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LLNL-TR-739170

# Plastic Substrate Active Matrix Displays Final Report CRADA No. TC-2011-00

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# PLASTIC SUBSTRATE ACTIVE MATRIX DISPLAYS

**Final Report**
**CRADA No. TC-2011-00**
**Date Technical Work Ended: May 30, 2001**

Date: July 11, 2003 Revision: 2

## A. Parties

This project was a relationship between Lawrence Livermore National Laboratory (LLNL) and FlexICs, Inc.


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## B. Project Scope

This project was a collaborative effort between the University of California, Lawrence Livermore National Laboratory (LLNL) and FlexICs, Inc. to develop thin film transistor (TFT) electronics for active matrix displays.

The technical objectives of the project were to:

a) Refine existing TFT on plastic technology to make poly-Si TFTs suitable for active matrix OLED displays.

b) Move from fabricating individual transistors to a complete 3-inch viewable diagonal dimension display backplane.

c) Design (with DARPA team members) and build a 3-inch monochrome OLED display backplane.

d) Integrate the backplane with OLED material and build a complete display, including drive electronics (both these will be performed by the DARPA team members).

e) Move from a moderate resolution (70 dpi) monochrome display to a high resolution (133 dpi) color display. This entails refinement of the TFT process for smaller devices (6 μm gate or smaller), redesign of the display, and the development of multilayer OLED patterning capability on the part of the DARPA team members.

The first three goals of the program were met, the last two were not met during the active course of the CRADA, but have been substantially met by the CRADA partner subsequently due in substantial part to advances made during the CRADA.

This CRADA was originally designated as a thirty-six (36) month project. Work on the project was stopped before the originally designated scope of work was completed due to a shift in LLNL program priorities.

## C. Technical Accomplishments

The following tasks were successfully completed:

1. Designed 3-inch diagonal monochrome display, completed mask set
2. Upgraded LLNL B197 facilities
3. Fabricated display backplane
4. Test display backplane

The specific accomplishments were:

- low temperature deposition of high quality CMOS gate oxide
- fabrication of thin film transistor with acceptable threshold voltage and industry standard on/off ratio
- control of fabrication process, especially thermal budget, so that multiple masking layers registered within specification across the area of the plastic film display substrate

## D. Expected Economic Impact

Flat panel displays use glass sheets as substrates for circuitry and optically active materials. The glass sheets are the principal component of breakage and weight in flat panel displays. Plastic sheet, which is both flexible and shock resistant, will replace glass in many applications as soon as the problems alluded to above are solved. New markets for hand held, notebook, flexible and super rugged displays are anticipated. Market value of such displays is on the order of a billion dollars per year.

### D.1 Specific Benefits

<u>Benefits to DOE</u>
The U.S. Government has designated the manufacture of flat panel displays as a critical National capability. Currently, however, more than ninety-five percent (95%) of these displays are

manufactured overseas. The lack of a large-volume, domestic source for any type of flat panel technology puts the U.S. at a competitive disadvantage. More importantly, as defense systems become more reliant on flat panel technology, the lack of an on-shore source threatens the National Security. The ASCI Program of DOE will directly benefit from the availability of large area displays that will evolve from the basic work done on this CRADA. The ASCI sponsored VIEWS visualization program has a requirement for large area displays in excess of 10 million pixels. Such displays will be deployed in specially equipped visualization conference rooms (commonly known as visualization caves) and offices. These displays are used for real-time, direct-viewing of ASCI simulations in a large area format by large number of people, and are aimed at enabling the development of codes on Pacific Blue for application to stockpile stewardship weapons simulation. Similar displays are needed by the National Reconnaissance Office (NRO) for large area briefing room display of satellite images and are to be provided through the DOE/NRO partnership program by DOE. Due to the large size and pixel counts of such displays, fabrication on plastic substrates using a large area format is the only practical technological approach ensuring success. The process and package simplifications resulting from this program should reduce overall system cost to a level that will allow U.S. manufacturers to capture a significant fraction of the market share in both the multibillion dollar, direct-view display industry. The large volume, domestic sources that result will, in turn, guarantee the availability of advanced visualization systems for military and intelligence applications. Spin offs from this technology include the development of a variety of capabilities for developing electronic systems on low temperature, lightweight, plastic substrates for national security applications. We have been in discussion with the NAI and Engineering Directorates at LLNL to identify specific applications for this technology and have identified remote sensor platforms and MEMs technology, a present DOE applications area that could have future direct benefits and are presently pursuing programs within both areas.

LLNL has supported research in the area of pulsed laser crystallization and doping of amorphous deposited thin films for the past five years through a combination of internal research spending and DARPA funding. As a result, the low temperature electronics program at LLNL has become a world leader in the area TFT fabrication at temperatures as low as 100°C for use on flexible plastic films. As an integral part of the work, the Labs researchers have developed world-class processing equipment and test facilities. This long-term strategy has resulted in major advances and now promises to pay off in terms of major contracts to design and develop even more advanced low temperature processes for future applications.

In relation to core competencies, products resulting from this work can be utilized for virtual reality and advanced visualization of data, meshing well with two major efforts at the Lab.

Benefits to Industry

Flat panel displays use glass sheets as substrates for circuitry and optically active materials. The glass are the principal component of breakage and weight in flat panel displays. Plastic sheet, which is both flexible and shock resistant, will replace glass in many applications as soon as the problems alluded to above are solved. New markets for hand held, notebook, flexible and super rugged displays are anticipated. Market value of such displays is on the order of a billion dollars per year.

## E. Partner Contribution

FlexICs, Inc. personnel worked along side LLNL personnel, principally but not exclusively on LLNL equipment at LLNL. LLNL possesses facilities constructed specifically for the development of thin film transistor (TFT) electronics on low temperature (less than 500°C) substrates. FlexICs possesses unsurpassed technical expertise related to this technology, familiarity with the LLNL equipment, and process-specific knowledge.

The partner has licensed LLNL technology created prior to the CRADA. No subject inventions were created during the CRADA.

## F. Documents/Reference List

**Reports**

None

**Copyright Activity**

None

**Subject Inventions**

None

**Background Intellectual Property**

LLNL disclosed the following Background Intellectual Property (BIP) for this project:

U.S. Patent No. 5,114,876, (LLNL Docket IL-8255) - *Method of Semiconductor Fabrication Using GILD Process*; issued 5/19/92; Inventor: Kurt H. Weiner

U.S. Patent No. 5,456,763, (LLNL Docket IL-8798) - *Solar Cells Utilizing Pulsed-Energy Crystallized Microcrystalline/Polycrystalline Silicon*; issued 10/10/95; Inventors: James L. Kaschmitter, Thomas W. Sigmon

U.S. Patent No. 5,346,850, (LLNL Docket IL-8807) - *Crystallization and Doping of Amorphous Silicon on Low Temperature Plastic*; issued 9/13/94; Inventors: James L. Kaschmitter, Thomas W. Sigmon, Joel B. Truher, Kurt H. Weiner

U.S. Patent No. 6,303,446, (LLNL Docket IL-9124) - *Method of Making Self-Aligned Lightly-Doped-Drain Structure for MOS Transistors*; issued 10/16/01; Inventors: Kurt H. Weiner, Paul G. Carey

U.S. Patent No. 6,221,726, (LLNL Docket IL-9125) - *Process for Fabricating Device Structure for Real-Time Process Control of Silicon Doping*; issued 4/24/01; Inventor: Kurt H. Weiner

U.S. Patent No. 5,773,309, (LLNL Docket IL-9436B) - *Method for Producing Silicon Thin-Film Transistors with Enhanced Forward Current Drive*; issued 6/30/98; Inventor: Kurt H. Weiner

U.S. Patent No. 5,569,624, (LLNL Docket IL-9447) - *Method for Shallow Junction Formation*; issued 10/29/96; Inventor: Kurt H. Weiner

U.S. Patent No. 5,817,550, (LLNL Docket IL-9814A) - *Method for Formation of Thin Film Transistors on Plastic Substrates*; issued 10/6/99; Inventors: Paul G. Carey, Patrick M. Smith, Thomas W. Sigmon, Randy C. Aceves

IL-9814B, Patent Pending

U.S. Patent No. 5,918,140, (LLNL Docket IL-10092) - *Deposition of Dopant Impurities and Pulsed Energy Drive-in*; issued 6/29/99; Inventors: Paul Wickboldt, Paul G. Carey, Patrick M. Smith, Albert R. Ellingboe

U.S. Patent No. 5,994,174, (LLNL Docket IL-10117) - *Method of Fabrication of Display Pixels Driven by Silicon Film Transistors*; issued 11/30/99; Inventors: Paul G. Carey, Patrick M. Smith

U.S. Patent No. 5,856,858, (LLNL Docket IL-10128) - *Plastic Substrates for Active Matrix Liquid Crystal Display Incapable of Withstanding Processing Temperature of Over 200°C and Method of Fabrication*; issued 1/5/99; Inventors: Paul G. Carey, Patrick M. Smith, John Havens, Phil Jones

IL-10387, Patent Pending

U.S. Patent No. 6,436,739, (LLNL Docket IL-10568) - *Thick Adherent Dielectric Films on Plastic Substrates and Method for Depositing Same*; issued 8/20/02; Inventors: Paul Wickboldt, Steven D. Theiss, Patrick M. Smith, Albert R. Ellingboe

U.S. Patent No. 6,541,316, (LLNL Docket IL-10609A) - *Process for Direct Integration of a Thin-Film Silicon p-n Junction Diode with a Magnetic Tunnel Junction*; issued 4/1/03; Inventors: Daniel Toet, Thomas W. Sigmon

The above LLNL BIP was licensed to FlexICs, Inc. under LLNL Case No. TL-1628-99, executed on February 12, 2000.

FlexICs did not disclose any BIP for this project.

## G. Acknowledgement

Participant's signature of the final report indicates the following:

1) The Participant has reviewed the final report and concurs with the statements made therein.
2) The Participant agrees that any modifications or changes from the initial proposal were discussed and agreed to during the term of the project.
3) The Participant certifies that all reports either completed or in process are listed and all subject inventions and the associated intellectual property protection measures generated by his/her respective company and attributable to the project have been disclosed and included in Section E or are included on a list attached to this report.
4) The Participant certifies that if tangible personal property was exchanged during the agreement, all has either been returned to the initial custodian or transferred permanently.
5) The Participant certifies that proprietary information has been returned or destroyed by LLNL.

8/4/03

Patrick M. Smith, Technical Advisor — Date
FlexICs, Inc.

8/11/03

Anthony F. Bernhardt, LLNL Principal Investigator — Date
Lawrence Livermore National Laboratory

8/18/03

Karena D. McKinley, IPAC Director — Date
Lawrence Livermore National Laboratory

Attachment I – Final Abstract

# PLASTIC SUBSTRATE ACTIVE MATRIX DISPLAYS

**Final Abstract (Attachment I)**
**CRADA No. TC-2011-00**
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availability of advanced visualization systems for military and intelligence applications. Spin offs from this technology include the development of a variety of capabilities for developing electronic systems on low temperature, lightweight, plastic substrates for national security applications. We have been in discussion with the NAI and Engineering Directorates at LLNL to identify specific applications for this technology and have identified remote sensor platforms and MEMs technology, a present DOE applications area that could have future direct benefits and are presently pursuing programs within both areas.

LLNL has supported research in the area of pulsed laser crystallization and doping of amorphous deposited thin films for the past five years through a combination of internal research spending and DARPA funding. As a result, the low temperature electronics program at LLNL has become a world leader in the area TFT fabrication at temperatures as low as 100°C for use on flexible plastic films. As an integral part of the work, the Labs researchers have developed world-class processing equipment and test facilities. This long-term strategy has resulted in major advances and now promises to pay off in terms of major contracts to design and develop even more advanced low temperature processes for future applications.

In relation to core competencies, products resulting from this work can be utilized for virtual reality and advanced visualization of data, meshing well with two major efforts at the Lab.

## E. Project Dates

The work on this project began on June 7, 2000, with an original expiration date of June 7, 2003. Due to a shift in LLNL Program priorities, project work was stopped on May 30, 2001.