Solving the TFT LCD Yield Problem

Thin film transistor active matrix liquid crystal displays (TFT AM LCDs) are the "state of the art" in high performance color LCDs. Active matrix (AM) refers to an LCD pixel design that utilizes an active element. The active element in most designs is a transistor, deposited on the glass substrate using a thin film process. This process is very similar to semiconductor fabrication, and various materials are used to form the TFTs. By incorporating a switch (the TFT) at each pixel, TFT LCDs offer better contrast ratios and brightness than passive matrix LCDs.

TFT LCDs are currently a critical component of most color portable computers, hand held televisions and other consumer products. By the year 2000, the market for TFT LCDs is expected to grow to greater than $4 billion.

However, the major Japanese electronics companies who have invested billions of yen in TFT LCD development have found that TFT LCDs are very difficult to manufacture. Yields of TFT LCDs have been reported to be as low as 10%. As a result of low yields, today's TFT LCDs are very expensive. For example, an average 10" color TFT LCD used in a laptop computer is priced at about $1,500. Industry observers believe the market demand for TFT LCDs will increase only as a result of decreased prices. The same 10" TFT LCD must sell for less than $500 before it will appeal to a mass market.

The only way manufacturers can decrease their prices is to dramatically increase their yields and reduce their production costs. A major obstacle in the effort to increase yields has been the absence of in-process automatic test equipment (ATE) designed specifically for TFT LCDs.

ATE designed for the final test of LCDs has been available for many years. However, repairing a completed LCD on which faults have been detected is not cost effective because the cost of disassembly, repair, and reassembly exceeds the value of the repaired LCD. A more logical test strategy is to also test the LCD at the substrate stage. At this stage the TFTs and electrodes have been fabricated on the glass but no other materials have been added (see figure 1). If a TFT LCD can be tested at the substrate stage, the manufacturer has the choice of repairing it at a reasonable cost or scrapping it before more value is added. Scrapping LCDs with faults at this stage is a major cost savings since it is estimated that the manufacturer has added less than 50% of the TFT LCD's value. Therefore, an in-process ATE system provides immediate yield and cost improvements to TFT LCD manufacturers.

To address these problems, GenRad and Tokyo Electron Limited (TEL) jointly developed the GTS-1 LCD Test and Measurement System. TEL, the world's leading manufacturer of semiconductor probers, developed the GTS-1 Automatic Prober and Substrate Handling Subsystem. GenRad, the world's leading manufacturer of board test systems, invented a patented transfer admittance test technique and developed the GTS-1 Test and Measurement Subsystem.

The key feature of the GTS-1 System is the ability to precisely measure TFT characteristics and therefore provide extensive pixel data beyond simple pass/fail. This measurement data is critical to manufacturers for three reasons. First, the GTS-1

System utilizes this pixel measurement data and software algorithms to provide detailed pixel diagnostic information to the manufacturer.

Since many faults can be repaired and the repair process is not replacing pixels but actually repairing pixel circuitry, the more diagnostic information provided to the manufacturers the more efficient their repair process will be. Secondly, this measurement data provides process control information to the manufacturers which will enable them to effect longer term yield improvements. Lastly, measurement data provides design characteristic information to the manufacturers which will enable them to improve future TFT LCD designs.

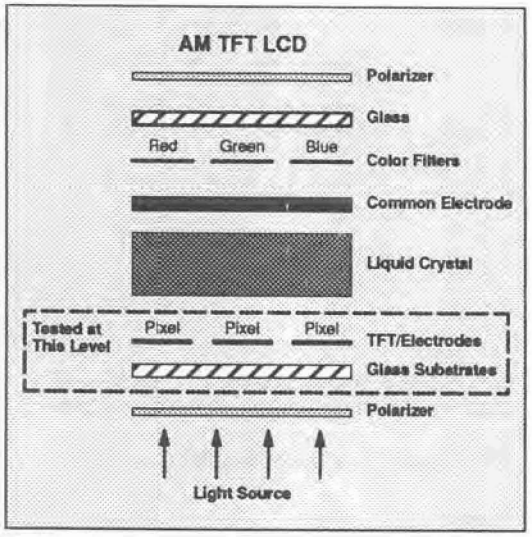
The GTS−1 System measures each pixel on the substrate by applying ac voltage to the gate or control line (row) and measuring the resulting current in the drain or data line (column). The ratio of output current to input voltage is admittance, Y, the reciprocal of impedance, Z. It is a transfer admittance measurement because the voltage and current are measured with reference to a third point, the common terminal or guard (see figure 2).

This is the technique used in in−circuit measurements because impedances from input or output to the common or guard (Za and Zb) have, theoretically, no effect. The single element to be measured can be isolated by connecting all shunt current paths to the guard point.

Because an ac signal has both magnitude and phase, an ac admittance is complex, having both in−phase (real) and quadrature (imaginary) parts. For a capacitive admittance (as is the case) $Y = G + j\omega C$ where G is conductance, C is capacitance and $w = 2\pi$ frequency. Thus, each measurement gives two pieces of information, G and C. These quantities are small compared to the admittances of most resistors or capacitors and are measured in nano−Siemens (1 nS = $1/(10^9$ ohms)) and pico−Farads. Nevertheless, these small quantities can be measured very quickly using modern signal−processing methods.

A single measurement of each pixel would detect several faults, such as line shorts or opens. However, much more information can be obtained by making two measurements on each pixel, one when the TFT is on and one when it is off. Obviously, if there is no change in the admittance, the pixel is not functioning properly. By analyzing the size of the change the GTS−1 System can usually determine why the pixel is not working properly.

The TFT is turned on or off by applying a dc bias to the gate line as shown in figure 3. This gives four pieces of data: Goff, Coff, Gon and Con which provide extensive information about the pixel. The most sensitive indicator of some faults is ΔC =Con − Coff. If this is abnormal,



The polarized material is applied to the back and front of the display. The front polarizer is shifted 90 degrees from the back polarizer. This allows light to pass through the display because the liquid crystals in their normal state twist the light 90 degrees. When voltage is applied between the pixels and the common electrode, the liquid crystals align with the electric field. This blocks the light coming through the display because the liquid crystals no longer twist the light 90 degrees as the light passes through the display.

Figure 1. AM TFT LCD Operation

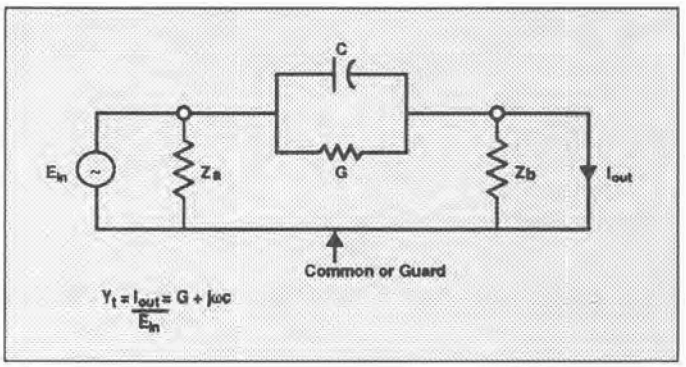


Figure 2. Transfer Admittance Measurement

the pixel is abnormal and thus faulty. A high Goff or ΔG indicates other fault types. There are very few types of faults that can not be detected. Fortunately, these are rare and, if present, would probably have detectable secondary effects.

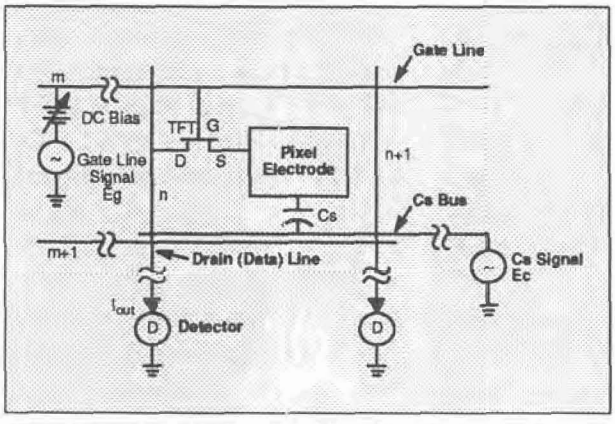
Examples of the data for two types of faults are shown in figure 4. It is obvious which pixel is bad in both cases. Additional measurements are necessary to accurately identify most fault types. These measurements can be made with one source removed (see figure 3), at a different bias level, or on an adjacent pixel.

The GTS−1 System is a measurement system as well as a test system. Individual pixel capacitances and conductances can be measured separately or calculated from several measurements. Higher measurement accuracy is obtained by making slower measurements at optimum frequencies and by calibration of each detector using internal impedance standards.

The GTS−1 System can also measure the dynamic characteristics of a pixel or the substrate as a whole. For example, the TFT conductance vs DCV turn−on characteristic can be measured to determine the threshold voltage.

Measuring the phase shift of admittance over the panel area, caused by line resistance and capacitance, determines the RC time constant along these lines.

In summary, the GTS−1 System enables TFT LCD manufacturers to increase their yields and lower their production costs by detecting, locating and diagnosing faults on TFT LCD glass substrates. This new diagnostic capability provides manufacturers with data required to repair substrates. The GTS−1 System also offers extensive measurement capabilities for process control and design characterization of substrates.



This design utilizes a separate storage capacitance bus, C_s. Other designs may also be tested.

Figure 3. Measurement of Single Pixel m,n

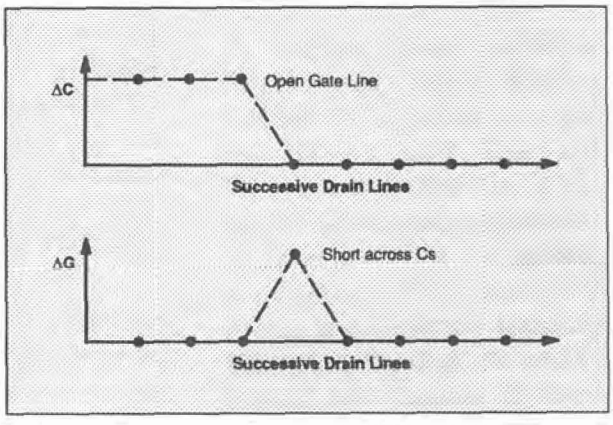


Figure 4. Typical Fault Data

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