resolution is demanded for the medical, information and TV applications in a large-screen display of more than 60 inch display. Fig.2 shows the resolution image from FHD to 8K. 8K resolution is 16 times more information quantity than FHD. Therefore, in the field where accurate information is required, it is becoming the necessary resolution.

In spite of the large-screen display, the pixel size is 200 μm with 4K resolution at 100-inch display. At 8K resolution, it is 90 μm or less. Fig. 3 shows the relationship between resolution and pixel size. It is important to reduce the time constant (RC) since 8K display increases the number of pixels and the number of gate and data signal crossing lines. The time constants (RC) of these displays depend on (1) signal line resistances, (2) signal line crossing capacitance, and (3) parasitic capacitance (Cgd) of TFT. It is important to lower these three factors.

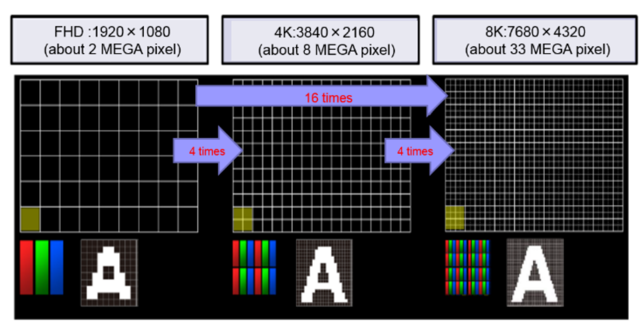


**Figure 2.** 8K resolution image from FHD to 8K.

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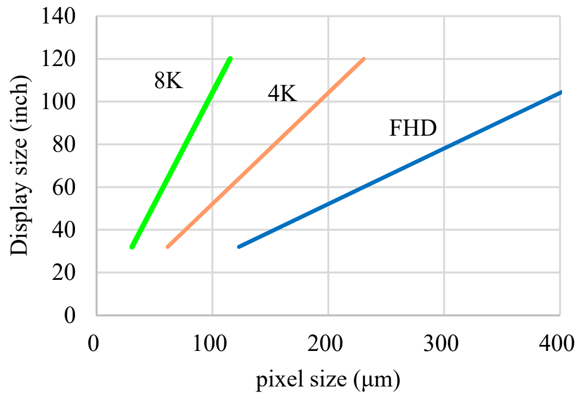
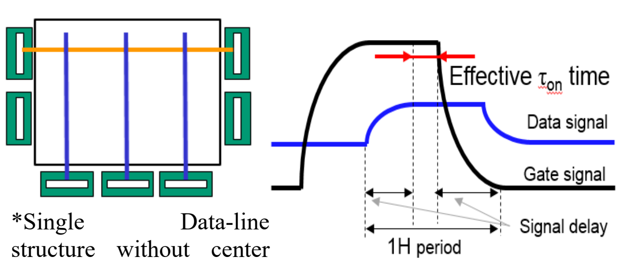



**Figure 3.** Display size vs pixel size.

Furthermore, at 8K resolution, the pixel charging time τon for TFT allocated to 1H is shortened due to the increase in the number of pixels. Figure 4 shows a signal timing of the effective charging time of the gate signal and the data signal for pixel charging. It is a single data-line structure without center split (fig.4 (a)). The waveforms of the gate and data signals are weakened from the delay by the time constant. Therefore, extracting the rise and decay time of the gate and data signals, the effective τon time is further shortened. Considering that the τon time at 4 K resolution with 120Hz is about 4 µsec, it is about 2 µsec at 8 K resolution. So, it is required for the back-plane to improve the charging capability of TFT and reduce the time constant of metal wirings.

In this paper, we report that we developed Novel-TFT (IGZO5) for large-screen 8K display. And also we optimized metal wiring process for latest TFT process for 8K-LCD.




(a) schematic structure (b) Signal timing

**Figure 4.** (a) Schematic design and (b) Signal timing of Gate and Data signal.

## 2. IGZO-TFT Characteristics

Fig.5 shows the TFT characteristics of Novel-TFT. These are TFT characteristics with 25 points at the G8 mother glass. Typical values of TFT characteristics are as follows: its mobility is 15 cm2 / Vs, Vth is 3.2 V, and S factor is 0.4 V / dec. The uniformity of Vth is under 10%, which is an excellent result when considered in the G8 mother glass. This good distribution shows high reliability when applied to GIP (gate driver in panel) circuit. Although the mobility is improved, the off-TFT characteristic is less than 10 fA. Those characteristics are equivalent to those of the conventional IGZO-TFT. So, The ON / OFF ratio of the TFT characteristics is upgraded.

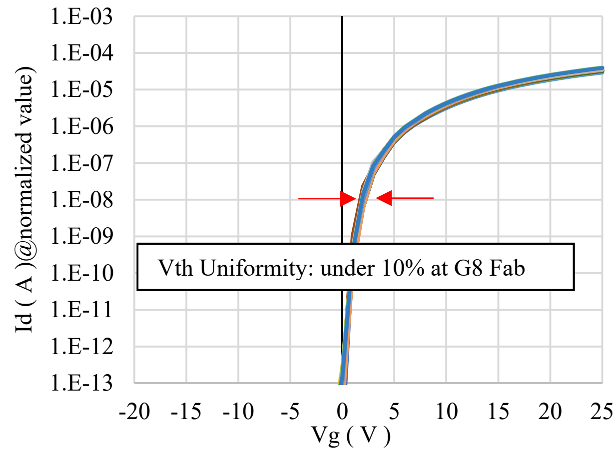



**Figure 5.** Novel-TFT property at 25-point mother glass.

Fig.6 shows the results of stress test of Novel-TFT. Novel-TFT is evaluated under a stress condition of PBT (Positive Bias Temperature) and NBT (Negative Bias Temperature). The PBT condition is Voltage=+30V (DC), temperature=60 ° C. the NBT condition is Voltage=-30V (DC), temperature=60 ° C. The vertical axis is normalized with the shift amount of Vth based on the PBT value of a-Si-TFT. The result indicates that in PBT, Novel-TFT has improved Vth shift by 70% compared with a-Si-TFT. In addition, each IGZO-TFT has a high advantage in NBT compared with a-Si-TFT. Even in comparison with the process difference of IGZO-TFT, Novel-TFT (CE-type) has better PBT results than ES-type TFT (IGZO2). It is excellent reliability property with Novel-TFT.

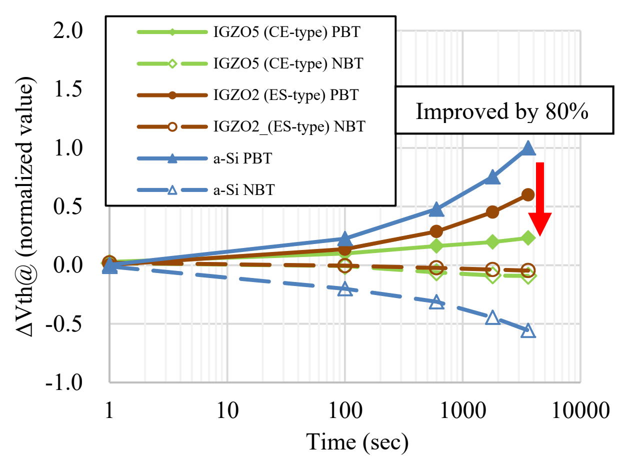



**Figure 6**. Stress evaluation at various IGZO-TFT.

Figure 7 shows the temperature characteristics of Novel-TFT. It is generally known that TFT has a change in Vth depending on temperature. When the temperature property has large variation, it affects display quality and long-term reliability. Especially, in the GIP circuit, it is necessary to design a circuit considering the temperature property. The greater the temperature dependence is, the larger the circuit area (display frame) becomes. The temperature dependence of Novel-TFT is the same as IGZO-TFT of ES type, which is almost 0, when a-Si-TFT has big dependence. From temperature evaluation, it was confirmed that the Novel-TFT had excellent temperature characteristics. Note that the temperature characteristics of the IGZO-TFT may depend on the process conditions. This temperature characteristics with high reliability is because of optimized TFT process.

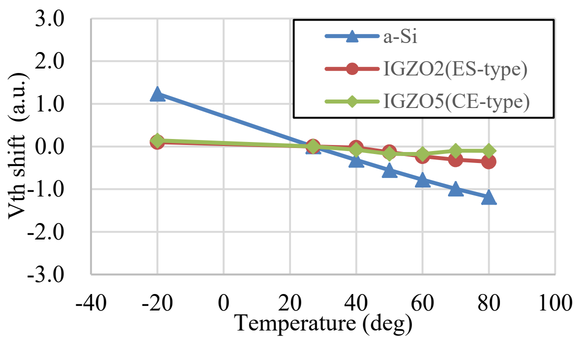



**Figure 7.** Temperature characteristics of various IGZO-TFT.

In recent years, it is demanded to have a narrow frame and high-speed driving of 120 Hz or more for high-end model. GIP is necessary for such a display, and also requires an enhancement type TFT, high mobility, low shift Vth, and low production variation. In general, high Vth and low Vth shifts are trade-off for TFT property with high mobility. However, the Novel-TFT meets the requirements of high mobility, high Vth (enhancement type), low Vth shift. We can realize long-term reliability of GIP and high-speed driving such as 120 Hz.

The GIP circuit using Novel-TFT has been evaluated by a 50% Duty Plus stress test. This evaluation is an indicator of the long-term reliability of the GIP circuit. Fig.9 shows the result of Vth shift in 50% duty plus stress test. As a result, Novel-TFT has improved Vth shift amount by 80% compared to a-Si-TFT. Therefore, it is possible to further reduce the area of GIP circuits (LCD frame) and to drive at high speed.

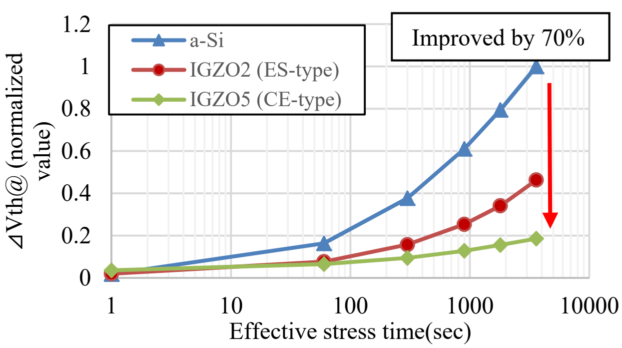



**Figure 8.** Plus stress evaluation of IGZO5-TFT vs a-Si TFT.

## 3. Low Resistance Technology

In the conventional process, it has been necessary to increase the thickness of the gate metal film in order to satisfy the sheet resistance of the gate wiring, which is required for the high speed driving for large-screen 8K display. However, the thicker the metal thickness is, the more glass breakage occurs, due to the film stress of gate metal. And there is a limit to lower the sheet resistance. Therefore, we have developed a process to reduce the sheet resistance by a method other than increasing film thickness.

In the past, we have used Cu metal for gate lines. A multi-structure of Cu/Ti have been employed from the reasons of reliability such as metal corrosion. The role of lower layer (Ti) is to get adhesion between glass and gate wiring for reliability. It is essentially inevitable that Ti is diffused into the pure-Cu side due to the thermal influence of the CVD process and thermal profile of TFT process so that the sheet resistance of the gate line is increased. Therefore, we reduce the resistance by excluding Ti this time and have adopted a method in which Cu is directly deposited on glass. And we have confirmed that there is no problem with adhesion to glass, reliability and processing in the factory.

Figure 9 shows the sheet resistance of the new gate process developed at this time. Compared with the conventional gate sheet resistance, it was confirmed that sheet resistance reduction was 50%. The reason is that there is no Ti diffusion into Pure-Cu and it is suppressed to increase the gate sheet resistance.

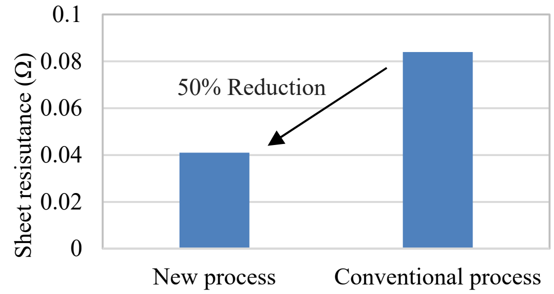



**Figure 9.** Sheet resistance of gate metal line.

## 4. 8K designing Simulation

It is designed by simulation using low resistance process and Novel-TFT for large-screen 8K LCD. Fig.10 shows the simulation results of Turn-on time and pixel charging ratio with TFT size assuming pixel for 8K resolution. At 8K resolution, since the pixel size is so small, the minimum processing TFT size should be used for high aperture and low gate load. Novel-TFT with the minimum TFT size satisfies the charging ratio even with 120Hz driving at 100-inch. In the Novel-TFT which can use the minimum TFT size, the gate capacitance can be reduced. In the case of using Novel-TFT, it is found that a single-source input 8K4K 120 Hz-driving panel is established without changing the size of TFT W, source driving method and the signal input method. However, in conventional a-Si TFT, it is impossible to charge pixel in the TFT of the smallest processing size due to its low mobility. For this reason, the W size of a-Si TFT needs to be 6 times as large as Novel-TFT. However, due to the trade-off of increasing the W size of the TFT in order to charge pixel, the gate load becomes larger. Further upsizing W size is the opposite effect, it is impossible to design to perform sufficient pixel charging. In order to establish with a-Si TFT, it is necessary to further adjust TFT W size, the source driving method and the signal input method.

Therefore, in the Novel-TFT and low resistance process, it is possible to get sufficient pixel charging and reduce the time

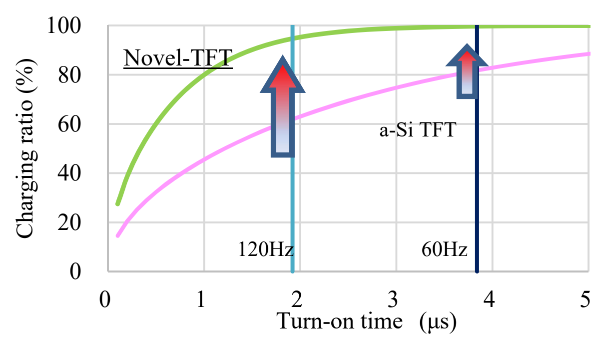



**Figure 10.** Charging ratio for Pixel at 60 Hz and 120Hz at 100-inch.

constant of the gate and data line by processing minimum TFT. We have confirmed that it is possible to develop display with 8 K resolution up to 120 Hz with single data-line structure [6].

Fig.11 shows the sheet resistance of the gate wiring and the value of the time constant τg. Since Novel-TFT deploys the minimum size of TFT, Cgd, which is the parasitic capacitance of the TFT, is the smallest. In particular, the τg reduction rate on the gate wiring has a reduction effect of 70% compared with the conventional a-Si-TFT. This is a very large factor because the turn-on time needs to be adjusted in about 2μs. Also, it shows that not only the rise of charging but also the decay is improved. It is possible to greatly improve the deterioration of display quality (ghost phenomenon etc) by recharging.

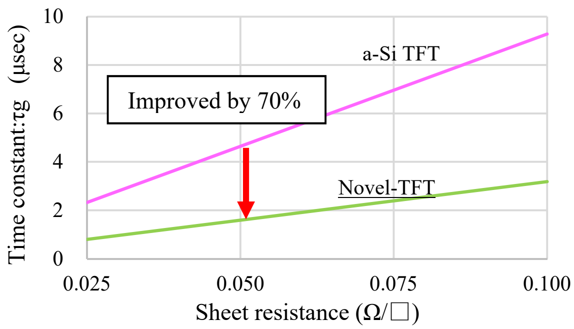



**Figure 11.** Relationship between sheet resistance of gate line and time constant (τg).

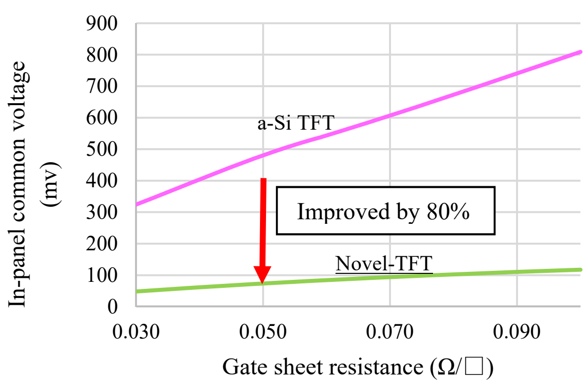



**Figure 12.** In-panel common voltage at Novel-TFT and a-Si TFT.

In addition, since display sizes of 60 inch or more are larger than the size of the photomask, it is impossible to expose photolithography by one scanning. So it is exposed with a plurality of repetitions, it is impossible to correct the optimum of the parasitic capacitance (Cgd) along the gate line using panel design. In the case of using a conventional a-Si-TFT, since the mobility is low, the TFT size increases. So in-panel distribution of common voltage becomes larger and it causes problems such as image sticking of LCD. With the newly developed Novel-TFT, the TFT size can be set to the minimum processing size and the in-panel common voltage can be suppressed to 100 mV or less, comparable to that of the mobile size panel, as shown in Fig.12.

## 5. New Technologies Utilizing IGZO-TFT

Fig.13 shows the prototype display of 27 inch with 8K4K resolution [6]. It is driven at 120 Hz. Further applying the Novel-TFT and low resistance technology, we have made the prototype display for signage with 80-inch 8K4K in Fig.14. This also realizes 120 Hz driving and indicates the verification of large panel process mass production with single data-line structure. From now on, it can contribute in a wide range of applications such as TV, signage, monitor and the medical with 120Hz driving applied Novel-TFT and low resistance technology.


**Figure 13.** 27 inch 8K4K for signage (prototype) with 120Hz driving.


**Figure 14.** 80 inch 8K4K for monitor (prototype) with 120Hz driving.

## 6. Impact

In this paper, we developed the fifth generation IGZO-TFT. Its mobility was 15 cm 2 / Vs, and high reliability was confirmed. In addition, we developed a low resistance technology and reduced the wiring resistance by 50%. By combining these technologies, it was possible to simulate the feasibility of a 120 Hz panel of a large-screen 8K4K display with single-data line structure, and confirmed that the display quality was mass-production level. By applying these technologies to all applications, we can develop LCD of high definition, narrow frame, high frequency, and in-cell touch panel. Moreover, it can be applied as an effective backplane for displays other than LCD.

## 7. Acknowledgements

Authors would like to gratefully acknowledge all the associated members of Kameyama FAB2 Group, Research and Development Group, and associated Groups

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