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31.2: FPD Test, Inspection, and Repair Technologies: State of the Art and Future Directions

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ABSTRACT

Flat-panel display (FPD) manufacturing requires sophisticated Test, Inspection, and Repair (TIR) equipment to become practical and cost effective. Today's state-of-the-art TIR equipment has advanced measurement technologies to measure pixel performance in a non-contact manner with automated repair vectoring . This paper will introduce current equipment capabilities and outline the improvements in resolution, throughput, and cost of ownership required to fully integrate modern TIR equipment in FPD mass-production lines.

I. Introduction

The flat-panel industry is moving towards mass-production with products rivaling CRTs in picture quality, sharpness, and brightness. The leading technical approach for producing these flat-panels, Active-Matrix LCD (AMLCD), is currently experiencing yield problems, resulting in higher prices and lower than expected market penetration for high-definition flat-panel products. Yield continues to be a major problem preventing AMLCD manufacturers from serving their markets with products at a reasonable cost. Building redundant rows or columns similar to the RAM industry is not a viable option since the display is visual and no pixels can be substituted. Other methods of redundancy often complicate the active plate and lower the yield gains.

Industry analysts agree that should the cost of these flat-panel displays fall to the ¥50,000 level, an explosion in demand will be realized. The potential applications include laptop, notebook, PC, and workstation computers, monitors, data displays, consumer appliance displays, and televisions.

II. Current Mass-Production TIR Needs

The need for better TIR equipment was realized in the late 1980s when first generation AMLCD manufacturing lines were not yielding with reproducible results. Running such a complex process "open-loop" invited long and frequent line shut-downs, erratic display quality, and low overall yield. The early open/short probe systems borrowed from simple-matrix array manufacturing which manual repair had proven inadequate for modern FPD manufacturing.

FPD mass-production lines need fast, reliable information to make go/nogo decisions in actual production and to analyze and correct any yield and cost issue which surfaced during manufacturing.

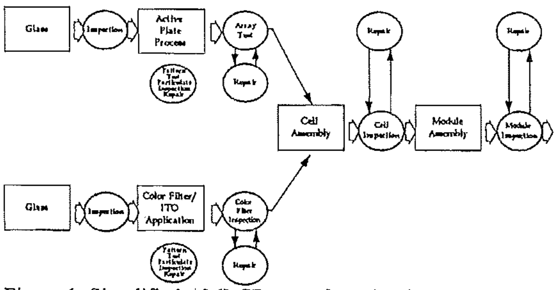

Figure 1: Simplified AMLCD manufacturing line including TIR equipment.

The steps where TIR equipment can be utilized is shown in Figure 1. Although the AMLCD process is shown in the example, the fundamental use of TIR equipment as a manufacturing feedback and go/nogo tool holds for any FPD technology. In the figure, test/inspection and sometimes repair is made available at each important manufacturing step. The intent is to "divide and conquer" the complex process through intermediate process data which correlate and estimate final display quality without waiting to complete the FPD. Significant cost savings are possible once information with sufficient reliability can decide production quality early in the process.

A complete FPD TIR infrastructure as shown in Figure 1 is not available. The missing capabilities in Table 1. The Table shows that ARPA and USDC has launched certain programs and request for proposals (RFPs) to support core technology development and its integration in practical TIR equipment. To date, most funded work has yielded new approaches which promise mass-production capabilities in areas such as array test and repair. Most actual equipment from these efforts are pilot production capable but need more work to yield true mass-production capabilities.

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Table 1

Equipment	Current Program	Test Coverage	Cost of Ownership	Through put	Auto-mation
1. Glass Inspection	USDC	X	X	X	X
2a. Pattern Test	None	O	-	-	O
2b. Particulate Inspection	None	-	-	-	X
2c. Plate Repair	None	O	O	O	X
3. Array Voltage Imaging	ARPA	O	O	-	X
3. Array Test: Indirect Measure-ment	None	-	X	O	O
3. Array Open/ Short	None	X	X	O	O
4. Array & Color Filter Repair	ARPA	O	O	O	X
5. Color Filter Inspection	None	X	X	X	X
6. Cell Inspection	USDC	O	O	X	X
7. Module Inspection	None	O	O	X	X
8. Cell/ Module Repair	None	O	O	O	X

O: Approach has advantages in this area
-: Approach is neutral in this area
X: Approach has disadvantage or currently inadequate in this area

It is expected that this core work can be extended to other TIR areas not currently being served, such as cell test technology being fundamentally applicable to module test or glass inspection technology being applicable to color filter and particulate inspection. In this respect, the current ARPA/USDC programs should yield a large portion of the TIR infrastructure if the chosen approach has broad applicability.

III. Types of TIR Equipment

In-Process Array Test Systems

Array test systems are to be distinguished from the simpler line test systems, usually called open/short testers (O/S testers). An array test system has the added capability of detecting not only line defects but also the functionality of the TFT pixel. O/S testers are usually not desired for serious AMLCD mass-production because of its inability to predict final display quality through pixel functional test and as a result cannot be used as an SPC tool.

Other than O/S testers there are three classes of array testers: Optical, Electrical and Electro-Optic. The optical test systems survey the plate and flags defects (optically different areas). The main advantage of this technology is its general use as a process improvement tool. It has little test coverage; however, its high throughput is useful in mass-production test. The electrical array testers use more traditional high pin count probe cards with added electronics to infer indirectly the pixel performance by its electrical interaction with the data line. [1,2] Detection schemes can be time domain (IBM technique) or frequency domain (Genrad); but all must use large pin count probe frames. Test coverage is higher than O/S but limited to specific FPD plate designs. Although requiring less pins for test, E-Beam test technology is also of the indirect measurement type. The electro-optic array tester measures pixel voltages directly through the use of a process known as Voltage Imaging™ The technology measures true voltage and therefore has the highest test coverage. The technique does not require high pincount probe frames, thereby significantly reducing changeover time and other related costs.[3]

Cell and Module Inspection Systems

Currently, most manufacturers employ human inspectors using equipment originally developed to inspect solar cells, the early predecessor to the modern α-Si TFT. Using computer generated test patterns and complicated probe card systems, operators typically spend 3-5 minutes visually inspecting displays for pixel defects, line defects, and other gross anomalies. Unfortunately the results are often inconsistent, subjective, and incomplete. Compounding this problem are the inherent limitations in the human visual system, especially when inspection time is limited. Figure 2 shows the correlation between inspection time and defect detection sensitivity.

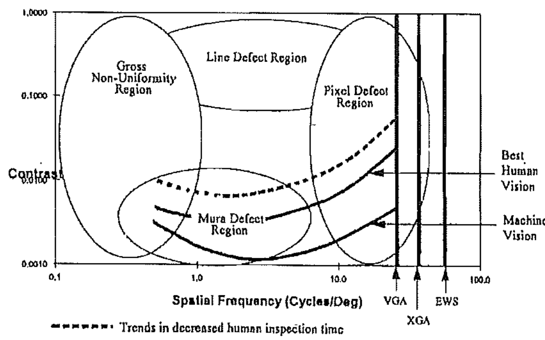

Figure 2: Machine Vision vs. Human Visual Response in defect detection

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Further, display end-users are demanding that the LCD industry move from VGA to XGA, EWS, and beyond. Confronted with these challenges, it is clear that human inspection can no longer provide effective product inspection and manufacturing process control. Quietly, human vision is being replaced by machine vision. The cell and module inspection system currently can utilize one of the following four technologies: scanning, step/repeat camera, multiple cameras, or N-Aliasing™ - single camera.

Scanning technology scans the display much like a copying machine to detect cell/panel defects. The main disadvantage is its inability to measure mura with precision because time variations on panels cause measurement artifacts. Another limitation is its perpendicular measurement geometry which cannot provide any viewing angle data.

Step/Repeat camera systems use a high-magnification camera which is mechanically stepped across the display. High cost and complexity prohibits this system from being commercialized. Viewing angle changes and any panel drift makes mura detection and accurate measurement difficult. Due to the complexity and low throughput only R&D systems are available.

The multiple camera approach can give the required resolution and accuracy with a cost and complexity penalty. Although taking all data simultaneously, viewing angle changes make mura detection and accurate measurement difficult.

Single camera technology inherently provides higher system reliability, lower cost, and easier system calibration, alignment, and maintenance, as well as reducing system hardware and software complexity. Additionally, software techniques such as N-Aliasing™ have been developed to enhance the ability of a single camera to substantially improve its spatial resolution detection. N-Aliasing™ is a technique which significantly reduces the systematic error associated with the moiré patterns generated by the overlap of the VGA pixels on the camera's CCD array, allowing a test system employing this technique to provide much higher spatial frequency resolution than a native camera. N-Aliasing™ provides the system with a higher capability to accurately place the location of the defect on the panel. These technology strides have made machine vision effective, usable, and reliable.

Repair Systems

Low yields of LCD panel manufactures have created a high demand for an effective laser process to salvage the defective displays during LCD panel production. The LCD repair system is designed to be installed in a manufacturing process line and will do the various laser functions of welding, ablating, cutting and writing, depending on the repair strategy used by the manufacturer. There are fundamentally two kinds of repair strategies, and thus two types of repair systems: Deposition/cutting systems and Cut/Weld systems. The deposition-capable systems can effectuate open repairs at the plate level by depositing a suitable conductive material. This repair process is compatible at the plate repair stage only. Depending on the deposition system-gas chamber, vacuum chamber, or open environment-deposition is necessary. The cut/weld type systems can both cut material (usually for short repair) and, in some systems, can weld two conductive traces for open repair [4]. In this case the array structure needs to be modified to incorporate repair rings outside of the active area. For the cut/weld system, plate and cell repair is possible since no material deposition is utilized.

IV. Future TIR Directions

The future direction of TIR equipment is in automation and networking. Utilizing cluster tool automation concepts with seamless factory automation and information management will realize the advantages of using TIR equipment. Throughout this section the cluster concept with network links for Statistical Process Control (SPC) and Computer Integrated Manufacturing (CIM) utilizing Automated Guided Vehicles (AGV), will be discussed.

The next step for the array testers previously mentioned will be to include SPC so that cost control can be implemented at the critical stages in manufacturing. System selection criteria include operating costs (with all running costs such as probe cards), sensitivity, test coverage, footprint, automation, and second/third generation LCD plant compatibility.

In the cell and module test arena there is also been a trend to move towards automated, quantitative cell and module inspection to allow for SPC and factory automation for mass-production. [5] This is seen in addition to large growth in both the pixel density (making visual inspection increasingly difficult) and general market growth. Table 2 estimates this growth requirement and an inherent need to move to automation.

The above inspection load increase has a parallel in the semiconductor industry. During the late 1970s, semiconductor mask inspection was done using a line of human visual inspectors using microscopes. As the device count increased, the time to inspect lengthened unreasonably and the inspection error rates also increased. With the growth of the industry, human inspection was eliminated and replaced by automated optical inspection.

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