Flexible Microelectronics; New Application of Thin Film Transistors to Fingerprint Sensors

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Thin film transistors (TFTs) are field-effect transistors that can be used to create large-scale integrated (LSI) circuits. The combination of Suftla technology and high-performance TFTs has the potential to foster the rise of a new flexible microelectronics industry. This paper discusses the current status of flexible microelectronics, using a TFT fingerprint sensor (FPS) as an example. Technology used in active matrix displays can easily be applied to the TFT FPS. TFT technology should not be confined to the display industry; its use should be expanded into the semiconductor industry. With the result presented in this paper, we declare a new era of flexible microelectronics open.

1. Introduction

Some people, it seems, confuse thin film transistors (TFTs) with liquid crystal displays (LCDs) because, at present, TFTs are found only in the LCD industry. A TFT, however, is a metal-oxide-semiconductor field-effect transistor (MOSFET) and one that may one day compete with ordinary single-crystal silicon MOSFETs fabricated on a bulk silicon wafer. In terms of transistor electrical properties, a polycrystalline silicon TFT (polysilicon TFT) is positioned between an amorphous silicon TFT (a-Si TFT) and a single-crystal silicon MOSFET. But polysilicon TFT electrical properties are inching their way towards equivalence with those of single-crystal silicon MOSFETs. Early on, when polysilicon TFT technology first became feasible, polysilicon TFT circuits were only able to transfer a few triggering pulses [1]. Today, however, no one is surprised to hear that digital-to-analog conversion circuits [2] or signal-processing circuits, such as a γ-adjusting circuit of an LCD [3], have been integrated on a glass substrate with polysilicon TFTs. Polysilicon TFT technology will soon become an integral part of the semiconductor industry, where it will enable TFT large-scale integrated (TFT LSI) circuits on glass or on plastic.

Suftla (surface-free technology by laser annealing/ablation) is a superb technology that enables TFT circuits to be transferred to a plastic sheet [4, 5]. The combination of Suftla and high-performance polysilicon TFT technologies will foster a new flexible microelectronics industry, which will realize TFT LSI circuits on a plastic sheet.

This paper discusses the current state of flexible microelectronics, especially focusing on the highly functional TFT circuit. The world's first practical TFT fingerprint sensor (FPS) is presented as an example of TFT LSI circuits.

2. TFT Scaling Rule

Semiconductor device geometries have historically shrunk in line with the scaling rule. Polysilicon TFT scaling obeys the same rule.

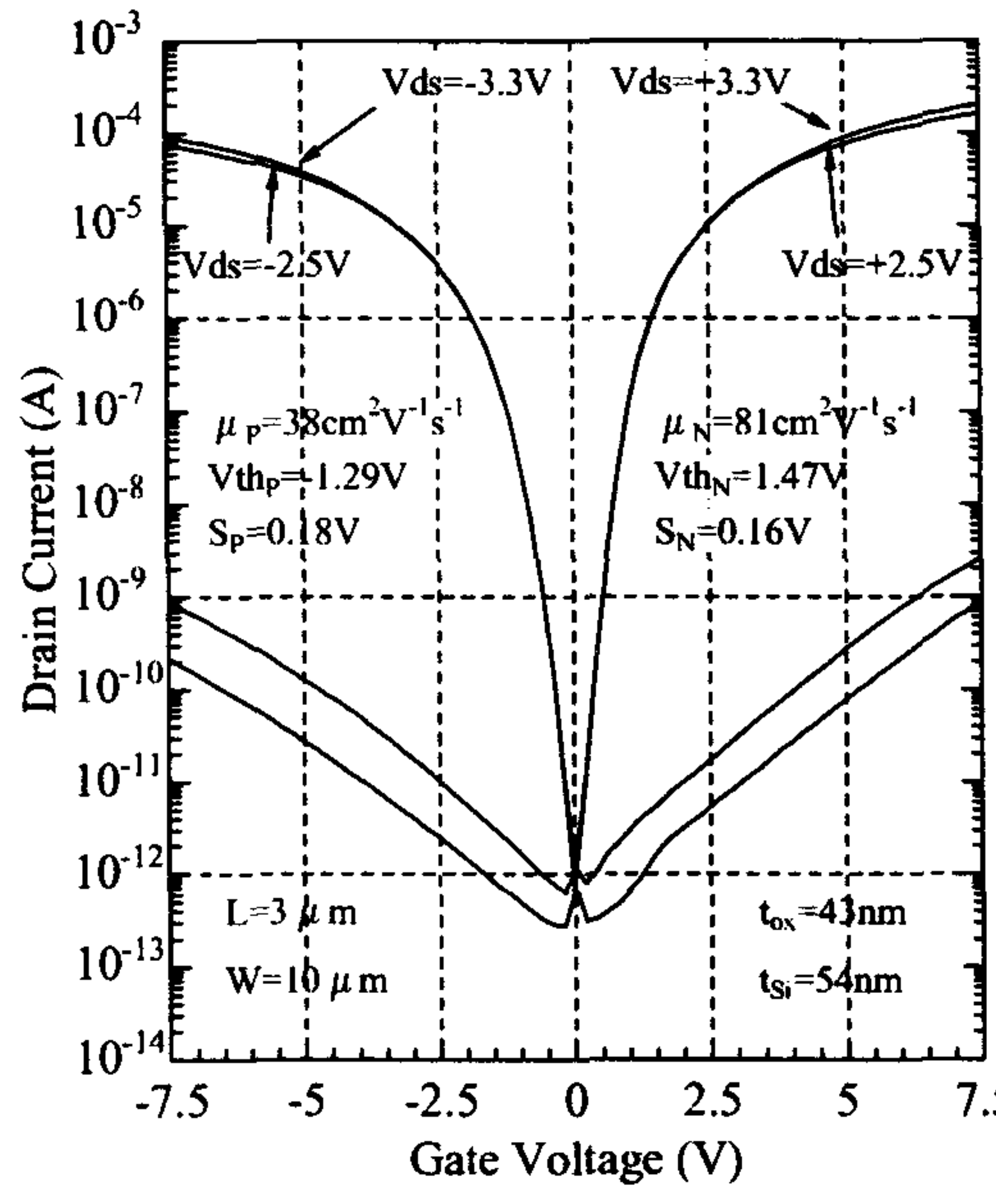

Fig. 1 Transfer characteristics of high-performance TFTs

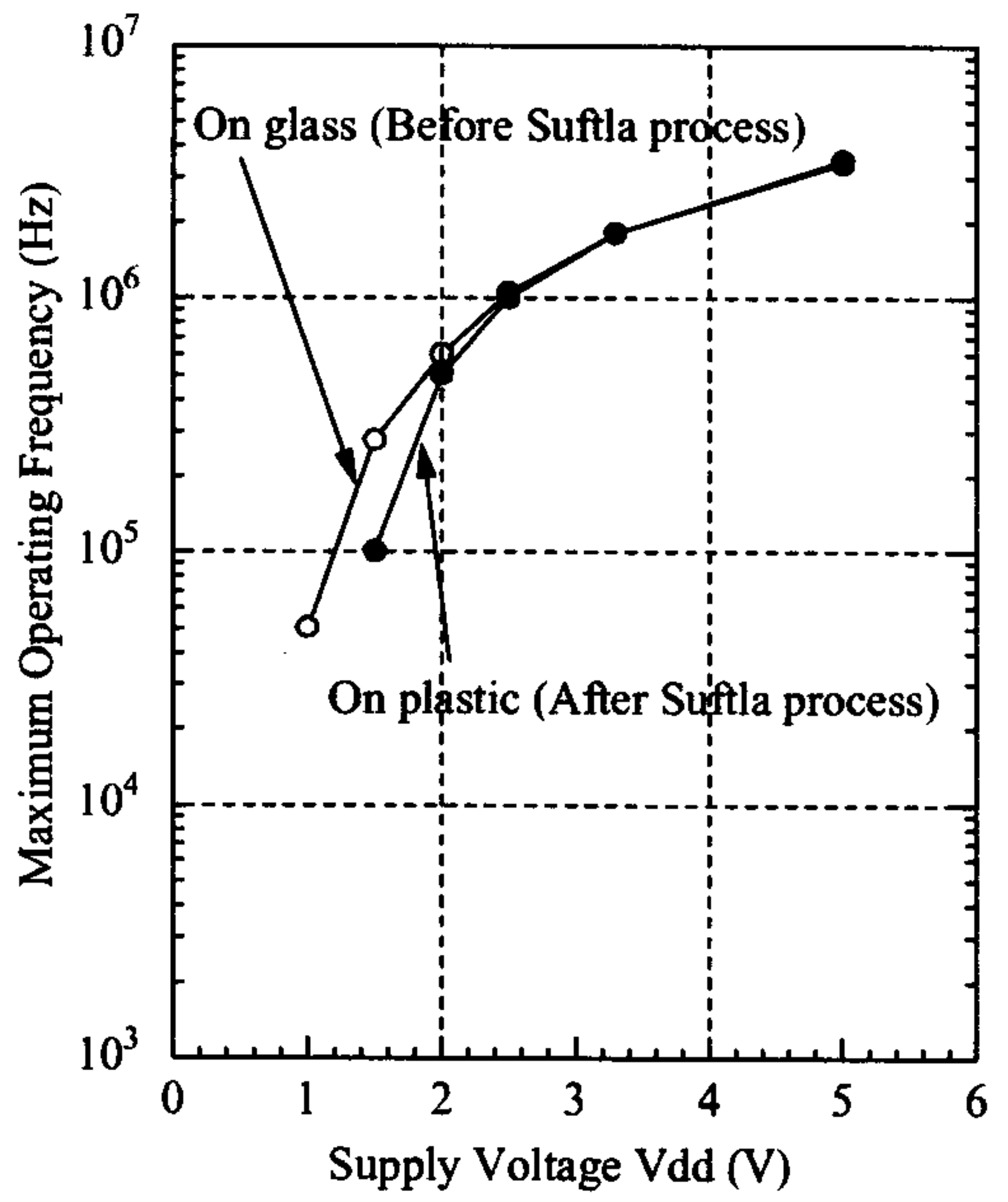

Fig. 2 Shift register circuit operation

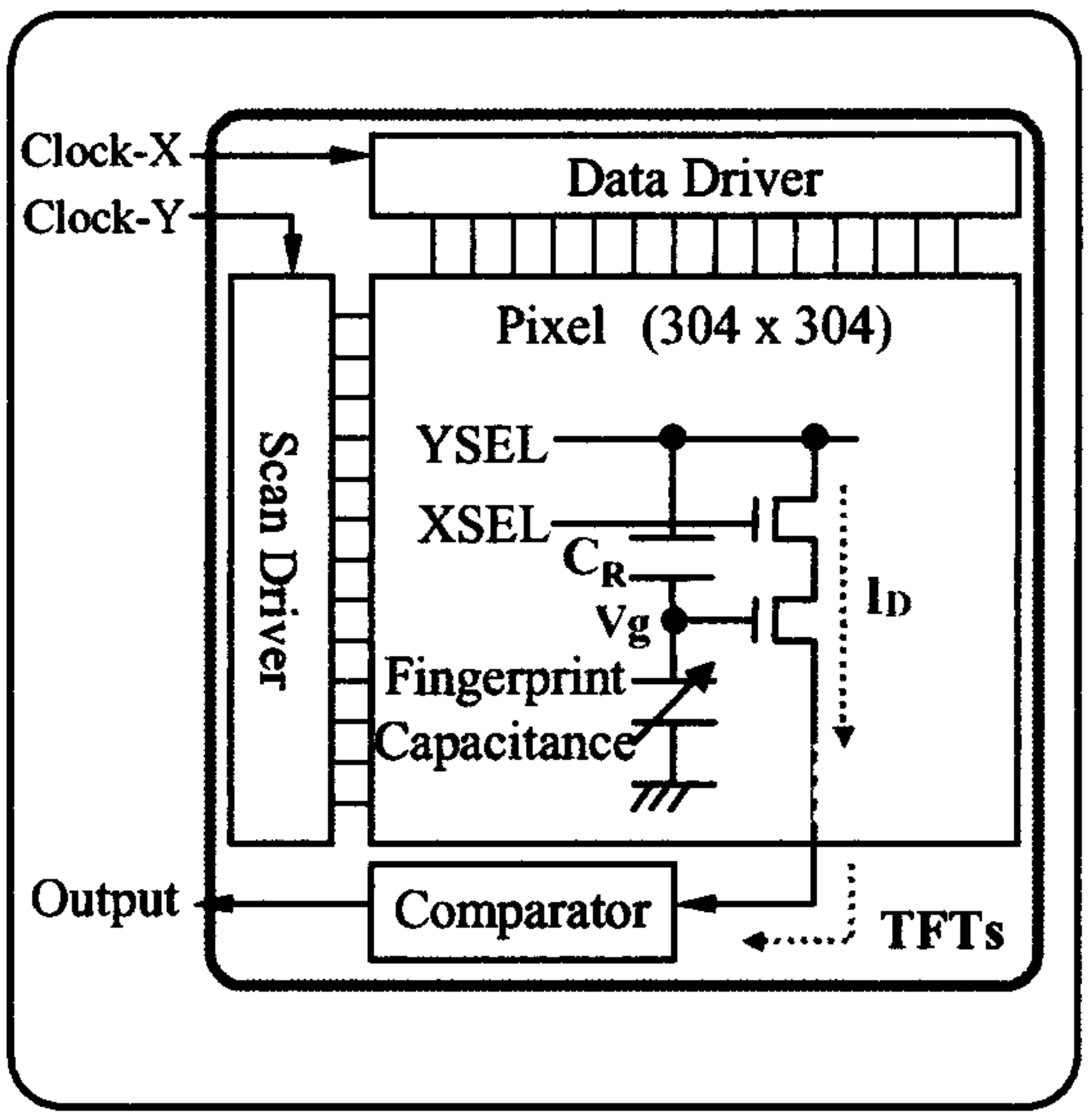

Fig. 3 TFT fingerprint sensor

Device geometries need to be reduced in order to fabricate a highly functional TFT circuit for an FPS, for example. The typical dimensions of the current TFT FPS are as follows. The gate length is 3 µm (the highest resolution allowed by a conventional LCD stepper). The NMOS lightly-doped drain (LDD) length is 0.5 µm. The gate width is made 5 µm to reduce transistor capacitance. The gate-oxide (SiO_2) film has a thickness of 42 nm. Accordingly, operation voltage drops to 2.5 V or 3.3 V. Polysilicon TFTs are fabricated through a standard low-temperature process: silicon films are crystallized with the excimer laser light, tetra-ethoxy-silane (TEOS) SiO_2 is used as a gate-dielectric, and donor and acceptor ions are activated at low-temperature (400°C).

Figure 1 shows the transfer characteristics of the polysilicon TFTs thus fabricated (LDD TFT for NMOS and self-aligned TFT for PMOS). Due to the small device dimensions, NMOS and PMOS threshold voltage values are as low as 1.47 V and −1.29 V, respectively. The polysilicon TFTs can be in an on-state with an operation voltage of 2.5 V. The transfer characteristics shown in Fig. 1 were taken from TFTs formed on a glass substrate, but these characteristics are completely preserved after the TFT devices are Suftla-processed and transferred onto a plastic sheet.

The low voltage operation of the polysilicon TFT circuits is successfully confirmed both on a glass substrate and a plastic sheet (Fig. 2). A 304-stage static shift register circuit is measured. The dependence of the maximum operation frequency on supply voltage is drawn in Fig. 2. Although the circuit exhibits slightly different performance on a plastic sheet (after Suftla processing) than it does when it is on a glass substrate (as-fabricated), the circuit on the plastic sheet operates correctly at voltage as low as VDD = 1.5 V. Since the TFT FPS requires an operation frequency of 250 kHz, the circuit on a plastic sheet satisfies this requirement at VDD = 2.0 V and the circuit on a glass substrate satisfies it at an even lower voltage value of VDD = 1.5 V. The scaling rule applied to polysilicon TFTs can dramatically reduce the operating voltage values and thus the electric power consumption.

3. TFT Fingerprint Sensor

TFT fingerprint sensors are classified into two groups: optical and electrical [6, 7]. Our TFT fingerprint sensor reads the surface contours of a fingerprint by detecting electrostatic capacitance, which changes according to the depth of the fingerprint valleys.

The sensor consists of active-matrix pixels, a data driver, a scan driver and a comparator (Fig.3). It has 304 scan lines and 304 data lines in a matrix of 304 rows and 304 columns. Each pixel is formed at the intersection between a scan line and a data line and detects fingerprint capacitance. The sensor operates in a manner quite similar to that of an active-matrix LCD. In order to address a pixel, the scan driver selects one of the 304 scan lines (YSEL) and the data driver selects one of the 304 data lines (XSEL). Fingerprint data obtained at the pixel thus addressed is ferried into the comparator and amplified for output.

The pixel includes a capacitance-detecting electrode, a capacitance-detecting dielectric layer, a reference capacitor (C_R) and a signal-amplifying element. A finger, the capacitance-detecting electrode and the capacitance-detecting dielectric layer form the fingerprint capacitor, which is serially connected to the reference capacitor. One of two electrodes of the reference capacitor is connected to the scan line. The other electrode is connected to the capacitance-detecting electrode. The finger should be grounded (*VSS*). Therefore, when the scan line is selected to be high in voltage (*VDD*), the *VDD* is applied to one electrode of the reference capacitor and shared between the reference capacitor and the fingerprint capacitor. The signal-amplifying element is a TFT (signal-amplifying TFT). The gate electrode of the signal-amplifying TFT is connected to the capacitance-detecting electrode. The gate potential of the signal-amplifying TFT changes in accordance to the surface contours of a fingerprint, because *VDD* is divided between the fingerprint capacitance (C_F) and the reference capacitance (C_R). The source electrode of the signal-amplifying TFT connects to an input terminal of the comparator and the drain electrode connects to the scan line. Since the scan line is selected to be high in voltage, and since the gate potential determines the electric conductance of the signal-amplifying TFT, the input potential of the comparator changes, reflecting the surface contours of a fingerprint. In our TFT FPS, the signal-amplifying TFT enters the on-state to boost the voltage of the comparator's input terminal when a valley of a fingerprint is present over the capacitance-detecting dielectric layer. In contrast, when a ridge of a fingerprint is in contact with the capacitance-detecting dielectric layer, the signal-amplifying TFT enters the off-state to lower the voltage of the comparator's input terminal. The comparator compares the input potential with a reference potential to judge the surface contours, namely valley or ridge, and outputs binary signals.

Detection method	Capacitance-coupling
Sensor Size	20 mm × 20 mm
Number of Pixels	304 × 304
Pixel Size	66 µm × 66 µm
Resolution	385 dpi
Frame Frequency	5.41 Hz
Scan Frequency	1.645 kHz
Selection Period per Pixel	2 µs
Output	Binary signals
VDD	2.5 V - 5.0V

Table 1 Specifications of TFT FPS

The specifications of the TFT FPS are listed in Table 1. The TFT sensor is larger than a standard silicon fingerprint sensor (FPS made on a bulk silicon wafer), because the glass substrate is much larger than a silicon wafer. We can easily produce a large-area sensor using TFT technology. The resolution is 304 dpi. This value is slightly lower than the 500 dpi of the silicon fingerprint sensor, yet high enough for personal identification purposes. The frame frequency is 5.41 Hz. The operating voltage of the TFT sensor ranges nearly the same as that of the standard silicon sensor. Output data are serial binary signals. Although our TFT FPS cannot output gray scale signals, it does make highly legible fingerprint images (Fig. 4). The fingerprint image shown in Fig. 4 was taken at *VDD* = 4 V. The TFT FPS can compete with a standard

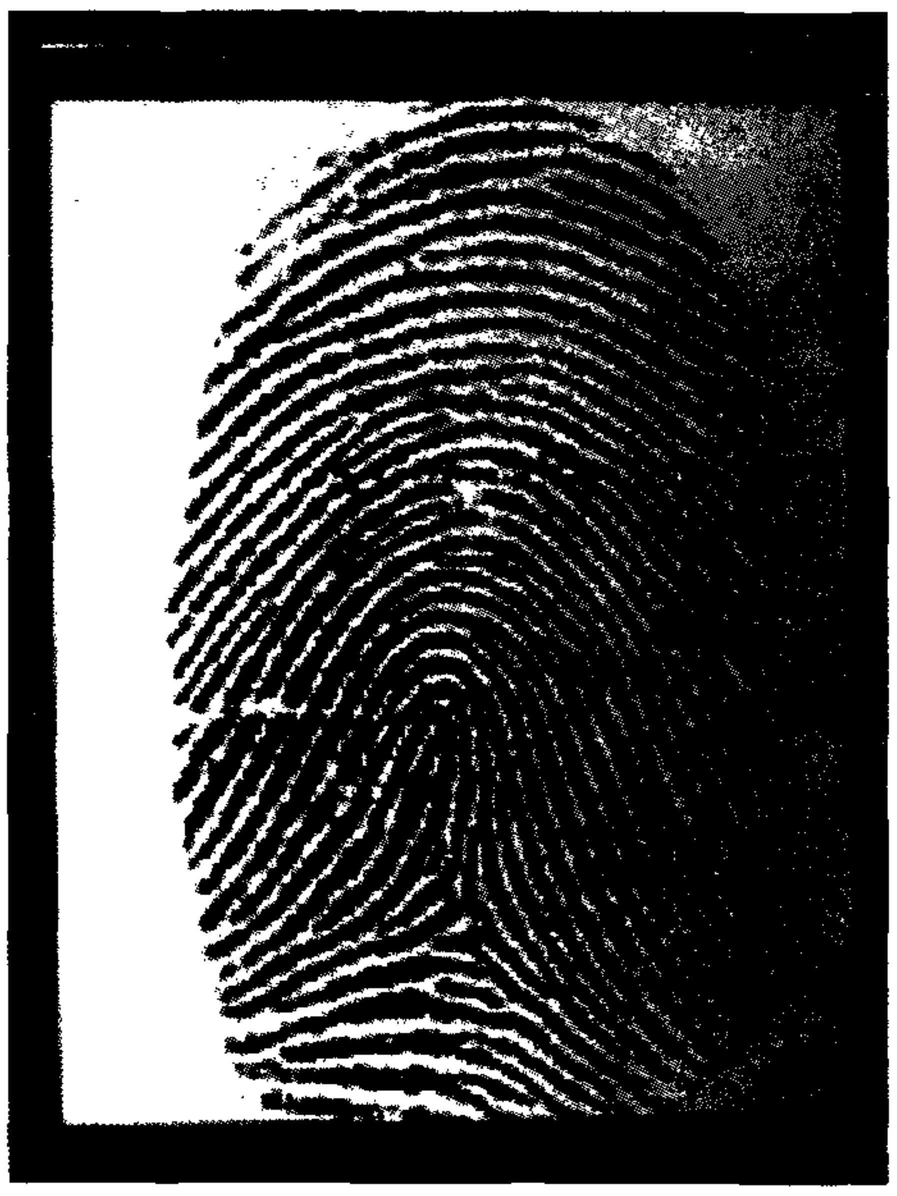

Fig. 4 A fingerprint image taken by our TFT FPS

Fig. 5 TFT FPS on plastic

silicon FPS.

4. Suftla

Suftla is a technology that is used to transfer TFT circuits from an original glass substrate to another material, such as a plastic sheet, thereby lifting the restriction that LSI devices must be made on silicon wafers.

Before fabricating TFT circuits on an original glass substrate, a sacrificial amorphous silicon (a-Si) layer is formed on the substrate. This follows the standard fabrication of polysilicon TFTs through a low-temperature process. After completion of polysilicon TFTs on the original glass substrate, a temporary glass substrate is glued onto the TFT surface using a temporary water-soluble adhesive. Xenon chlorine (XeCl) excimer laser light (λ = 308 nm) is then irradiated onto the sacrificial a-Si layer from the back side of the original glass substrate. This process weakens the sticking force at the interface of the sacrificial a-Si layer, resulting in the easy separation of the TFT devices from the original glass substrate. After separation, the back side of the TFT devices is glued onto a target substrate, such as a plastic sheet, using a permanent adhesive that is not water-soluble. Finally, the temporary water-soluble adhesive is dissolved in water so that the TFT devices can be removed from the temporary substrate. The TFT devices are thus transferred onto the plastic sheet.

Suftla technology enables TFT FPS to be easily and completely transferred. Neither severe degradation of transistor properties nor fatal mechanical damage of TFT circuits due to the Suftla transfer process has been observed. (However, as seen in Fig. 2, circuit performance is not entirely the same pre- and post-Suftla processing.) The transfer yield is almost 100%. Figure 5 shows a Suftla TFT FPS. The Suftla technology enables us to make TFT-LSI circuits, such as TFT FPS, on plastic sheets.

Fingerprint sensors made on thin, flexible plastic (plastic FPS) have important implications. For example, a TFT FPS affixed to a passport could store personal data and heighten security. A plastic FPS can also be mounted on the curved surfaces of a personal computer, a cellular phone, a car, and so on. The era of flexible microelectronics is about to begin. It could improve our life.

6. Conclusions

TFT technology is advancing day by day and will become a part of the semiconductor industry in the not-too-distant future. The combination of TFT and Suftla technologies will usher in a new era of life-enhancing flexible microelectronics.

The world's first practical TFT FPS is presented as an example of flexible microelectronics. The TFT FPS easily takes highly legible fingerprint images. The device performs comparably to a standard silicon senor. This result demonstrates the tremendous potential of polysilicon TFT technology and hints at the promise of a future flexible microelectronics industry.

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