STATE OF THE ART IN THIN FILM TRANSISTOR: A REVIEW OF THE USED INSULATOR–SEMICONDUCTOR COMBINATIONS

ANDRÉ VAN CALSTER and ALEXIS DE VOS

Laboratorium voor elektronika en meettechniek, Rijksuniversiteit te Gent, Sint Pietersnieuwstraat 41, B–9000 Gent, Belgium.

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This paper deals with the technology of the thin film transistor (TFT). It deals with the different semiconductors used successfully in a TFT, as well as the different gate insulators employed. A variety of structures have been realized in the past. The most important difficulty with the use of these TFT structures consisted of low frequency instabilities, caused by mobile ions in the insulator and slow states at the semiconductor-insulator interface. Various proposed solutions to these problems will be discussed.

1. INTRODUCTION

Already in 1961, P. Weimer¹ realized the first TFT. This insulated gate field effect transistor consisted of a CdS semiconductor film, an SiO gate insulator film, and Au electrode films, all evaporated upon a glass substrate, during one single vacuum cycle. Figure 1 shows the geometry of the device. Its operation is familiar to the MOSFET.

With this active thin film device, together with thin film resistors and thin film capacitors, complete circuits could be deposited on an insulating substrate. Recently, interest in such circuits has largely grown, mainly because of potential combination with electroluminescent elements. Large area alphanumeric displays and flat television panels (an alternative to the CRT) are possible applications.^{2,3,4}

FIGURE 1 TFT geometry.

2. THE SEMICONDUCTOR FILM

The semiconductor layer is a thin polycrystalline film of 100 to 1,000 Å thick. A low carrier concentration and a high carrier mobility are desired. In most cases compound semiconductors are evaporated in order to grow the film. Stoichiometric films are pursued by heating the substrate during the evaporation or by a post deposition treatment.

Most important are the II–IV compounds CdS^{1,5} and CdSe.^{6,7,8} Of these semiconductors CdSe shows the highest-mobility and therefore the highest transistor transconductance. Also important are the III–V compounds InSb^{9,10} and InAs.¹¹ Whereas the narrow bandgap (0.17 eV) of InSb makes this material more convenient for low temperature applications,^{1,2} InAs gives rise to high-gain transistors at room temperature, but needs a 3-temperature evaporation technique.¹¹ Further we have the IV–VI compounds PbS^{13,14} and PbTe.⁹ Almost all aforementioned semiconductor films have a donor-like doping, and are thus *n*-type. Only PbTe shows *p*-type conduction. A more important *p*-type film however is Te.¹⁵ It is also the only elemental semiconductor used successfully in TFT. It needs no substrate heating. At last we mention the semiconducting oxides ZnO, SnO₂ and In₂O₃.^{16,17}

As an illustration, Figure 2 shows the drain characteristics of 3 TFT's fabricated in the same vacuum plant at our laboratory. Scales are: drain voltage V_D horizontally 2 V/div and drain current I_D vertically 0.2 mA/div. Voltage steps at the gate are

FIGURE 2 TFT characteristics for different semiconductors Horizontal scale: 2 V/div Vertical scale: 0.2 mA/div.

indicated between brackets. The semiconductors used, are: CdSe (500 Å) InSb (200 Å) and Te (130 Å). The insulator is SiO (respectively 1,000 Å, 200 Å and 1,200 Å).

3. THE INSULATOR FILM

For the insulator film, high permittivity and high dielectric strength are desired. Mobile ions have to be avoided (see later). Mostly used is silicon oxide, as in MOS technology. Not only SiO₂, but also SiO and intermediate compositions SiO_x are used. Other suitable oxides are: Al₂O₃, Dy₂O₃, La₂O₃, Yb₂O₃, Nd₂O₃ and MgO. Also fluorides have been successful: MgF₂, CaF₂, AlF₃ and LiF. Recently, a TFT has been presented with a polymer thin film: polytetrafluoroethylene.¹⁸

4. DRIFT

The most important difficulty with the use of thin film transistors consists of low frequency instabilities (drift phenomena). This is illustrated as follows: suppose one drain characteristic I_D versus V_D is displayed with a curve tracer. If, at the moment $t = t_0$, the gate voltage V_G is changed, immediately a new characteristic appears. After this, however, a relaxation mechanism occurs: the new curve drifts towards an equilibrium state. See Figure 3.

FIGURE 3 Drifting TFT characteristic.

Two phenomena are responsible for this low frequency instability:

- a) Mobile ions in the insulator film, who cause a delayed gain of the field-effect (as on Figure 3) and
- b) slow states at the interface semiconductor-insulator, which cause a delayed attenuation of the field-effect.

Figure 4 shows the response of the drain current I_D (at constant V_D) to a square wave gate voltage (for an n -type transistor).

FIGURE 4 Different drain current responses to square wave gate voltage.

For example, an evaporated SiO_x film often contains alkali ions (sodium) and oxygen vacancies, who move through the film, driven by the electric field in the gate capacitor, and cause the first kind of undesired relaxation phenomena.¹⁹ Analogous effects happen in other dielectrics. The interface of semiconductor and insulator films contain specific electron states. Some of these are filled and emptied with large time constants, what causes the second type of relaxation process. These "surface" states can be located at the interface itself as well as in the insulator.^{19,20} In this last case communication with the electron traps occurs through tunnelling.

5. AVOIDING THE DRIFT

Different methods have been suggested to decrease and even avoid the drift in TFT's. We will discuss here the most important ones:

a) Waxman^{2,1} suggests the following insulator-semiconductor set: Al_2O_3 -CdSe. He first deposits the aluminium gate electrode. This film is then anodized in a dry oxygen plasma to form a layer of 500 Å Al_2O_3 . Then the CdSe and source and drain are evaporated, to realize an inverted TFT. An important disadvantage of the technique is the need of a complicated substrate mounting or supplementary photolithographic fabrication steps. Therefore the proposed method deteriorates the main advantage of TFT technology: its simple fabrication process.

b) Recently, Kramer¹⁴ has suggested the combination Al_2O_3 -PbS. The Al_2O_3 insulator is evaporated by electron gun, in an oxygen background. The PbS is evaporated from an indirectly heated boat, also in oxygen background. So, ionic drift instability is eliminated with the use of the Al_2O_3 dielectric, whereas the interface density of traps is reduced, probably thanks to the formation of lead oxide near the interface, reducing abrupt discontinuities.

c) Anderson^{2,2,3} has presented an SiO_2 -CdSe device with long-term stability. Here the way of depositing the SiO_2 layer is new: sputtering of quartz.

d) An attractive alternative to the oxides and fluorides seems to be possible thanks to the polymer thin films. De Wilde²⁴ has shown that polytetrafluoroethylene films evaporated by electron gun contain no mobile ions. De Vos and Hindryckx¹⁸ have realized a PTFE-Te transistor with this dielectric. But the transistor showed drift, partly introduced by the high temperature annealing of the transistor. Further research in this field can be interesting, in view of the large spectrum of thin polymer films and the many ways of deposition that can be used.^{2,5}

6. CONCLUSION

We may conclude that from the many insulator-semiconductor combinations, the Al_2O_3 -CdSe and the Al_2O_3 -PbS are the most promising ones. With these combinations stable, drift-free thin film transistors can be made. Both devices have already been used successfully in large complex macro-circuits.^{2,3}

The thin film transistor may be considered to be the most suitable device for large area circuits (such as displays) because of the appropriate thin film

vacuum technology. But perhaps also in the area of micro-electronics, such as hybrids, the thin film transistor may become an alternative to the monolithic active devices.

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