New Test Realities for Evolving FPD Technologies

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Characterizing the active elements in flat panel displays (FPDs) is similar to IC device testing on other types of semiconductors. However, to optimize throughput and accuracy in LCD, OLED, and LEP applications, significant modifications to parametric test systems, cabling, and methodologies are required.

Evolving FPD Trends

Flat Panel Display (FPD) manufacturers are placing heavy bets on new technologies to fill the needs of demanding applications. These applications include larger and lower cost laptop monitors, small area/low power panels for cell phones and other portable devices, HDTV and widescreen formats for home television, and high reliability daylight-readable displays for the “glass cockpits” of fighter aircraft, battle tanks, and warships. Display technologies range from amorphous and low temperature polysilicon (LTPS) LCD panels to emerging organic LEDs and others. These emerging technologies promise to deliver higher value-added products, but they significantly increase a display OEM’s investment in new tools and methods in order to shorten their time to market, start up new production lines, and overcome lower than ideal yields. All of this requires more efficient testing with instruments and systems that provide higher throughput and accuracy, both in R&D and production areas.

Display device measurements use probers and parametric testers similar to those found in conventional CMOS and bipolar fabs, so this market is a natural one for Keithley. For years, we have supplied semiconductor characterization systems and parametric testers to CMOS and bipolar IC fabricators, as well as key manufacturers of Active Matrix Liquid Crystal Diode (AMLCD) displays. Many of these AMLCD manufacturer customers are located in Asia. The measurement and test technology associated with active matrix FPDs is essentially the same as for other semiconductors. However, we are finding significant differences that require a fresh approach to test and measurement.

Display OEMs and semiconductor fabs use distinctly different types of prototyping and production equipment. Typically, in display testing, the prober is physically larger and associated instruments are farther away from the device under test (DUT) than with conventional semiconductor wafers. This greater distance leads to cabling length problems, such as higher parasitic capacitance and noise, which can reduce sensitivity, increase measurement settling times, and lower throughput – just the opposite of what is needed. To avoid these problems when testing new display devices, innovative measurement techniques and test equipment modifications are often required.

Amorphous Silicon LCD Testing

Amorphous silicon (*a-si*), the traditional technology for AMLCDs, still holds the dominant share of the market for applications from cell phones to PDAs and laptops, desktop monitors, and most TV applications. This is the result of the technology's high level of refinement and low cost, even though *a-si* thin-film transistor (TFT) devices are slower, larger, block more light, and require more external circuitry than newer LTPS LCDs. Now in their fifth and sixth generations, *a-si* substrate technologies are being used to create larger displays, and manufacturers are striving to reduce costs even more by producing in higher volumes and improving yields.

Cost is a dominant concern, so production test time must be kept to a minimum. Typically, only essential characteristics are measured in a production environment, including:

- I_d-V_g curve sweeps, with up/down hysteresis
- Voltage threshold, V_{th}
- Forward (on) current level
- Leakage (off) current, I_L
- Switching (response) time
- Resistance and capacitance of contact chains

These measurements are taken on a few Test Element Groups (TEGs) located around the outside edges of an LCD panel. Sometimes, a few working pixels are also measured to check for uniformity, and properties of the Indium/Tin Oxide (ITO) conductive layer may be spot-checked.

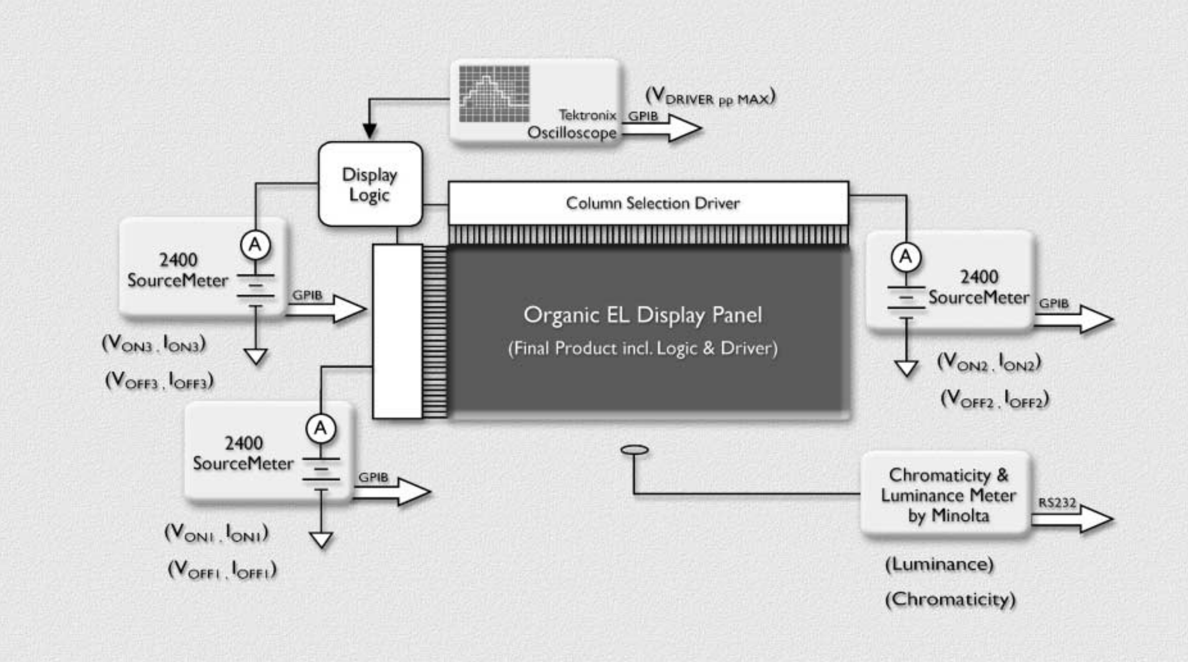

Fig. 1a. Typical FPD production test diagram.

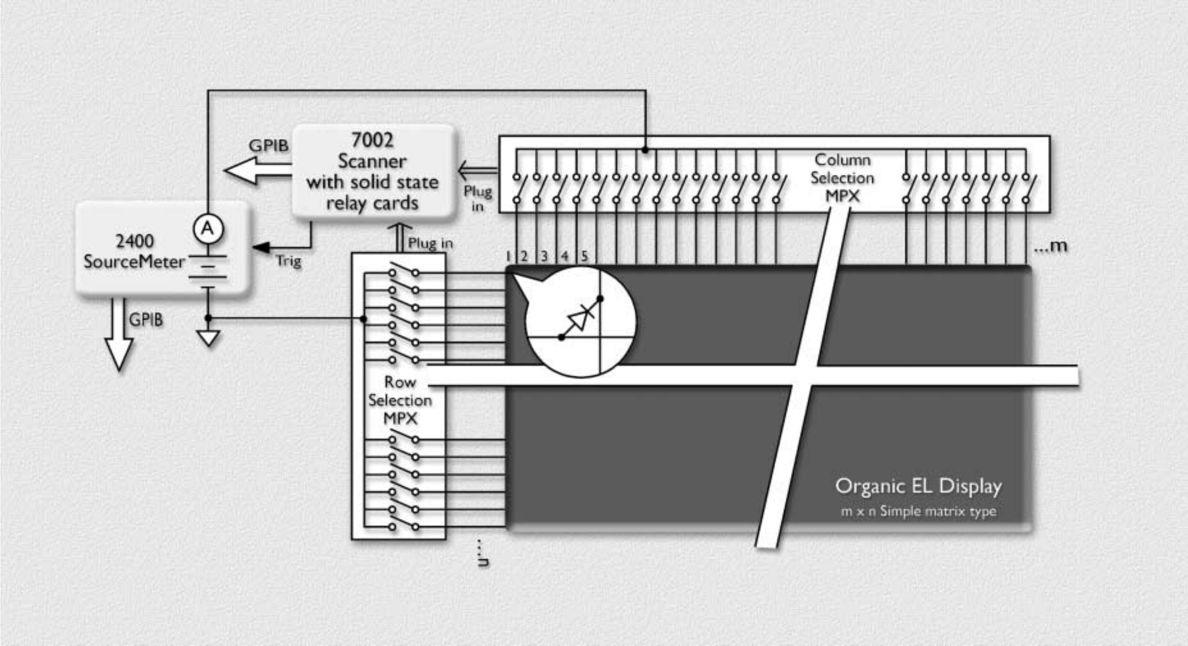

Fig. 1b. OEL Leakage current tester.

Typical systems that characterize active elements in an FPD (***Figure 1***) include DC source-measure units (SourceMeter®), a switch matrix (to allow testing multiple devices with one set of instruments), a probe station (not shown), and cabling between various components. Due to the large size of glass substrate panels, FPD production equipment also tends to be rather large and highly automated, including the associated probe station for making contact with LCD TEGs and working pixels. This complicates placing measuring instruments close to the signal source. The natural inclination is to interconnect the probe card and instrumentation test head with a long cable, but this common solution creates other measurement problems.

Parametric characterization of LCD TFTs typically requires extremely sensitive measurements of the drain current during the off state. If the threshold voltage and sub-threshold (leakage) current are too high, there is image ghosting, so I_L must be measured down to femtoamp levels. Gate leakage current also is important in device performance, as are other low current phenomena.

Too often, when an FPD characterization system is configured, the specifier tends to concentrate on DC parametric instrumentation while neglecting the rest of the system, such as cabling, probe cards, etc. In fact, these components of the system are the more likely sources of noise, given that poor quality or poorly shielded cables and high leakage switching systems often lie directly in the signal path.

For ultra-low current measurements, it’s very important to have a tightly integrated parametric characterization system, including not only the measuring instruments, but also the test fixture, probe station, switching system, connections, cabling, grounding, and shielding. Therefore, a test engineer needs to take a system-level view. Even with a properly configured system, these issues can affect measurement noise, accuracy, and throughput rate:

- Cabling and the parasitic capacitance and shunt resistance it introduces
- Grounding/shielding/guarding
- Offsets and leakage in switch matrices
- Probe card and test head design.
- Instrument noise and settling time
- Environmental electrical noise levels and types
- Test Element Group devices and associated test strategies

Unique Solutions for Unique Test Problems

Effective techniques must be employed to minimize errors, noise, and excessive test time that arise from the problem areas just mentioned. Often, this requires unique solutions for unique devices, material, and equipment problems. Drawing on its 30+ years of experience in semiconductor, LCD, and passive device testing, Keithley has developed innovative solutions for testing everything from conductive coatings and insulating oxides to complete multi-element displays. For example, the Keithley Model 4200-SCS Semiconductor Characterization System provides a low noise platform for LCD device testing. The Model 4200-SCS's modular design, local or remote pre-amplifiers, and flexible GUI software environment allow it to be customized for typical FPD production testing.

Generally, system noise has the greatest impact on measurement integrity when the DUT signal is very small (i.e., low signal-to-noise ratio). That's because it's difficult to amplify the signal without amplifying the noise right along with it. Clearly, the key to low level measurement accuracy in FPD testing is to increase the signal-to-noise ratio.

The Model 4200-SCS's noise specification is only about 0.2% of range, which means the peak-to-peak noise on the lowest current range is just a few femtoamps. Noise can be further reduced with proper signal averaging (through filtering and/or increasing the number of power line cycle integrations). If this creates a test throughput issue, its remote low noise pre-amp option allows measurements down to the sub-femtoamp level.

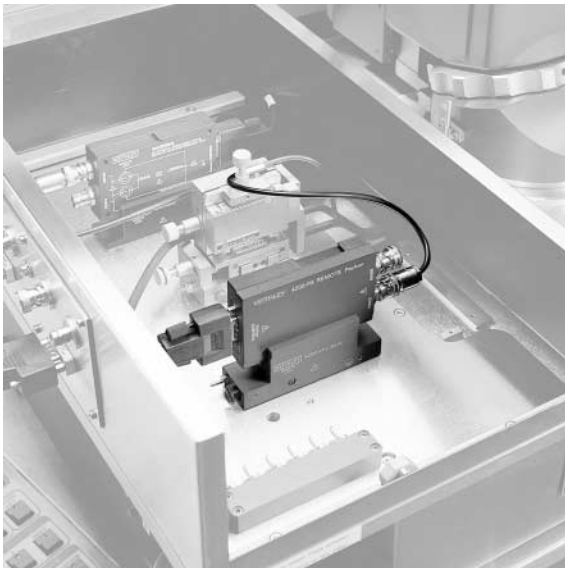

Figure 2. SMU pre-amp mounted remotely on a probe station platen.

To get that level of sensitivity, the pre-amps typically are remotely mounted on the probe station (***Figure 2***). With this arrangement, the signal travels only a short distance (just the length of the probe needle) before it is amplified. Then, the amplified signal is routed through the cables and switch matrix into the measurement hardware.

This arrangement also benefits test throughput by reducing measurement settling time because cable lengths, and therefore parasitic capacitances, are greatly reduced. Throughput is further enhanced with Keithley's line of matrix switching systems, which allow connecting multiple DUTs to the test system. Keithley's low leakage matrix switching cards are designed specifically for ultra-low current measurements.

Low Temperature Polysilicon Tests

Earlier polycrystalline silicon required high deposition temperatures that were impractical for LCD on glass manufacturing. However, today's LTPS technology has overcome many of these manufacturing problems, and its inherently higher speed provides visible benefits to displays. Another advantage of *p-si* on glass is that driver chips can also be produced during the same process, saving cost and space, and improving reliability. As new, lower cost production methods are developed for still lower temperatures, *p-si* displays will continue to gain in sophistication and market share. They are rapidly becoming smart, high value-added displays that will eventually include memory and CPUs, in addition to array drivers. These "System On Glass" FPDs will require less power, produce brighter images, have faster response, provide higher resolution, and require less external circuitry than current generations of either *a-si* or *p-si* technology.

LTPS displays require more tests because they incorporate other control devices in addition to the pixel TFTs, and they are intended for operation at video rates. These tests include measurements on the driver ICs, digital tests with clock signals, and checking high frequency operation. As a result, high test throughput is even more important than in traditional *a-si* products. Given that *p-si* active devices are smaller and operate more efficiently at lower currents, testing them may require higher measurement sensitivity than *a-si* devices do.

Otherwise, similar parametric testing is performed on *p-si* FPDs, with all the same measurement problems associated with *a-si* technology. However, additional signal sources and instruments make the integration of LTPS test system components more of a problem. These include parametric tester interfacing issues, synchronization problems, and software compatibility.

Optimizing Sensitivity and Speed

As high speed AMLCD panels for video applications evolved during the 1990s, Keithley developed complete high speed process monitoring system solutions that help display OEMs improve device yields and more easily control product quality. LTPS allows drivers and other advanced circuitry to be integrated on glass, so Keithley's TEG systems are being enhanced with pulsed and RF capabilities to support specific types of high speed functional testing. These capabilities can be combined with TEG testing earlier in the production process, thereby avoiding expensive packaging steps for bad devices, or making it economical to implement corrective actions and repairs.

Various test platforms are available that allow LTPS display OEMs to optimize measurement sensitivity and throughput. When ultra-low current measurements are not an issue, Keithley's Model S400 Automated Parametric Test (APT) System can increase throughput in a fully cabled application due to its ultra-low parasitic switching matrix and sensitive SMUs. Alternatively, when both low level measurements and high throughput are required, the Keithley S600 APT System allows both superior low current performance and high speed pseudo- and (in many cases) true-parallel testing operation.

To extend measurement sensitivity in S400 applications, the Model 4200-SCS can be connected through the system matrix with up to four separate pixel probe cards. With this arrangement, it is possible to achieve current sensitivity at the DUT in the range of 1–2fA. Many other hardware variations are possible to optimize the system for the particular application.

Organic Electroluminescent (OEL) FPDs

These advanced display devices are rapidly approaching commercialization, including both active and passive variations. ***Figure 3*** illustrates a typical OEL device. Two technologies have emerged, which seemingly fill different application niches.

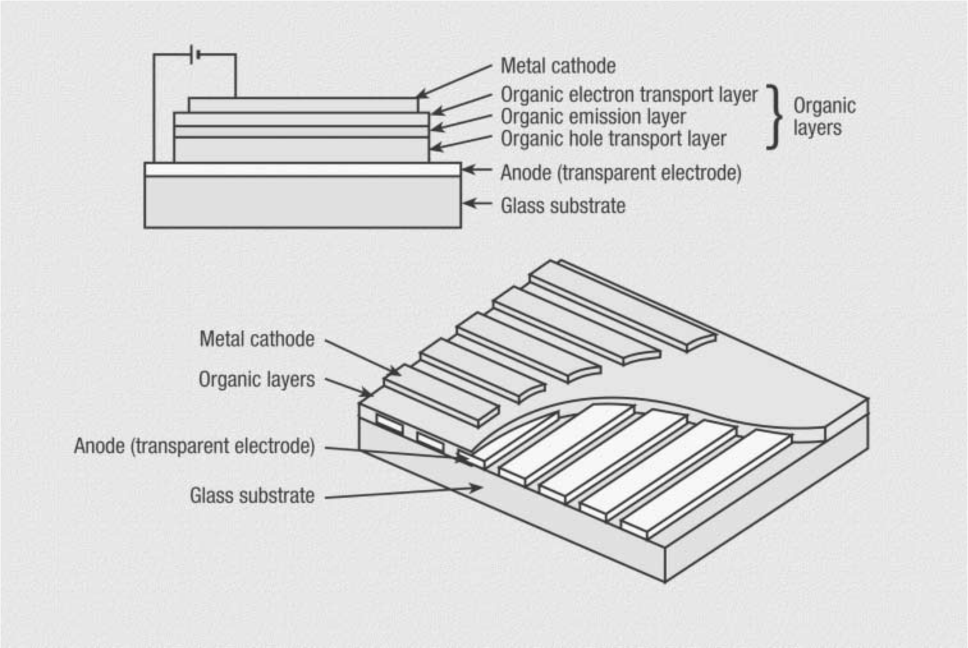

Figure 3. Typical OEL device construction. The organic layer is positioned perpendicularly between striped cathode and anode. From the anode side, the organic layer has a hole transport layer, emission layer, and electron transport layer. The structure closely resembles light emitting diodes with PIN junctions.

Light Emitting Polymer (LEP) devices are being developed based on large molecule polymer technology created by Burroughes and others at Cambridge University in the United Kingdom. This technology is being pursued for small area and low speed/resolution applications, such as cell phones, digital “ink & paper,” fabrics, greeting cards, window/POP advertising devices, etc. The stated advantage of polymer displays is the ability to spin the layers on the glass substrate and, in some cases, to pattern the films with photolithography. Thus, it is theoretically easy to achieve simple, low cost active matrix displays, and (at higher cost) higher resolution displays with fine stripes of different emitters for full color images.

OLED devices based on Kodak’s small-molecule technology are compatible with most semiconductor processing techniques, but their manufacture is considerably more complex than that of LEPs. Nevertheless, they are the front runners for high information content, video-bandwidth displays, such as monitors and TVs. In these applications, they will almost certainly disrupt the dominance of silicon-based LCDs, as there are many researchers and start-up companies working on this technology. (No one has ever succeeded in integrating an array of inorganic LEDs with a density as high as that possible in an active matrix OLED display.)

Material lifetime is still a key issue limiting widespread application of OEL FPD technology, so developmental testing is focused on evaluating materials, processes, and devices for light output vs. operating life. The test systems now required for device characterization during product and process development can be used later, with minor modifications, to monitor ongoing processes and help manufacturers climb up the yield and quality curves.

The development of such systems for OLED applications is possible with Keithley's instrument level solutions such as the SourceMeter® family of current and voltage sources, which also include precision current and voltage measurement capabilities. In addition, these core I-V tools provide system-level compatibility with other instruments and high density switching systems, such as the Series 2000 family of DMMs, the Series 7000 family of switching mainframes, and the Series 2700 integrated data logging family. These instruments can be combined in a wide variety of configurations to create manual and automatic test systems for lifetime, I-V, and light-current-voltage (LIV) characterization.

One of the issues associated with OLED testing is the higher level of capacitance in these structures. Although many of the measurements required are the same as for AMLCD devices, the test system and methodology must be able to handle higher capacitance without adding excessive test time. Also, given that OEL FPD pixels are active light-emitting devices, it is important to characterize LIV properties under both DC and pulsed DC operation. This creates additional test complexity.

Evolving OEL Test Systems

By combining its experience in conventional semiconductor and specialized laser diode testing, Keithley has developed I-V and LIV characterization instruments and systems for OLED and LEP researchers and process development engineers. For electrical testing needs on emerging production systems, Keithley instruments and system platforms are being tailored for advanced device measurements, while still meeting the requirements for high throughput and tightly integrated functional test systems.

By leveraging the Keithley Series 2400 and 2500 SourceMeter® I-V instrument families and LIV Characterization System capabilities, and combining them with our high density switching systems, we provide testing solutions ranging from tens to hundreds of channels. Thus, row/column I/O with widely customizable performance and price ranges can be created for prototyping or large production systems. By working closely with customers and learning about critical measurement needs, and knowing how to exploit our building block instruments to optimize measurements, we deliver tightly integrated systems with innovative test algorithms that shorten test time.

For example, the way source voltage or current is applied to a DUT can have a significant effect on how quickly the DUT and test instruments settle. A large, sudden voltage step applied to the DUT can result in a longer I-V settling tail due to the capacitance of the cables and DUT, and dielectric absorption properties of the probe card. If one measures too quickly, the resulting measurement will be unstable because there is a high probability that the measurement was taken during the exponential rise or fall portion of the I-V response curve. Adding an arbitrarily long delay can result in inefficient and slow measurements. These effects can be even worse with improper instrument ranging.

Often, it is better to break the large voltage step into smaller steps using the sweep capabilities of the instruments. By approaching the final voltage using smaller voltage steps, it is possible to improve the settling characteristics of the measurement. Another approach is to take advantage of the steady-state measurement commands of advanced parametric testers (for example, Keithley's ssmeas function). A steady state measurement command will instruct the tester to continue measuring until a user-defined change criterion is met, for example, "measure until the reading changes by no more than 3%."

Keithley's Contributions to Advanced FPD Development

As OEL technology continues to evolve, Keithley is working closely with key public and private sector researchers, material suppliers, and established and emerging commercialization partners. Keithley's contributions in these technology partnerships are new test techniques and instrumentation that help define and optimize products now in the development or concept stages.

Keithley is interested in discussing our current test solutions and future directions with leading participants in emerging LCD and OEL product technologies. We are particularly interested in exploring FPD test requirements that would benefit from the full range of our related optical and RF test technologies.

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