LAWRENCE LIVERMORE NATIONAL LABORATORY

LLNL-TR-747100

Development of Plastic Substrate Technology for Active Matrix Liquid Crystal Displays Final Report CRADA No. TC-761-93

P. Carey, H. Kamath

March 1, 2018

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

Development of Plastic Substrate Technology for Active Matrix Liquid Crystal Displays

Final Report
CRADA No. TC-761-93

Date: July 9, 1998

A. Parties

The project was a relationship between the Lawrence Livermore National Laboratory (LLNL) and Raychem Corporation.

University of California
Lawrence Livermore National Laboratory
7000 East Avenue, L-795
Livermore, CA 94550
Paul Carey

Raychem Corporation
300 Constitution Drive
Menlo Park, CA 94025-1164
Hundi Kamath
(650) 361-3333

B. Project Scope

Project Description:

Raychem Corporation (RYC) and the Lawrence Livermore National Laboratory (LLNL) conducted a development program with the goal to make rugged, low-cost, high-resolution flat panel displays based on RYC's proprietary Nematic Curvilinear Aligned Phase (NCAP) liquid crystal and LLNL's patented processes for the formation and doping of polycrystalline silicon on low-temperature, flexible, plastic substrates.

The program demonstrated that:

1. Thin-film transistors (TFT's) of adequate performance could be fabricated on low-cost, optical quality plastic substrates using a mix of conventional and laser processing. The maximum processing temperature of 100°C developed by the project is the lowest polysilicon TFT fabrication process reported to date.

2. TFTs fabricated on polyester provided adequate on/off current switching capability to switch RYC's NCAP material.

Deliverables:
The original proposed program included an 18-month Phase I and an 18-month follow-on Phase II. The original objective of Phase I was to demonstrate TFT performance suitable to make a 3-inch-diagonal, monochrome display with 24 x 24 pixel resolution using a silicon TFT on plastic substrate technology.

The Phase I performance targets for the TFT's and integrated displays were:

- Contrast ratio 5:1 at 50% on reflection with a diffuse Lambertian reflector in a diffuse lighting environment
- Switching speed less than 35 msec for video rate
- Viewing angle greater than 70 degrees for all directions

Display Resolution (pixels)	24x24	900x900
Pixel Pitch (μm)	3000	80
pixel capacitance (pF)	90	0.064
charge current (pA)	> 1.4	> 0.037
off-current (nA)	< 10	< 0.007
current ratio	> 140	> 5,000

In Phase II, the transistor technology in Phase I was refined with the goal to fabricate a 3-inch-diagonal, monochrome display with 300 dots/inch resolution. The display performance targets were identical to those listed for Phase I. However, the higher resolution required an improvement in the TFT characteristics. The revised performance requirements are listed above along with the low resolution requirements.

C. Technical Accomplishments

This program demonstrated a low temperature fabrication process capable of making polysilicon TFT's on polyester substrates using a maximum temperature of only 100°C. This technical demonstration is the first step towards the manufacturing and marketing of flexible display products. These products can potentially widen the $20 billion flat panel market with new applications that are enabled by the unique characteristics of plastic as compared to glass.

Milestones & Deliverables	Scheduled	Actual
Phase I: 24x24 pixel 3 inch diagonal a-Si TFT display on plastic. Performance: (i) 5:1 contrast ratio at 50% on reflection with a diffuse Lambertian reflector in a diffuse lighting environment. (ii)Switching speed less than 35msec for video rate. (iii)Viewing angle greater than 70 degrees for all directions. (iv)Pixel capacitance =90pF	12/95	-
Phase II: 300x300 pixel 3 inch diagonal a-Si TFT display on plastic. Performance: (i)Same as in Phase I for contrast, speed, and viewing angle. (ii)Pixel capacitance = 37fF	06/97	-

Milestones:			
Phase I:	1 - Large Gate Area (W&L>100µm) a-Si TFT on Plastic with I(on) > 1.4µA	05/95	04/96
	2 - Large Gate Area (W&L>100µm) a-Si TFT on Plastic with I(off)< 10nA	05/95	08/95*
	3 - Large Gate Area (W&L>100µm) a-Si TFT on Plastic with I(on)/I(off) > 140	06/95	08/95*
Phase II:	4 - Smaller Gate Area (W&L<80µm) a-Si TFT on Plastic with I(on) > 37nA	01/97	04/96
	5 - Smaller Gate Area (W&L<80µm) a-Si TFT on Plastic with I(off)< 7 pA	01/97	04/96
	6 - Smaller Gate Area (W&L<80µm) a-Si TFT on Plastic with I(on)/I(off) > 5,000	02/97	07/96
	* TFT's fabricated on Si wafer substrate; TFT's on plastic expected 8/95		

D. Expected Economic Impact

This type of flat panel display on flexible substrates can be made less expensively using high volume roll-to-roll processing techniques which may increase market opportunities.

E. Partner Contribution

RYC had planned to use its liquid crystal and display and module construction technologies and assembly expertise necessary to fabricate an operational display. However, RYC was unable to perform this phase of the project due to a reevaluation of their research and economic priorities in the display field. RYC did provide professional expertise in substrate selection and display design. Further, RYC furnished the plastic and test substrates as well as the photomasks necessary to complete the processing.

F. Documents/Reference List

Reports

Many unofficial weekly reports were written for this project. This final report is the only one required for the project.

Background Intellectual Property (BIP)

LLNL

IL-8807 "Crystallization and Doping of Amorphous Silicon on LowTemperature Plastic," James L. Kaschmitter, Joel B. Truher, Kurt H. Weiner, Thomas W. Sigmon

IL-9435 "Method for Materials Deposition By Ablation Transfer Processing," Kurt H. Weiner

IL-9436 "Fabrication Technique for Amorphous Silicon Thin Film Transistor With A Polycrystalline Silicon Surface Channel Region For Enhanced Forward Current Drive," Kurt H. Weiner

RYC

4,182,700 "Elastomeric polyurethane film containing dispersed discrete aggregates of liquid crystal and method of making the same"; William J. Benton, Joseph R. Quigley; issued 1/8/80

4,435,047 "Encapsulated liquid crystal and method"; James L. Fergason; issued 3/6/84

4,556,289 "Low birefringence encapsulated liquid crystal and optical shutter using same"; James L. Fergason; issued 12/3/85

4,596,445 "Colored encapsulated liquid crystal apparatus using enhanced scattering"; James L. Fergason; issued 6/24/86

4,613,207 "Liquid crystal projector and method"; James L. Fergason; issued 9/23/86

4,693,560 "Double layer display"; Richard Wiley; issued 9/15/87

4,726,662 "Display having a prismatic lens system or a prismatic reflective system"; Douglas A. Cromack; issued 2/23/88

4,732,456 "Scattering display for contrast enhancement including target"; James L. Fergason, Robert Parker; issued 3/22/88

4,806,922 "Display device utilizing a plurality of NCAP liquid crystal modules; Charles W. McLaughlin, James L. Fergason, Robert Parker; issued 2/21/89

4,878,741 "Liquid crystal color display and method"; James L. Fergason; issued 11/7/89

4,950,052 "Encapsulated liquid crystal apparatus with polymer additive" James L. Fergason, Ning S. Fan; issued 8/21/90

4,992,201 "Latex entrapped NCAP liquid crystal composition, method, and apparatus"; Kenneth N. Pearlman; issued 2/12/91

4,991,940 "Gain reflector liquid crystal display"; Andrew L. Dalisa, James McCoy, Richard Wiley; issued 2/12/91

5,016,982 "Liquid crystal display having a capacitor for overvoltage protection"; James L. Fergason, Manoocher Mohebban; issued 5/21/91

5,075,789 "Displays having improved contrast"; Philip J. Jones, A. Brian Macknick, Larry J. White; issued 12/24/91

5,113,272 "Three dimensional semiconductor display using liquid crystal"; Robert H. Reamey; issued 5/12/92

5,132,823 "Multipurpose liquid crystal display having means for removably positioning the retroreflector"; Hundi Kamath, Philip Jones; issued 7/21/92

5,136,403 "Display having light scattering electro-optical element"; Philip J. Jones, Akira Tomita; issued 8/4/92

138,472 "Display having light scattering centers"; Philip J. Jones, Akira Tomita, Mark F. Wartenberg; issued 8/11/92

5,156,452 "Encapsulated liquid crystal apparatus having low off-axis haze and operable by a sine-wave power source"; Paul S. Drzaic, Peter H. Van Konynenburg; issued 10/20/92

5,182,663 "Liquid crystal display having improved retroreflector; Philip J. Jones; issued 1/26/93

5,202,063 "Method for making encapsulated liquid crystal material"; Brackin L. Andrews, Gilbert Garza, Mark F. Wartenberg, William Seeley; issued 4/13/93

5,206,747 "Polymer dispersed liquid crystal display with birefringence of the liquid crystal at least 0.23"; Richard C. Wiley, Paul S. Drzaic; issued 4/27/93

5,216,530 "Encapsulated liquid crystal having a smectic phase"; Kenneth N.Pearlman, James L. Fergason, Ning S. Fan; issued 6/1/93

5,233,445 "Active matrix liquid crystal display with average dielectric constant greater than 6 and less than 1.8 meq/g cyano groups"; Hundi P. Kamath, Robert H. Reamey, Mark F. Wartenberg, Stephen S. Moore, Philip J. Jones; issued 8/3/93

5,307,185 "Liquid crystal projection display with complementary color dye added to longest wavelength imaging element"; Philip J. Jones, Wayne Montoya, Hundi P. Kamath, Akira Tomita; issued 4/26/94

08/028,497 "Encapsulated liquid crystal structures, apparatus containing the same, and methods therefor"; Mark F. Wartenberg, Harriette Atkins, Robert H. Reamey, Laurence Welsh, James Strain; Janusz Wojtowicz, Wayne Montoya, Paul S. Drzaic, John Havens, Akira Tomita, Aldrich N. K. Lau; filed 3/9/93

08/059,028 "Method of making liquid crystal material"; Robert H. Reamey; filed 5/6/93

08/074,570 "Apparatus for projecting colored images"; Philip J. Jones; filed 6/7/93

08/105,658 "Electrodeposition method of applying encapsulated liquid crystal material to electrodes"; Robert H. Reamey; filed 8/12/93

08/139,382 "Chiral nematic liquid crystal composition and devices comprising the same"; Philip J. Jones; filed 10/18/93

08/196,924 "Projector"; Akira Tomita; filed 2/15/94

08/217,581 "Method of making liquid crystal composite"; Robert H. Reamey, John Mazzanti; Mark Wartenberg, Gil Garza, John Havens, Anne Gonzales, Kathleen Di Zio, Harriette Atkins, Kevin Malloy; filed 3/24/94

not yet known "Liquid crystal composite and method of making"; John Havens; Kathleen Di Zio, Anne Gonzales, Robert H. Reamey, Harriette Atkins, Jinlong Cheng; filed 3/24/94

not yet known "Amphiphilic telomers"; Aldrich N. K. Lau; filed 3/31/94

CRADA Subject Inventions

LLNL

CIL-9814 "Method for Formation of Thin Film Transistors on Plastic Substrates," Paul G. Carey, Patrick M. Smith, Thomas W. Sigmon, and Randy C. Aceves *(note: patent awarded in 5/98, awaiting patent number).*

CIL-10092 "Deposition of Dopant Impurities and Pulsed Laser Drive-In," Paul Wickboldt, Paul G. Carey, Patrick M. Smith, Albert R. Ellingboe, and Thomas W. Sigmon

CIL-10117 "Method for Formation of Display Pixels Driven by Silicon Thin Film Transistors on Plastic Substrates." Paul G. Carey and Patrick M. Smith

Joint

CIL-10128 "Method for Formation of Active Matrix Liquid Crystal Displays on Plastic Substrates," Paul G. Carey, Patrick M. Smith, John Havens, and Phil Jones

Licensing

Work on this CRADA ended on October 31, 1996. Because RYC chose not to combine the LLNL and RYC technologies into an active matrix display on plastic, RYC elected not to pursue commercial applications of this technology. RYC opted not to license any technologies from this project.

G. Acknowledgment

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.

Steve Moore 7/28/98
Date
Raychem Corporation
Technical Director

Paul Carey 8/6/98
Date
Lawrence Livermore National Laboratory

Attachment I – Final Abstract
Attachment II – Project Accomplishments Summary
Attachment III – Final Quarterly Report

Development of Plastic Substrate Technology for Active Matrix Liquid Crystal Displays

Final Abstract
Attachment I
CRADA No. TC-761-93

July 9, 1998 Revision: 2

Raychem Corporation (RYC) and the Lawrence Livermore National Laboratory (LLNL) conducted a development program with the goal to make rugged, low-cost, high-resolution flat panel displays based on RYC's proprietary Nematic Curvilinear Aligned Phase (NCAP) liquid crystal and LLNL's patented processes for the doping of polycrystalline silicon and the fabrication of thin film transistors (TFTs) on low-temperature, flexible, plastic substrates.

The program demonstrated that thin-film transistors (TFT's) of adequate performance could be fabricated on low-cost, optical quality plastic substrates using a mix of conventional and laser processing. The maximum processing temperature of 100°C developed by the project is the lowest polysilicon TFT fabrication process reported to date.

Development of Plastic Substrate Technology for Active Matrix Liquid Crystal Displays

Project Accomplishments Summary (Attachment II)
CRADA No. TC-761-93

Date: July 24, 1998 Revision: 6

A. Parties
The project was a relationship between the Lawrence Livermore National Laboratory (LLNL) and Raychem Corporation.

University of California
Lawrence Livermore National Laboratory
7000 East Avenue, L-795
Livermore, CA 94550

Raychem Corporation
300 Constitution Drive
Menlo Park, CA 94025-1164

B. Background
The manufacture of flat panel displays (FPDs) is projected to be a $20 billion industry by the year 2000. Although many alternatives exist to produce FPDs, the active matrix liquid crystal display (AM-LCD) implemented using twisted nematic (TN) liquid crystal (LC) technology is emerging as the dominant product in the area. In 1993 at the beginning of this CRADA, Japanese manufacturers led in both the development and commercialization of this type of display. However, the LC technology they implemented had several critical manufacturing problems which kept the price of the display very high. For high contrast operation, the light-absorbing TN LC films needed to maintain a constant thickness and be backlit by polarized light. That necessitated the use of polarizers, very accurate spacing between the front and back display plates, and a power consuming backlight assembly. Moreover, full color displays required a color filter. All of these components were expensive, together representing as much as half the display cost. They also introduced packaging complexity and yield problems. Furthermore, the backlight brightness limited operation in harsh ambient light conditions while birefringence of the TN-LC restricted the viewing angle. Finally, the need for constant LC film thickness necessitated the use of rigid glass substrates which are heavy and susceptible to breakage.

Raychem Corporation (RYC) had developed an alternative type of liquid crystal which dealt with many of these problems. Nematic Curvilinear Aligned Phase (NCAP) LCs achieve high contrast by scattering light, rather than absorbing it. This, in turn, eliminates the need for polarizers and battery-draining backlights. As a result, the LC can operate in reflective mode with excellent contrast. The thickness of a solid NCAP liquid crystal film is highly uniform. Since such films are solids, they do not require the use of spacers as do conventional liquid crystal displays. It is also possible to incorporate dyes into the NCAP films during their manufacture. As a result, color filters can be eliminated. Since the display is reflective, it operates under the harshest lighting conditions, and because it relies on light scattering, the viewing angle is increased. Consequently, incorporation of this type of liquid crystal into an AM-LCD promises a significant reduction in price along with a substantial increase in performance.

To take full advantage of NCAP technology, however, the AM-LCD substrates needed to be plastic. By replacing glass with plastic, the substrate cost was lowered, the display weight was reduced by 50%, and breakage during production and use was no longer an issue. However, processing the thin-film transistors (TFTs) that were required to operate the display had not been possible because of the low deformation temperatures of plastic (~100°C).

Beginning in 1985, the Lawrence Livermore National Laboratory (LLNL) began developing pulsed laser processing techniques that allowed fabrication of the necessary TFTs at extremely low substrate temperatures. Using pulsed laser annealing, the thermal energy needed to build good quality TFTs was localized to the first few micrometers of the substrate surface in the area of the TFT device. Even though high temperatures were realized within the processed area, the bulk of the substrate never exceeded 100°C. These area-selective processing techniques were ideal for processing on plastic and opened the possibility of fabricating plastic-based AM-LCDs.

A new type of AM-LCD became possible by combining the unique advantages of the RYC's NCAP liquid crystal technology and the LLNL pulsed excimer laser processing. The proposed technology had the potential to fill the growing markets for lap-top computers. In addition, new markets could be created by taking advantage of the unique characteristics of a plastic display which included flexibility, low-cost, and very large size.

C. Description

The purpose of this CRADA was to develop technology necessary to make flexible active matrix displays on plastic using LLNL's low temperature TFT process that could be combined with RYC's NCAP liquid crystal material.

LLNL accomplished its task of fabricating TFT's on polyester substrates having the necessary electrical performance to make display pixels. RYC viewed this accomplishment as an unexpected milestone. However, LLNL and RYC were unable to combine their technologies into an active matrix display on plastic, because the additional monetary investment required to do so was denied by RYC management.

D. Expected Economic Impact

LLNL's success in making TFT's on polyester may result in potential manufacturing cost reductions if a roll-to-roll fabrication process can be designed and implemented. Much investment still needs to made to realize this cost reduction.

The industry would benefit by lowering its manufacturing costs and opening new types of display products. Consumers benefit by having more display choices at lower cost.

E. Benefits to DOE

The United States Government has designated the manufacture of flat panel displays as a critical National capability. At the time the CRADA was implemented, more than 95% of these displays were manufactured overseas. The lack of a large-volume, domestic source for any type of flat panel technology put 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 threatened the National Security. In response to this problem, the Department of Energy established a program to speed the development of emerging flat panel technologies. The process innovations resulting from this project can directly influence the competitive position of current and future U.S. manufacturers of the dominant flat-panel technology, active matrix liquid crystal displays and potentially make available advanced visualization systems for Military and Intelligence applications.

LLNL has supported research in the area of pulsed laser doping technology since 1985 through a combination of internal research spending and ARPA funding. As a result, the GILD program at LLNL became a world leader in the area of shallow junction formation for advanced ICs. As an integral part of the work, the Lab's researchers developed world-class processing equipment and test facilities. This long term strategy resulted in major advances and promised to pay off in terms of major contracts to design and develop even more advanced doping processes and equipment for future, single-wafer, flexible manufacturing environments.

The proposed display program built directly upon the accomplishments of the advanced IC processing initiative. By adapting the laser equipment present at LLNL to the requirements of display substrate processing, this program made the apparatus a much more powerful and unique tool. The program also took processing and test expertise gained from IC related work and expanded it into the field of amorphous and polysilicon TFTs. Thus, LLNL, as a research facility gained expertise in crystalline, polycrystalline, and amorphous silicon device technology and processing. 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.

F. Industry Area
Electronics, flat panel displays, semiconductors

G. Project Status
This project was completed in September of 1996 when it was terminated by LLNL. RYC was given the opportunity to continue funding the project as a Funds-In CRADA, but management decided not to take the risk.

H. LLNL Point of Contact for Project Information
LLNL was represented by Paul Carey, Principal Investigator, 925/422-4427; 925/422-7309 (fax); and Patrick Smith, Principal Investigator, 925/422-6683; 925/422-7309 (fax), both of the Physics Directorate.

I. Company Size and Point(s) of Contact
RYC was represented by Dr. Hundi Kamath, Director of Display Technology, 650/361-3333; 650/361-4913 (fax). Company sales are $1.7 billion, and the company employs 8500 people. The primary contacts during the project were Drs. John Havens and Phil Jones, neither of whom are still employed by RYC. In fact, Dr. Kamath is also no longer employed by RYC. Steve Moore is probably the most likely current employee who has knowledge of this project.

J. Project Examples
LLNL demonstrated swithing pixels with our TFT's switching RYC's's NCAP material. Also, our 4 inch diameter plastic substrates make great show and tell items, and have been used for this purpose many times.

K. Release of Information

I certify that all information contained in this report is accurate and releasable to the best of my knowledge.

Karena McKinley 8/17/98

Karena McKinley, Director **Date**
Industrial Partnerships
and Commercialization

Release Of Information

I have reviewed the attached Project Accomplishment Summary prepared by Lawrence Livermore National Laboratory and agree that the information about our CRADA may be released for external distribution.

Stephen Moore 7/24/98

Steve Moore
Raychem Corporation
Technical Director

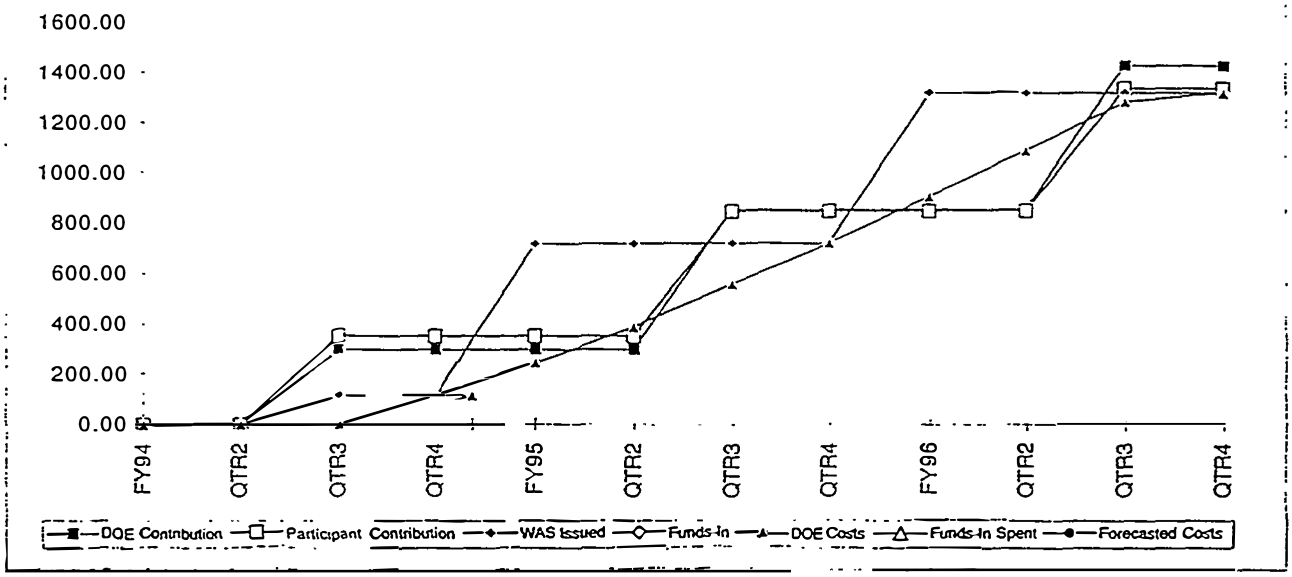
Date

Lawrence Livermore National Laboratory

Title:	Development of Plastic Substrates for LCDs	Reporting Period:	07/1/95 - 09/30/96
Participant:	Raychem Corp.	Date CRADA Executed:	6/30/94
DOE TTI No.:	94-LLNL-006-XX-1	DOE Approval Date:	6/15/94
CRADA No.:	TC-0761-93	Scheduled Ending Date:	6/29/97
TACT:	M&P	Project Completed:	
Account Numbers	4775-22 to 23	B & R Code (S):	DP0301
Accounts Closed:			Funds-In

Approved Funding Profile ($K)

	FY94	FY95	FY96	FY97	FYOUT	Total
DOE Contribution	300	550	570	0	0	1420
Add Fac & Dep	0	0	0	0	0	0
Participant In-Kind	355	487	487	0	0	1329
Participant Funds-In	0	0	0	0	0	0
WAS DP0301	116	599	595	0	0	1311
WAS 35DP03	0	0	0	0	0	0
Funds-In Received	0	0	0	0	0	0
Total Costs	116	599	595	0	0	1311



DP0301	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	FYTD
FY94	0	0	0	0	0	0	0	0	0	77	20	19	116
FY95	53	47	30	48	41	56	50	58	60	38	44	77	599
FY96	67	51	67	57	52	73	63	76	54	16	18	3	595

1311

35DP03	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	FYTD
FY94	0	0	0	0	0	0	0	0	0	0	0	0	0
FY95	0	0	0	0	0	0	0	0	0	0	0	0	0
FY96	0	0	0	0	0	0	0	0	0	0	0	0	0

0

Funds-In Spent	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	FYTD
FY94	0	0	0	0	0	0	0	0	0	0	0	0	0
FY95	0	0	0	0	0	0	0	0	0	0	0	0	0
FY96	0	0	0	0	0	0	0	0	0	0	0	0	0

0

STAFF w/phone:

Lab PI: Paul G. Carey (510) 422-4427 — Participant: Phil Jones (415) 361-3619

Resource Manager: Vicki Evans (510) 423-0158

DOE OAK: Jerry Scheinberg (510) 637-1653 — DOE HQ: C. Fowler (202) 586-5834

Lawrence Livermore National Laboratory

Reporting Period: 07/1/95 - 09/30/96

DOE TTI No.: 94-LLNL-006-XX-1

CRADA No.: TC-0761-93

Milestones and Deliverables:

List the complete set of milestones for all phases of the CRADA. Continue on a separate page if necessary.
Report any changes from the original CRADA or previous quarterly report on the CRADA Change Form.

	Completion Date: Scheduled	Actual
1 - (Phase I) 24x24 pixel 3 inch diagonal a-Si TFT display on plastic.	12/95	-
Performance: (i) 5:1 contrast ratio at 50% on reflection with a diffuse Lambertian reflector in a diffuse lighting environment.		
(ii) Switching speed less than 35msec for video rate.		
(iii) Viewing angle greater than 70 degrees for all directions.		
(iv) Pixel capacitance =90pF		
2 - (Phase II) 300x300 pixel 3 inch diagonal a-Si TFT display on plastic.	06/97	-
Performance: (i) Same as in Phase I for contrast, speed, and viewing angle.		
(ii) Pixel capacitance = 37fF		
Milestones:		
Phase I - 1 - Large Gate Area (W&L>100μm) a-Si TFT on Plastic with I(on) > 1.4μA	05/95	04/96
2 - Large Gate Area (W&L>100μm) a-Si TFT on Plastic with I(off)< 10nA	05/95	08/95
3 - Large Gate Area (W&L>100μm) a-Si TFT on Plastic with I(on)/I(off) > 140	06/95	08/95
Phase II - 4 - Smaller Gate Area (W&L<80μm) a-Si TFT on Plastic with I(on) > 37nA	01/97	04/96
5 - Smaller Gate Area (W&L<80μm) a-Si TFT on Plastic with I(off)< 7 pA	01/97	04/96
6 - Smaller Gate Area (W&L<80μm) a-Si TFT on Plastic with I(on)/I(off) > 5.000	02/97	07/96

* TFT's fabricated on Si wafer substrate; TFT's on plastic expected 8/95

Verification of participants' in-kind contribution was made in accordance with LLNL policy. Explain basis of verification: Please initial: YES X NO ____

I believe the participant's in-kind contribution is consistent with that agreed upon in the CRADA because the participant met the milestones that were described in the contract.

List any subject inventions by either party (include IL# for LLNL inventions), additional background intellectual property, patents applied for, software copyrights, publications, awards, licenses granted or reportable economic impacts

We have filed an invention disclosure related to fabricating these Si TFT devices using an ablation printing technique.

Verification that all equipment and proprietary information has been returned to the initial owner or permanently transferred Please initial: YES X NO ____

Accomplishments

Describe Technical/Non-Technical lessons learned and other observations.
Summarize causes/justification of deviations from original scope of work.

See attached.

Reviewed by CRADA project Program Manager: ________ Date: ________

Reviewed by Karena McKinley, Director, LLNL/IP&C: ________ Date: ________

Direct questions regarding this Report to IP&C Resource Manager, Carol Asher, at (510) 422-7618