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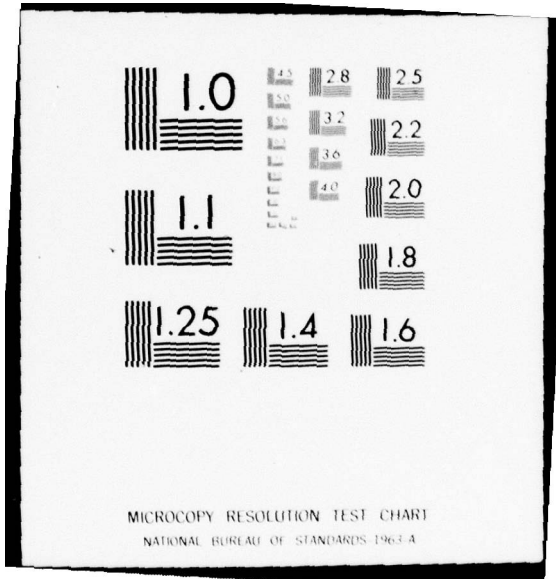
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FIFTH QUARTERLY REPORT ON
MANUFACTURING METHODS AND ENGINEERING
FOR TFT ADDRESSED DISPLAY

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for period of

May 7, 1977 to August 7, 1977

Prepared by W. L. Rogers, F. C. Luo,
H. Y. Wey, S. D. Burkholder, M. Green

CONTRACT DAAB07-76-C-0027

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UNITED STATES ARMY ELECTRONICS COMMAND
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with

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**FIFTH QUARTERLY REPORT ON
MANUFACTURING METHODS AND ENGINEERING
FOR TFT ADDRESSED DISPLAY.**

for period of ⁹ Quarterly rept. no. 5,
7 May ~~1977~~ Aug ~~1977~~,

¹⁰ Prepared by W. L./Rogers, F. C./Luo,
H. Y./Wey, S. D./Burkholder M./Green

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¹⁵

placed by ¹⁴ 78-860-DISPL-P1

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Abstract

This is the Fifth Quarterly Report on Contract DAAB07-76-C-0027; Manufacturing Methods and Technology Evaluation for the fabrication of thin film transistor based solid state displays. This quarter was one of major accomplishments. First, a substrate was fabricated which was virtually perfect over half the total display area. The primary defect in the inoperable area was identified as open busses due to cracked crossover insulators. As the result of corrective action taken to resolve this problem, the next run produced the excellent half panel shown in Figure 1. This is not only the best quality display made on the pilot equipment to date, it is comparable in quality to the best displays made on the X-Y equipment. Early indications are that the fabrication of this display is not an isolated event but the beginning of a period of improved production performance.

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FIGURE 1 BEST DMD SUBSTRATE PRODUCED IN PILOT FACILITY 9

ABSTRACT

This is the Fifth Quarterly Report on Contract DAAB07-76-C-0027; Manufacturing Methods and Technology Evaluation for the fabrication of this film transistor based solid state displays. This quarter was one of major accomplishments. First, a substrate was fabricated which was virtually perfect over half the total display area. The primary defect in the inoperable area was identified as open busses due to cracked crossover insulators. As the result of corrective action taken to resolve this problem, the next run produced the excellent half panel shown in Figure 1. This is not only the best quality display made on the pilot equipment to date, it is comparable in quality to the best displays made on the X-Y equipment. Early indications are that the fabrication of this display is not an isolated event but the beginning of a period of improved production performance.

1. PURPOSE

The overall objective of this program is to develop mass production methods and techniques for thin film transistor display technology. This novel technology is most amenable to computer control and the methods in development are based on an existing, Westinghouse developed, computer controlled thin film pilot line. Versions of the display in development have been made, with considerable success, in laboratory style equipment and this work continues under direct corporate support. The program includes the development of methods, procedures and optimal recipes followed by the rigorous examination of the displays for performance and life.

2. RESULTS AND DISCUSSION

2.1 Introduction

As reported previously, most of the major process and equipment problems preventing successful fabrication of high quality display panels have been overcome. Those problems still remaining were obviously quite subtle. As a result, Dr. F. C. Luo was added to the pilot line team to bring to bear his years of experience in making a similar device in the laboratory. The following sections will document the problems identified during this quarter, and, where appropriate, those solutions either implemented or planned.

2.2 Dielectric Film Quality

The defect characteristics observed during this quarter were essentially the same as those observed last quarter:

- Insulator cracks
- Specks deposited with the insulator
- Contamination

The results, however, are different.

2.2.1 Insulator Cracks, thought to be a minor problem in the context of the level of defects existing earlier, became more significant as the level of other defects was decreased. This particular defect was observed only in circuits produced in the pilot line, not those produced by the "X-Y" (movable mask) technique in the laboratory. A list of all known differences between the two processes was compiled (see Fourth Quarterly Report, Paragraph 2.2.1), and each one studied to pinpoint the cause.

One of the presumed differences which could be a contributor had to do with the time between substrate bakeout after cleaning, and the pumpdown with all substrates in the vacuum system. This time was significantly longer in the pilot line than in the laboratory, which meant that the opportunity for adsorption of contaminants (particularly moisture) onto the substrate was much greater in the pilot facility. To reduce this effect, great pains were taken to schedule the final substrate cleaning steps at the last possible moment before chamber closing and pumpdown. Furthermore, an infrared heater was installed in the laminar flow hood where the substrates were mounted on their holders, so that the substrates could be kept hot.

Another difference was found between the pilot line process and the laboratory process, which is probably much more significant. The circuit contains three (functional) types of insulators: Gate insulator, capacitor insulator and crossover insulator. A pattern finally evolved where it was noticed that the only insulators which cracked were the crossover insulators. This can be traced back to the original design of the dedicated masks (circa 1975). Both the capacitor insulator mask and the gate insulator mask had room for crossover insulators, so the crossover insulators were designed into both masks. This was thought to be a guardband feature in that by increasing the number of layers of crossover insulation, the probability of crossover shorts would be reduced. Thus, while other insulators are 6000 angstroms thick, since each mask is used twice. The crossover insulators are as much as 24,000 angstroms thick! This additional thickness meant higher (probably thermally-induced) stresses -- high enough that in some cases, cracking occurred. The solution was quite simple: the Kovar back-up plate under one of the insulator masks was shifted to cover the extra crossover insulator apertures. Since these changes were implemented, no cracked insulators have been observed.

2.2.2 Specks Deposited with the Insulator have been virtually eliminated by implementing procedural changes and minor equipment modifications. As described earlier, insulator masks are "backed up" by kovar plates with oversize apertures. This kovar back-up plate is periodically sandblasted with a very fine grit to increase its surface area and prevent peeling during deposition (flakes of insulator material would peel off the mask assembly and fall into the hot crucible, re-evaporating by explosion). Likewise, insulator material would peel off the mask wheel around the mask. The mask wheel could not be sandblasted (due to practical considerations, such as size and delicately adjusted cams), so an additional removable shield was installed just below the mask wheel. This shield is sandblasted before every run. The deposition well liner and shutter were modified to reduce peeling. A new procedure was implemented where the edges of the crucible are swept by the electron beam at the beginning of each insulator deposition to reduce buildup, and prevent pieces of evaporated and condensed insulator material from falling into the hot crucible after the shutter is opened. And, finally, the evaporant material is carefully screened to eliminate small particles which could explode.

2.2.3 Contamination of a particulate nature continues to be a problem, though to a lesser extent than before. The majority of the contaminants are believed to trace back to an inability to clean the insulator masks effectively, or to inspect them. As reported earlier, aluminum oxide builds up in the concave sides of the mask apertures (see Fourth Quarterly Report, Paragraph 2.3 and Figure 4). In addition, insulator material condenses on the underside of the mask, where it is scraped by the backup plate when the mask/backup plate assembly "oil cans" during magnetic pullup and substrate engagement. Many of these particles are picked up by the electrostatically charged substrate, and then redistributed, during the production process, to the other masks. These particles are, basically, transparent, and cannot be seen during mask inspection. Two things need to be done: A visual

inspection technique must be devised that will make these particles visible; a mask cleaning procedure must be developed which will eliminate these particles (the visual inspection technique is needed so that the cleaning procedure can be checked).

Another problem is airborne, particulate contamination (dust, etc.). Sufficient proof now exists to indicate that clean substrates, masks, removable tooling and the open area of the vacuum chamber cannot be subjected to (the present) class 10,000 conditions. A plan is under development to replace all fiberglass ceiling panels in the pilot facility to a non-shedding material, and to locate, strategically, class 100, vertical downflow, laminar flow areas around the vacuum chamber, between final assembly and inspection areas for substrate and masks, and the vacuum chamber, and in the final rinse area. These facility improvements will be implemented using W funds and should occur early in the first quarter of 1978.

In the meantime, a procedure has been implemented to reduce the effects of particulate contamination: Three clean substrates are used in an "exercise" mode at the beginning of each run to "mop up" particles on the masks. Initial indications are that while this is wasteful in terms of throughput, it is proving quite effective in terms of yield.

2.3 Metal Film Quality

Much progress has been made in developing procedures and techniques for metal deposition. All metals are evaporated by electron beam gun, using hearth liners to reduce heat loss. As a result, the entire metal slug is molten during evaporation, eliminating micro-explosions from porosity and low evaporation temperature contaminants.

2.3.1 Aluminum Interconnects are of excellent quality. Some particulate contamination had been observed which appeared to be caused by excessive cracking of the (carbon) hearth liner. Very small particles of carbon are generated during this cracking and can cause formation of various aluminum carbides. To reduce crack formation, the computer operating program was modified to keep the crucible hot between depositions, thereby reducing thermal cycling, and the hearth liner and its contents are replaced after every run.

Occasional spot defects are visible (see discussion of "rabbit tracks" in Fourth Quarterly), but appear to affect the circuit cosmetically rather than operationally. Likewise, occasional ripples, but these are always in the top layer where they cannot cause shorts, and do not affect conductivity.

2.3.2 Copper is used primarily for the transistor source - drains and as an interface between the source (or drain) and the electroluminescent pad, this latter pattern being called the "source-drain contact". The source-drain patterns are excellent. The source-drain contacts, however, occasionally tend toward fuzziness due to poor mask-to-substrate contact. As this mask is extremely "lacy" (that is, the number - and size - of its apertures are very large), it can present some problems. It has been found that sharp patterns can be made repeatably using a thin (.032 inches), instead of a thick (.047 inches) mask, due to its increased flexibility. Also, it was found that the molybdenum hearth liner will change its geometry after many heat cycles, and eventually conform to the crucible. This increases heat transfer, requiring more power to the gun, and increased heating of the mask. Changing this hearth liner periodically eliminates this problem.

Copper has been a slight problem during annealing. During this process, dry nitrogen gas is used to provide an inert atmosphere. Unfortunately, the current supplier of nitrogen bottles occasionally supplies a mixture of nitrogen and oxygen ---- which, predictably, cause

the copper films to deteriorate. The annealing furnace will be connected to the building nitrogen supply, with a dryer, shortly.

2.3.3 Indium is used as an adhesion layer for the copper source-drain and as a "dopant" for the semiconductor. Recent results indicate that this material was primarily responsible for gate to source-drain transistor shorts. Shorted transistors are characterized by small specks in the vicinity of the shorts. However, as there are so many film layers in the region, and indium was the thinnest, it was the last to be suspected. Recently implemented procedures for rigorously scraping the surface of the indium slug before every run, and then high rate (and high temperature) evaporation of a relatively large amount of indium during the pre-heat cycle, have virtually eliminated this defect.

2.3.4 Edge Contacts occasionally have been open due to migration of the aluminum bus bars, to which they connect, into the gold contact. This problem has been eliminated by a different formulation; 200 angstroms aluminum for adhesion, followed by 1500 angstroms of copper for conduction and as an interface, followed by 300 angstroms of gold for the corrosion resistance.

2.4 Transistor Characteristics

Transistor characteristics now appear well in hand. For many months, two recipes have been in use: A "standard" recipe used for correlation, and an experimental recipe which adds one step to the "standard". This additional step consisted of three angstroms of indium added directly onto the semiconductor in the source-drain gap. Enough experimental evidence has now been gathered to indicate that "doping the gap" has very little effect on transistor characteristics except stability, which is much improved.

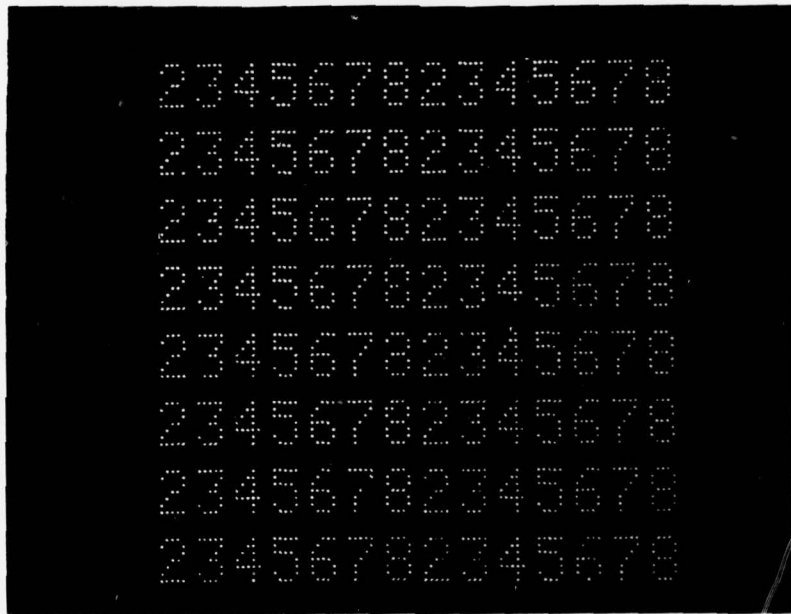
2.5 Subsequent Circuit Processing

No significant problems are being encountered in this area, which is still in the same general situation as reported in the Fourth Quarter.

Throughput is increasing, though, and the ability of these subsequent processes to sustain yield is beginning to be tested. It has not yet been found wanting.

2.6 Overall Manufacturing Process

The first objective of this program is to move a technology out of the laboratory and into (pilot) production. That this is actually being accomplished is proved by a photograph of an actual DMD substrate produced in the pilot facility in July (Figure 1). This is not only comparable in quality to the best units made in the laboratory, since the pilot facility has demonstrated significant repeatability, it promises to be not an "accident", but the beginning of quality production.



BEST DMD SUBSTRATE PRODUCED IN PILOT FACILITY

FIGURE 1

3. RESULTS OF X-Y FABRICATION OF DISPLAYS

This is a parallel, laboratory effort to improve DMD-type panels, and is Westinghouse-funded. As mentioned last quarter, with the reassignment of Dr. F. C. Luo to the Pilot Facility Team, Dr. H. Y. Wey has been assigned to the X-Y facility. Developments on this program are being reported here in the hope that they may be of some help on the manufacturing methods program.

Double-sided scotch tape had been used to hold the substrate and the movable masks in position during vacuum processing. This had been causing problems, as evaporation heating (particularly insulator evaporation) caused the adhesive to soften and allowed the substrate and masks to move. Furthermore, the adhesive leaves a residue which is virtually impossible to remove. A high-temperature double-sided Kapton tape with a silicon-based adhesive is now being used with excellent results; not only do substrates no longer fall off the holder, and masks not move, but the silicon adhesive leaves no residue.

Much work has been done to modify procedures to reduce contamination. The masks and substrate are assembled together in a laminar flow clean room and "sealed" before being transported to the vacuum system. The vacuum system itself, after sandblasting is cleaned with rags and methanol until all (visible) dust is removed. Source materials and their hearth liners are cleaned with methanol in an ultra-sonic cleaner to remove surface contaminants.

A heat shield was installed under the jig to minimize movement due to thermal expansion.

A boron nitride hearth liner is being tried for aluminum. Its advantages are that it is a better thermal insulator than Poco, it does not generate aluminum carbide or aluminum oxide. Its disadvantage is that it cracks rather easily. Work is being directed to reduce this cracking.

Several process changes have been made. Aluminum bus bars are deposited with a 100% overlap, instead of the previous ~ 4 mils, to provide redundancy and eliminate opens due to filamentary contamination and partially blocked apertures. All crossovers are covered with an alumina overcoat so that underlying opens can be repaired by placing conductive epoxy on top to bridge the open without shorting to the other bus.

Process time has been reduced from 2-1/2 days to 1-1/2 days by preheating the substrate and masks to approximately 27°C, and then allowing only 2 hours cooling time after the insulator layer, instead of the previous 4 hours.

Short circuits are still the major failure mode, although the last 7 substrates produced during this period had no crossover shorts, and averaged 7 to 8 capacitor shorts. These shorts are thought to be caused by particulate contamination which is very small, random and difficult to trace.

4. CONCLUSIONS AND OBSERVATIONS

Moving technology out of the laboratory and into (even pilot) production is a difficult and time-consuming task. With the latest substrate (Figure 1), it now appears that the first and probably most difficult portion of the work -- achieving equivalent quality product -- is being achieved. Other very significant objectives remain, however: higher quality, high yield, reasonable throughput and reasonable cost. The first two of these will be the subject of efforts during the next several months. In particular, cleanliness improvement will probably be a prime objective for (at least) many months to come. Repeatability must be improved to achieve high yields, particularly in the areas of improved tooling, especially masking, and deposition techniques and procedures. Cleaning procedures still need to be improved. Mask inspection techniques need to be devised to permit detection of small particles. None of these, however, appears insurmountable in light of the problems which, demonstrably, have now been overcome.

5. EXPECTED RESULTS NEXT QUARTER

At least 6 good quality substrates will be produced for packaging as engineering samples.

Process and procedure development will be carried out to improve product quality, repeatability and yield, but not, as yet, throughput.

6. PUBLICATIONS AND REPORTS

None

7. IDENTIFICATION OF PERSONNEL

A listing of people and hours charged to this contract in this quarter would only constitute a small amount of the total program since, as is well known to the Army, a major company funded program parallels this effort. All the Research Thin Film Devices personnel are now carried on the Westinghouse program. They include:

<u>Engineers</u>	<u>Technicians</u>
Dr. David H. Davies	F. S. Youngk
Dr. F. C. Luo	H. B. Shaffer
Mr. R. E. Stapleton	D. Leksell
Mr. S. D. Burkholder	
Dr. H. Y. Wey	

All the above are substantially 100% on the program.

Directly charged to the program in this quarter are:

	<u>Hours Charged</u>
Engineering: T. Csakvary	66
W. L. Rogers	80
Management: Dr. M. Green	~ 80

Additional minor efforts were put by various personnel.

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