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IEEE Open Journal of the Solid-State Circuits Society Special Section on *Integrated Circuits and Systems Based on Thin-Film Transistors*

I. INTRODUCTION

THIN-FILM transistors (TFTs) are ubiquitous today as a backplane technology for various display and imager products. Those transistors act as switches in active-matrix liquid-crystal displays (AM-LCDs) or as full-pixel engines, including driving and threshold compensation, in active-matrix organic light-emitting diodes (AM-OLEDs) panels. TFT manufacturing requires only a limited amount of photolithographic steps, making it a relatively simple transistor technology, compared to the traditional Si CMOS technologies. The processing temperature of TFT technologies is sufficiently low to be compatible with glass and can even enable flexible substrates. Finally, these transistors have been developed specifically for large-area applications, such as televisions and X-ray scanners. Consequently, the backplane size for TFTs has evolved from the generation-1 glass panel of 270 mm by 360 mm to generation-10.5, which is manufactured on a glass panel of 2.94 m $\times$ 3.37 m [1]. This is profoundly different from traditional Si CMOS integrated circuits, which are fabricated nowadays on 200 mm or 300 mm round wafers. The critical dimension of the TFT technology on glass or flexible substrate in production is in the range of a few micrometers. The TFT research in the display field focuses on enabling increasingly better pixel resolution, improved visual quality, larger panels for LED walls, flexible displays, camera-behind display, sensor integration, and many more.

The four most popular TFT technologies are based on different semiconductors [2], more precisely amorphous silicon, or a-Si, complex amorphous metal oxides, such as Indium–Gallium–Zinc–Oxide or IGZO, low-temperature polycrystalline silicon or LTPS, and organic semiconductors. A-Si, LTPS, and IGZO are commercially available in backplane products today, each with their own advantages. A-Si and IGZO exhibit the simplest process flow, can be upscaled to the largest panel sizes, and yield therefore the lowest cost per unit area, however, both are unipolar technologies, e.g., IGZO enables only n-type transistors posing some challenges to the backplane design. LTPS on the contrary has both p-type and n-type TFTs available and provides a higher charge carrier mobility compared to IGZO and a-Si, at the cost of a more complex process flow, a lower upscaling possibility for larger substrates and therefore a larger cost per unit area. A recent trend is the hybrid integration of n-type IGZO transistors with their superior leakage characteristics and p-type LTPS transistors enabling complementary circuits and backplanes for display products [3], [4].

The key advantages of TFTs, such as the potential for large-area manufacturing on flexible surfaces at a relatively low cost per unit area make them also attractive for applications beyond the display and imager fields. Novel emerging applications can be categorized as array-based [5], [6], [7], [8], [9], [10] or individual-integrated-circuits-based [11], [12], [13], [14], [15], [16], [17]. Array-based electronics, similar to displays, combines several identical pixels into arrays, e.g., to interface an array of biosensors, to control droplet movements in lab-on-chip applications like microfluidics, or to drive actuators, such as piezoelectric micromachined ultrasonic transducer (pMUT) and capacitive micromachined ultrasonic transducer (cMUT) arrays for large-area mid-air haptic feedback applications. Individual integrated circuits manufactured with TFTs can be used for peripheral or standalone electronics. The former encompasses integrated readout and drive circuitry acting as an interface between the pixel arrays and Si CMOS chips, which take care of more complex backend and/or communication functions. The latter category consists of standalone integrated TFT circuits for Internet-of-Things applications, such as sensor tags, wearable health patches, etc.

This special section covers three diverse and interesting papers that deal with new concepts in the field of TFT electronics. The first invited publication [A1] focuses on large-area electronics devices based on zinc-oxide transistors for wireless and Internet of Things. The target application is large-area wireless energy transfer, either using the base carrier frequency of 13.56 MHz for radio-frequency identification reader arrays or using GHz phased arrays for far-field radiation beam steering. This work clearly shows that technology-aware design concepts can enable unprecedented approaches for future applications.

The second paper [A2] focuses on an ultra-high sensitivity biosensor array application based on electrolyte-gated organic TFTs. The innovation in this work is to enable interfacing between a Si CMOS front-end and the organic biosensors using organic TFT (OTFT) electronics. The Si CMOS and biosensors operate at 1.2 V, whereas the OTFTs require a 30-V supply. The interface electronics consist of an OTFT multiplexer controlled by an OTFT line driver. The current-domain interface transfers signals between the low-voltage sensors and the Si frontend via the high-voltage TFT circuits. In this way, a cost-effective solution is provided to readout a matrix of biosensors using a compact Si chip.

The third publication in this special section also focuses on peripheral circuits for sensor-array electronics, which could be biosensors, but also photodiodes for (medical) imagers or CMUTs [A3]. The TFT technology is different from the first two publications, as this paper implements LTPS-based circuits. The sensors targeted in this work have a charge output, requiring charge-integrating amplifiers as peripheral circuits for the arrays. The LTPS technology offers several benefits over the organic or oxide TFTs, such as a high charge carrier mobility and the availability of a complementary transistor, which is exploited in this work by realizing a more complex readout. This approach will allow to further simplify the Si CMOS backend and therefore the system architecture in applications requiring a large number of sensors.

APPENDIX: RELATED ARTICLES

[A1] Y. Ma et al., "Device, circuit, and system design for enabling gigahertz large-area electronics," *IEEE Open J. Solid-State Circuits Soc.*, vol. 2, pp. 177–192, 2022.
[A2] E. Genco et al., "A 4×4 biosensor array with a 42-lW/channel multiplexed current sensitive front-end featuring 137-dB DR and zeptomolar sensitivity," *IEEE Open J. Solid-State Circuits Soc.*, vol. 2, pp. 193–207, 2022.
[A3] M. Dandekar, K. Myny, and W. Dehaene, "An all LTPS-TFT based charge-integrating-amplifier for sensor-array readout circuit on flexible substrate," *IEEE Open J. Solid-State Circuits Soc.*, vol. 2, pp. 208–216, 2022.

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