A conductor-based thin-film transistor with no apparent channel for simplified, high aperture-ratio pixel architectures

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ABSTRACT

A major bottleneck issue of oxide TFTs is the instability under bias stress and illumination. Furthermore, the current driving capability or carrier mobility is insufficient for high spec displays, forcing the introduction of expensive LTPO. Our recent work on ITO based source-gated transistors are reviewed which largely overcome these issues.

1 Introduction

Despite of rapid adoption of oxide semiconductors to replace amorphous silicon in display backplane drivers, a major bottleneck issue of oxide thin-film transistors (TFTs) is the instability under bias stress and illumination. Furthermore, the current driving capability is becoming insufficient in high pixel density and high brightness displays, forcing the introduction of hybrid LTPO at a much higher cost. Finally, OLED aging causes threshold voltage drift, hence requiring complex pixel driving circuits. Here, we review our recent work on ITO based source-gated transistors (SGT) which can largely overcome the above issues.

2 Experiment

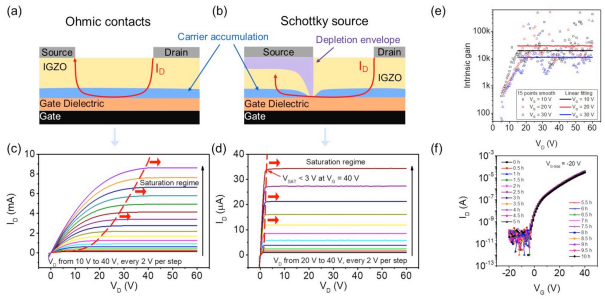

Fig. 1 Structure and conduction path of (a) TFT and (b) SGT. Output curves of (c) TFT and (d) SGT. (e) Intrinsic gain and (f) NBTIS of the IGZO SGT [1].

A conventional TFT comprises ohmic source and drain electrodes which are joined by a semiconductor channel. The carrier concentration can be tuned by a gate electrode via an insulating dielectric, and the gate voltage, V_G, controls the conductivity of the channel as shown in Fig. 1(a). In SGTs, as shown in Fig. 1(b), a Schottky contact is used as the source contact, which determines the current. This is in contrast to a conventional TFT, in which the channel determines the current[1].

One major effect of replacing the ohmic source with a Schottky source can be noticed from the output curves of an IGZO TFT and SGT in Figs. 1(c) and 1(d) [1]. The TFT current only saturates at $V_D = V_G - V_{TH}$, where V_D is the drain voltage and V_{TH} is the threshold voltage. The low saturation voltages in the SGT is attributed to the full depletion of the semiconductor layer by the Schottky source as shown in Fig. 1(b). As shown in Fig. 1e, the better saturation in the SGT enables an intrinsic gain up to 23,000 V/V, which is to the best of our knowledge the highest ever achieved with a solid-state transistor. As the current is controlled by the Schottky junction under the Source contact (rather than the channel), such device also shows little shift in the NBTIS test, as shown in Fig. 1(d) [1].

The Schottky source offers an extra depletion profile under the source contact in an SGT. This opens a possibility to deplete even a semi-metal or conducting material when it is used as the channel layer. Here, we have tried to use conducting ITO (which is conventionally used only as a transparent conductor) to replace IGZO as the channel layer [1]. The ITO channel material is highly doped, so it is difficult for the gate to modulate the conductivity except in the area under the source, where the extra depletion due to the Schottky barrier exists. The high carrier concentration also reduces the effective barrier height of the Schottky source, resulting in a higher on-current than a conventional SGT. This suggests that it is not necessary to have the gate extending beyond the source, which provides a new design for SGTs as shown in Fig. 2(a) [2]. Here ITO is used as the channel as well as the drain. The gate can be placed only under the Schottky source rather than the channel. The total device area is just the source, which is around one third of the conventional TFT, as shown in Fig. 2(a). This design is highly preferable in displays as it not only simplifies the fabrication process, but also improves the aperture ratio [2].

Figure 2(b) shows an ITO SGT matrix with the novel design. The gate line overlaps with the data line and the ITO is used as both channel material and transparent area. As the semiconductor, source contact, and gate

electrode are overlapped and hide under the data line, for the same line width, the active area of the SGT pixel is larger than the TFT one. This becomes more significant when increasing the pixel density. The novel design will provide a higher the aperture ratio for LCD displays, and a more stable driving current if using ITO SGT as the driving TFT in the OLED pixels.

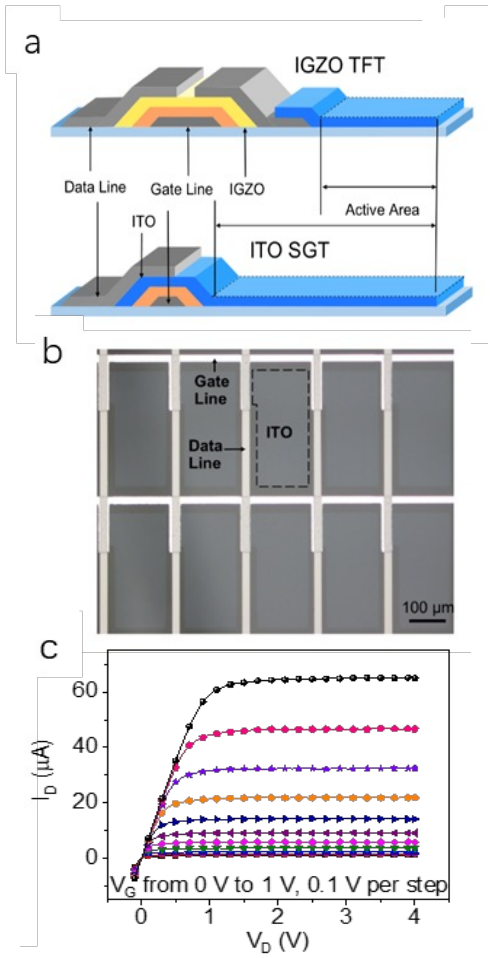

Fig. 2 (a) Comparison of IGZO TFTs and ITO SGTs. (b) ITO SGT pixel matrix. (c) Output characteristics of the ITO SGT [2].

The TFT size in an OLED pixel determines the required OLED driving current density for a given brightness. An ITO SGT uses the same ITO for both the channel and the drain electrode. This enables aggressive scaling for much higher pixel aperture [2]. The higher aperture ratio also allows for a lower OLED driving current density and thereby reduces the OLED aging effect.

OLED aging induced brightness drift is another challenging issue. Our simulation of a 5T2C pixel circuit indicates that the image brightness can be maintained more consistently when using the SGT as the driving transistor when the threshold of OLED drifts because of aging [3,4]. Furthermore, our study shows that the SGT can provide a much more stable output current over a wide range of V_{dd} in OLED driving circuits.

3 Conclusions

Rather than using an ohmic metal contact as the source electrode, a high work-function Schottky source contact enables depletion around the TFT source region. This results in an intrinsic immunity to negative bias illumination stress, no obvious short channel effect, and superb current saturation over a wide range of drain voltage. The flat saturation current gives rise to an extremely high voltage gain reaching 23,000, which is, to the best of our knowledge, the highest gain ever achieved by a solid-state transistor to date. The threshold voltage is also found to remain stable under different drain voltages, in contrast to standard TFTs, which may be useful in large area displays where the drain voltages of the drive TFTs may differ due to line resistance. Moreover, the depletion provided by the Schottky source electrode allows utilizing semi-metal ITO to replace IGZO as the TFT channel layer, which significantly enhances the carrier mobility and current driving capability. The resulted higher pixel aperture ratio allows for a higher brightness, a higher OLED pixel density, a lower OLED driving current density and thereby, a much reduced OLED aging effect.

References

[1] J. Zhang, J. Wilson, G. Auton, Y. Wang, M. Xu, Q. Xin, and A. Song, “Extremely high-gain source-gated transistors”, PNAS 116 (11), 4843 (2019).

[2] J. Wilson, J. Zhang, A. Song, “A thin‐film transistor with no apparent channel for simplified, high aperture ratio pixel architectures”, J. Soc. Inf. Display, 30 (10), 765-774 (2022).

[3] Z Wang, L Luo, Y Wang, J Zhang, A Song, “Comparative study of short-channel effects between source-gated transistors and standard thin-film transistors”, IEEE Transactions on Electron Devices, 69 (2), 561-566 (2022).

[4] Shan Huang, Jidong Jin, Jaekyun Kim, Wenjing Wu, Aimin Song, and Jiawei Zhang, “IGZO Source-Gated Transistor for AMOLED Pixel Circuit”, IEEE Transactions on Electron Devices, 70 (7), 3637 – 3642 (2023).