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Thin-Film Transistor Technology and its Applications: A Review

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Abstract

This paper presents a review on state-of-the-art of thin-film transistor (TFT) technology and its wide range of applications, not only in liquid crystal displays (TFT-LCDs), but also in sensing devices. The history of the evolution of the technology is first given. Then the standard applications of TFT-LCDs, and X-ray detectors, followed by state-of-the-art applications in the field of chemical and biochemical sensing are presented. TFT technology allows the fabrication of dense arrays of independent and transparent microelectrodes on large glass substrates. The potential of these devices as electrical substrates for biological cell applications is then described

Introduction:

Thin-film-transistor (TFT) technology is a well-known technology widely used in flat-panel displays, computers, smart phones, video game systems and personal digital assistants. This technology has revolutionized video systems, allowing flat panels with increasingly larger dimensions to be obtained: 164 inch. is the diagonal dimension of the substrates used nowadays for TFT liquid crystal display (TFT-LCD) fabrication. The first fully transparent zinc oxide thin-film transistor (ZnO TFT) was developed in 2003 (1) and numerous important works have been reported (2–6). Organic and hydrogenated amorphous silicon (a-Si:H) TFTs have also been demonstrated but their applications were limited by the low mobility of the conductive channels. ZnO and related materials have thus emerged as promising candidates for channel materials in flexible and transparent TFTs since the birth of this subject field at 2003-2004(1, 4). Compared with other inorganic wide bandgap semiconductors, such as gallium nitride (GaN) and silicon carbide (SiC), the great advantage of ZnO materials for flexible devices is their low synthesis temperature and this is exactly the most important requirement in flexible device fabrication processes.

History of development of TFT technology

In 1973, the first TFT-LCD was demonstrated which define the main direction of the research and development for TFT technology (7). The first TFT was a CdS TFT, which was followed by a CdSeTFT. Both had reasonably high carrier mobility, of above 40 cm^2V^{-1} s^{-1} (8). However, owing to difficulties in the fabrication, such as the stability of thequality of the semiconductor on a large surface, and the reliability of the devices, application to LCDs did not reach commercialization. At the beginning of the 1980s owing to the development of hydrogenated amorphous silicon (a-Si:H) which greatly improved the stability and the characteristics of TFTs, this technology underwent a major improvement, allowing the production of active matrix (AM)LCDs, and this in 1989 the first TFT-LCD was commercialized. Improvement of the semiconducting layer followed owing to with the development of other materials. Table II summarizes the evolution and compares the different semiconductor materials developed for TFT-LCDs since the 1960s. The development of transparent oxide semiconductors such as indium gallium zinc oxide (IGZO) was a major step forward in improving even further characteristics of TFTs. Power consumption was further reduced due to the high carrier mobility, and transparent transistors were obtained giving larger aperture ratio of the LCDs (9).

Applications using TFT technology

The rapid development of science and technology in flexible transparent electronics, many wonderful products are very close to achieving commercial-productions (10, 11). In fact, IGZO panels have already been used in iPadand iPad Pro products, and Apple is considering IGZO panel for its new iPhone in late 2017.As for flexible transparent display and other more applications, there are still difficulties before desirable products come into use. They have been manufactured since the beginning of the 2010’s by companies including LG Display, AUO and JDI (12). The TFT array substrate is integrated with an OLED layer and a pressure sensor layer. The latter transduces a pressure into an electrical signal which is in turn transmitted to TFTs which control and modulate the OLED.The pressure sensor can be a pressure sensitive rubber whose resistance changes with the pressure, such as poly (methyl methacrylate) (PMMA) or a soft polymer containing conductive particles (13).

For all these sensors, postprocessing of the TFT array substrate is needed in order to add a layer sensitive to the species to be detected. Many of these sensors are OTFTs because of the easier postprocessing. Among the chemical sensors, ion-sensitive field-effect transistor (ISFET) sensors are well known. In such devices the gate of the TFT has to be extended in order to increase the area of the surface used for detection and these sensors have to be covered with a thin layer of an insulator such as silicon nitride. A typical sensitivity of 54mV/pH has been reported (14). Concerning TFT gas sensors, many applications related to the environment and the detection of hazards have been realized. They are in competition with commercially available gas sensors which are often based on metal oxides and operate at high temperatures. The advantages of TFT gas sensors are the short response time, high sensitivity and roomtemperature functioning. However, stability with time and usage is a limitation.

Most TFT biosensors are based on OTFT technology. Those that are not based on OTFTs generally use semiconductors with high mobility such as ZnO or carbon nano tubes. Many applications involve the fabrication of immune sensors for cancer detection (15, 16). Biosensors are very specific sensors as molecular recognition is usually performed by means of complementary couples such as antigens/antibodies and enzyme/enzymatic substrate or by the hybridization of a DNA-probe strand and a DNA-target strand. Similarly to chemical sensors, a sensitive layer is necessary to transduce the biochemical signal into a physical parameter that is electrically measurable. The antibodies, enzyme or DNA-probes are attached onto the sensitive layer.

The reaction of the target molecules with the complementary molecules changes the surface electrical characteristics of the sensing layer, causing charge accumulation or increasing or decreasing the conductivity. These variations are detected by the TFT whose source–drain current is modulated by these effects. The first applications that were targeted were the detection by enzymatic reactions. In particular, glucose sensing using glucose oxidase was among the first targets (17, 18).

TFT technology has been used not only for LCDs but also for physical, chemical and biochemical sensing. However, the structure of the TFT devices used for LCDs exhibit very interesting characteristics for applications involving bio-logical cells and can potentially be used as an electrical platform for experiments on cells.

Conclusion

In this article, we discussed the possibility of using TFT technology for experiments on biological cells. A detailed background on the history of TFT technology development and common applications such as LCDs, X-ray detection, pressure sensing for touch panel displays, IR sensing and biochemical sensing has been given.

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