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A REVIEW ON THIN FILM TRANSISTORS

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ABSTRACT

Thin-film transistors (TFTs) are a key element of flexible electronics implemented on low-cost substrates. Thin film transistors (TFTs) are considered as an ideal candidate to implement flexible electronics, due to its compatibility with low-temperature and low-cost processes on flexible substrates. With a common substrate, consisting of the gate, the insulator and the source and drain electrodes, rapidly many different types of TFTs based on different materials can be made. Such flexibility in production is especially of interest to research. This paper gives a brief review on the operation of TFTs, their important parameters and their area of application.

Keywords- *Thin film transistors, threshold voltage, mobility, flat panel displays, amorphous, polycrystalline.*

I. INTRODUCTION

Electronic devices and systems fabricated on flexible substrates are the subjects of growing attention within both the research and the industrial community. Rapid development of wireless telecommunications increases demand in portable, low power, and inexpensive electronics. Here, the use of flexible substrates enables the development of such new products as roll able light-weight displays, flexible solar cells integrated into clothing, or cylindrical and spherical cameras for security applications. Furthermore, the fabrication cost of electronic devices on flexible substrates can be reduced compared to existing planar or flat-panel technology due to implementation of high-throughput roll-to-roll technology. Deposition of layers onto flexible substrates (like plastics), demand the low temperature processes.

A direct approach to integrate high-performance devices on low-melting point platforms is to reduce the maximum fabrication temperature of inorganic thin film transistors (TFTs) to a level compatible with the thermal budget of the low-cost substrates. This approach has several advantages:

- **(1)** wider variety of substrate materials available, including low-cost plastics, paper, or tissue;
- **(2)** lower thermal budget materials can be integrated in the process, such as adhesives, polymers, and biomaterials;
- **(3)** thermal deformations of the substrate are reduced, and so is mechanical stress occurring due to mismatch between thermal expansion coefficients of the substrate and the films;
- **(4)** material science, device physics, fabrication process, and equipment are already well established, for example, in a-Si:H technology.

Therefore, accommodation of existing inorganic amorphous, nanocrystalline, or polycrystalline thin-film technology to flexible substrates achievable by the reduction of deposition temperature seems to be the most promising approach to enable flexible electronics in the near future.

The reason TFT's are so important to flexible electronics is that almost every rigid electronic device that is in use today depends upon transistors to function. For flexible electronics to accommodate several markets, especially those beyond large-area displays, TFT's will be necessary as power sources, logic devices, switches and more.

TFT device can be made with a wide variety of structures, of which the four basic configurations are staggered, inverted staggered, coplanar and inverted coplanar. Depending on the material used as the semiconductor, one of these configurations is preferred. Inverted configurations are referred to as the bottom gate, while non-inverted ones are referred to as the top gate. The different TFT structures are as shown in Fig 1.

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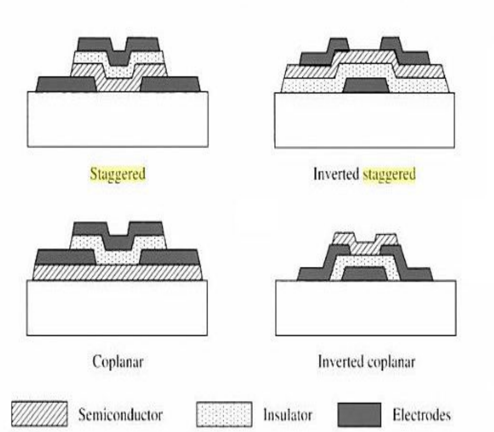

Fig 1. Basic TFT structures

A wide variety of materials can be used for the semiconductor layer of the TFT. The most widely used are the amorphous silicon and the polycrystalline silicon. TABLE 1 lists out the advantages and disadvantages of using amorphous or polycrystalline silicon. In the case if a-Si: H(hydrogenated amorphous silicon which is most widely used) TFTs the inverted staggered (bottom gate) configuration is usually preferred because of the sequence of the deposition temperatures.

TABLE 1 Comparison of amorphous silicon and polycrystalline silicon for the semiconductor layer in TFTs

Parameters/ Materials	a-Si TFTs	Polysilicon TFTs
Advantages	Cheap and reliable technology for very large area IC	Higher speed, inherent stability, brighter and higher resolution.
Application	Flat panel displays, imagers, printers, copiers, consumer products.	High resolution projection displays.
Market	Probably the second most important technology (after CMOS and MOS technology).	Challenge a-Si:H in future.
Disadvantages	Very slow technology and sensitive to heat and light, reduced brightness.	Expensive due to the higher processing temperatures, larger OFF state current leakage.

II. TFT OPERATION

A TFT is Field Effect Transistor (FET) working in the accumulation, unlike the Metal Oxide Field Effect Transistor (MOSFET) which works in the inversion mode. It has like a MOSFET, a source, drain and the gate terminals. That is, a TFT is a three terminal device. In case if a-Si:H TFT as the gate voltage increases, electrons accumulate in the a-SI:H and the gate insulator in the dangling bond states, in the bandtail states and in the conduction band states. Electrons can also be captured using the interface states, and the density of the latter must therefore be kept as low as possible by careful process optimisation. When the gate voltage increases beyond the threshold voltage and conduction channel is formed in the semiconductor (a-Si:H) layer. Due to the issues of the mobility, p-type a-SI:H TFTs are not and only n-type a-Si: H TFTs are in practice.

When the voltage is applied across the source and the drain terminals the current Id (drain current) starts flowing through the conduction channel. The Id–Vd and Id-Vg characteristics of the TFT devices are found to be very much similar to that of the MOSFETs. An example of Id-Vd characteristic of a TFT is as shown in Fig 2. As can be seen from Fig 2, the characteristic is much similar to that of the MOSFET device, depicting the cut-off, triode or linear and saturation region of operation.

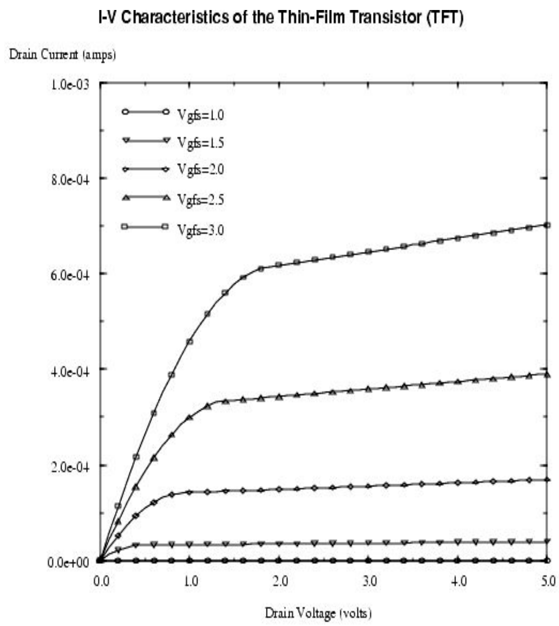

Fig 2. Id Vd Characteristics of a TFT

III. TFT PARAMETERS

This section describes the various parameters of interest for a TFT device.

A .Mobility

The mobility and conductivity of the semiconductor layer are receiving significant attention for transistor characteristics and a reliable operation of the transistor requires larger mobility. The amorphous silicon layer has a very low mobility compared to the polycrystalline layer. The mobility of any layer in general can be increased by increasing the doping concentration of the semiconductor layer. Several organic materials have been found whose mobility can challenge the mobility of the amorphous silicon layer. The search for such conducting polymers and organic polymers have led to TFTs with wide range of materials which include pentacene etc.

B. On/off (Ion/Ioff) Current Ratio

Ion/Ioff is the ratio of the current in the accumulation mode over the current in the depletion mode. The transistor applications depend on the mobility, charge density, conductivity and thickness of the organic semiconductor layer. When a small or no current flows between the source and drain electrodes at a given source-drain voltage then the current is *Ioff*, whereas *Ion* is drain-source current for the given drain-source voltage when the transistor is in accumulation mode. On/off ratio of PTFTs increases with thinner semiconducting layer. On/off current ratio should

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bemore than 10^6 for memory & display devices. Short channel devices have higher on/off current ratio than long channel devices.

C. Threshold voltage

The threshold voltage (*Vt*) of TFTs varies with either the gate insulator capacitance or the thickness of the semiconductor film. The devices with shorter channel length and thicker films tend to have smaller threshold voltages. with lesser threshold voltage, these devices can be used in low power application, thus expanding the avenues for the use of TFTs. The dependence of current on the threshold voltage is almost similar to the MOSFET devices.

IV. TFT parameter extraction

This section describes how the TFT parameters are extracted. Specifically we discuss how to measure the threshold voltage (V_{TH}), linear and saturation electron field effect mobilities (µLIN and µSAT), the ON to OFF current ratio (ION/IOFF) and the subthreshold slope (S). All of the TFT parameters can be calculated using a "transfer characteristic". To obtain transfer characteristic, sweep I_{DS} versus V_{GS} while setting V_{DS} at a desired range. Then sweep V_{GS} and measure I_{DS} while setting V_{DS} at a desired range. A schematic of the measurement set-up is shown in Fig 3. The measured I_{DS} and I_{GS} for both sweeps are plotted on a semi-log plot (using the same set of axes). An example of a transfer curve is plotted in Fig 4.

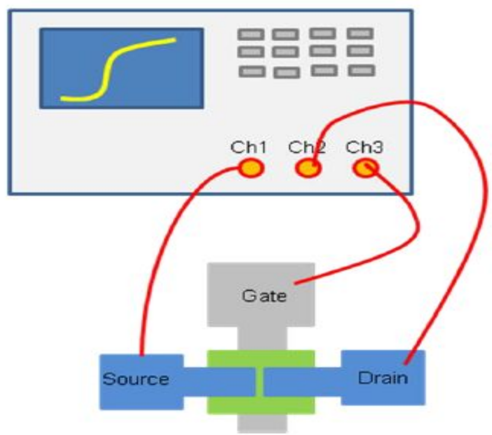

Fig. 3 Schematic of the measurement set-up used to measure the TFT transfer characteristics

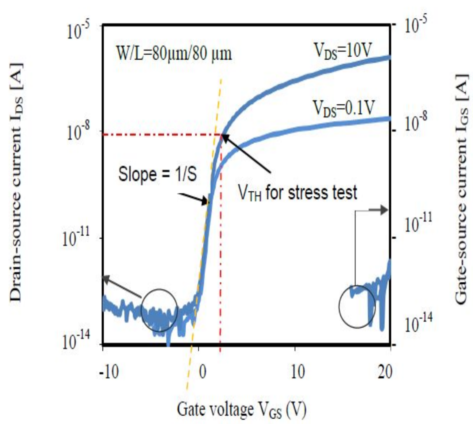

Fig .4 Example of a transfer characteristic for an a-Si:H TFT made on clear plastic

We can now extract the TFT performance parameters from the transfer characteristic. Noting that the device is analogous to a MOSFET in operation, these parameters can be obtained using the following equations

In the linear regime,

$$I_{DS}=\frac{W}{L}\mu_{lin}C_i[(V_{GS}-V_{TH})V_{DS}-\frac{VDS^2}{2}] \quad (1)$$

$0< V_{DS}< V_{GS}-V_{TH}$

In the saturation regime

$$I_{DS}=\frac{W}{2L}\mu_{lin}C_i(VGS-VTH^2) \quad (2)$$

$V_{DS}> V_{GS}-V_{TH}$

Where,

$$Ci=\frac{\epsilon}{t} \quad (3)$$

is the capacitance per unit area for the SiNx gate dielectric.

V. APPLICATIONS

TFTs have an advantage of low cost and low temperature fabrication process. They can also be easily fabricated in short time compared to MOSFETs. The thin films can be deposited on flexible substrates making them as a potential candidate for flexible, large area and wearable electronics. TFTs find application in Flat Panel Displays. The demand for lightweight, portable, rugged, low-power and high-resolution have made FPDs a common place in the displays of portable electronic devices. Active-matrix liquid-crystal displays (AMLCDs) are the leading flat-panel display technology. A display is composed of a grid (or matrix) of picture elements ("pixels"). Thousands or millions of these pixels together create an image on the display. Thin-film transistors (TFTs) act as switches to individually turn each pixel "on" (light) or "off" (dark). The TFTs are the active elements, arranged in a matrix, on the display. Hydrogenated amorphous silicon TFT (a-Si:H TFT) is widely used for the AMLCD (active matrix liquid crystal display). Mobility of a-Si:H TFT is very low around 0.5 cm^2/Vs, however, it provides low cost, low temperature and large substrate process.

Organic thin-film transistors (OTFTs) which are based on conjugated polymers, oligomers, or other molecules seem to be an enticing alternative to more traditional, mainstream thin-film transistors (TFTs) based on inorganic materials. The processing characteristics and demonstrated performance of OTFTs suggest that they can be competitive for existing or novel thin-film-transistor applications requiring large-area coverage, structural flexibility, low-temperature processing, and, especially, low cost. Such applications include switching devices for active-matrix flat-panel displays (AMFPDs) based on either liquid crystal pixels (AMLCDs) or organic light-emitting diodes (AMOLEDDs). OTFTs with
electrical characteristics comparable to or better than amorphous silicon hydrogenated (a-Si: H) devices have been demonstrated on glass substrates and inexpensive flexible plastic substrates.

The development of a thin-film transistor (TFT) technology for use with plastic substrates is still not matured. There is still a significant room for improvement in ultra-low temperature fabricated poly-Si TFTs. High mobilities, low leakage currents and threshold voltages are desirable for high-performance active-matrix LCD applications, particularly for the integration of driver circuitry, but low processing temperatures (<150ºC) must be maintained for compatibility with low-cost plastic substrate materials. In general, superior poly-Si TFT performance is achieved with higher-temperature fabrication processes, because the quality of the critical gate-dielectric interface is highly sensitive to process temperature.

TFTs based gate dielectric for pH sensing using H+ adsorption in suspended gate dielectric structure and for memory using PZT dielectric have been reported. TFTs are also used for gas sensing which involves H2O, alcohols, N2O adsorption on semiconductor layer. Other applications of TFTs include Protein/DNA analysis, X-ray imaging, Photo sensing, Memory etc. OTFTs have attractive features and advantages of organic memories such as low cost, low temperature processing, low fabrication cost and high mechanical flexibility. Therefore, non-volatile Pentacene TFTs memories are being fabricated. Memory devices based on organic field-effect transistors have been demonstrated under different device structures including: (i) the application of ferroelectric polymer dielectric materials (ii) embedding metal nanoparticles (NPs) into gate dielectric and (iii) incorporating the metal NPs within the organic semiconductor layer

TFTs of various structures and materials can be easily modified or connected to other devices to detect or generate changes of chemical, biological, optical, magnetic, radioactive, and other properties through controlling the transport of charge carriers, emission of photons, etc. The device can be embedded in any environment be it solid, liquid, or gas. Although this area has been explored for many years, more new applications can still be discovered with the inclusion of nanodots or one-dimensional nanomaterials (i.e., nanowires) in the structure.

VI. CONCLUSION

TFT has become an area of interest for researches due to its simplicity in fabrication process and with the ability to use a wide range of materials for its construction. TFTs have mainly been used in display application and are now being explored for sensors and memories. Inorganic TFTs make use of a semiconductor material for the active layer, whereas organic TFTs use polymers and organic compounds for the active layer. Its similarity with MOSFETs in operation has great led to the use of these devices in area never explored before. TFTs are a splendid candidate for flexible and large area electronics. The extensive research in this field can make it a potential competitor for the MOSFETs.

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