DEVELOPMENT OF AN ELECTROPHORETIC IMAGE DISPLAY

QUARTERLY TECHNICAL REPORT

February 1 to April 30, 1981

Sponsored by

DEFENSE ADVANCED RESEARCH PROJECTS AGENCY

DARPA Order No. 3802

Contract No. MDA903-79-C-0439

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Contract Period: 20 Sept. 1979 - 30 Sept. 1981

Prepared by

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May 1981

(9) Quarterly technical rept. 1 Feb - 30 Apr 81,

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER	2. GOVT ACCESSION NO. AD-A101 297
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle) (6) DEVELOPMENT OF AN ELECTROPHORETIC IMAGE DISPLAY	5. TYPE OF REPORT & PERIOD COVERED Quarterly Technical Report February 1 to April 30, 1981
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) (10) Richard Liebert, Joseph Lalak, Howard Sorkin	8. CONTRACT OR GRANT NUMBER(s) (15) MDA903-79-C-0439, DARPA Order-3802
9. PERFORMING ORGANIZATION NAME AND ADDRESS PHILIPS LABORATORIES A Division of North American Philips Corp. Briarcliff Manor, New York 10510	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS DARPA Order No. 3802
11. CONTROLLING OFFICE NAME AND ADDRESS Defense Advanced Research Projects Agency 1400 Wilson Boulevard Arlington, Virginia 22209	12. REPORT DATE (11) May 1981
	13. NUMBER OF PAGES 17 (12) 16
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report) UNCLASSIFIED
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

APPROVED FOR PUBLIC RELEASE
DISTRIBUTION UNLIMITED

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

electrophoretic image display
control-grid electrode
ion-beam milling
indium oxide
matrix-addressed display
sealing
display drive circuits

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The purpose of this work is to develop an X-Y addressed electrophoretic image display. A device capable of displaying 512 characters in a 5 x 7 dot matrix format was successfully operated. The display has only seven faults out of 228 column electrodes and only one fault out of 148 row electrodes. Sticking of the pigment to the control-electrode structure eventually degraded the contrast of the displayed information. Experiments with physical and chemical coatings of the control-electrode structure indicate that the → cont

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20. ABSTRACT (Cont'd.)

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PREFACE

This work is being performed by Philips Laboratories, a Division of North American Philips Corporation, Briarcliff Manor, New York under the overall supervision of Dr. Barry Singer, Director, Component and Device Research Group. Mr. Richard Liebert, Metallurgist, is the Program Leader; Mr. Joseph Lalak, Electronic Engineer, is responsible for cell fabrication and technology. Mr. Karl Wittig, Electrical Engineer, is responsible for circuit design; Dr. Howard Sorkin, Organic Chemist, is responsible for electrophoretic suspensions.

This program is sponsored by the Defense Advanced Research Projects Agency (DARPA) and was initiated under Contract No. MDA903-79-C-0439. Dr. Robert E. Kahn is the Contracting Officer's Technical Representative for DARPA.

The work described in this seventh Quarterly Technical Report covers the period from 1 February to 30 April 1981.

SUMMARY

The purpose of this work is to develop an X-Y addressed electrophoretic image display. A device capable of displaying 512 characters in a 5 x 7 dot matrix format was successfully operated. The display has only seven faults out of 228 column electrodes and only one fault out of 148 row electrodes. Sticking of the pigment to the control-electrode structure eventually degraded the contrast of the displayed information. Experiments with physical and chemical coatings of the control-electrode structure indicate that the sticking can be reduced. Opens in column electrodes resulting from heat-sealing the perimeter seal have been eliminated by using a room-temperature curing epoxy. Intermittent shorts which are believed to be due to dislodged redeposited material from the ion-beam milling process have been noted; the effect of the milling angle on redeposition is being investigated. Design of the Phase II display having 640 columns and 384 rows is complete. The mask drawings were digitized, and the pattern-generator tapes needed to produce the photomasks were made. Photosensitive polymers are being considered as an alternate to Mylar in the Phase II display to eliminate the need for ion-beam milling of very large areas. In preliminary tests, potential wells 14 μm deep with slightly sloping walls were made. The alignment/exposure system for the Phase II display was received and is now in operation.

TABLE OF CONTENTS

1. INTRODUCTION

A Phase I device with only seven faults out of 228 column electrodes and one fault out of 148 row electrodes was successfully operated. Twenty-five rows of 21 characters in a 5 x 7 dot matrix format were displayed on this device. Several devices substantially free of shorts and one free of shorts were completed. Upon operation, however, shorts developed in these devices. Sticking of pigment to the control-electrode structure has been noted and efforts are being made to eliminate it. Opens in the column electrodes have been substantially reduced by using a room-temperature-curing epoxy for the perimeter seal, rather than a heat-sealing technique.

Design of the Phase II device is complete and the mask drawings have been digitized. The device will have 640 column electrodes and 384 row electrodes. As soon as the accuracy of plots from the pattern generator tapes has been established, the Phase II masks will be ordered. An alignment/exposure system suitable for fabrication of the Phase II device is now in operation and is being used to fabricate the Phase I device. A photo-fabrication method as an alternate to ion-beam milling is under investigation. Potential wells 14 µm deep with nearly vertical walls have been formed.

2. FABRICATION TECHNOLOGY

2.1 Fabrication of Row Electrodes

A suitable source of defect-free transparent conductive layers of sufficient thickness has not yet been found; therefore, we have continued to use substrates to which the necessary In_2O_3 is added by reactive evaporation. Delineation of the row electrodes by ion-beam milling is now routine. The improvements in the fabrication technology instituted during the last quarter have now eliminated the row electrode shorts. Row-electrode substrates free of shorts or opens can now be made routinely.

2.2 Fabrication of Control Electrodes

The following fabrication steps have been found to be reliable: epoxy-bonded Mylar as the dielectric in the control-electrode structure; reactively evaporated In_2O_3; blanket-exposed, well-baked photoresist; and electron-beam evaporated aluminum. The incidence of column-to-column shorts has been substantially reduced.

The redeposit of materials on the vertical walls of the potential wells during ion-beam milling is being investigated extensively. In addition to the difficulty in removal of the aluminum mask noted in the previous quarterly report (Nov. 1, 1980 to Jan. 31, 1981), we suspect that an increased incidence of row-to-column shorts may be related to redeposit. Two possibilities are being investigated, viz., the walls of the Mylar may have become conducting; an edge rim is being formed which may be conducting. Figure 1 is a photograph of a SEM image of this edge rim. The rim consists of material which is not completely removed when the lift-off photoresist and aluminum mask are removed. Figure 2 shows a long piece of this rim which is partially dislodged. If this rim is conducting, such dislodged pieces could result in shorts between the column electrode and the row or anode electrodes when the device is operated.

Attempts are being made to analyze this rim in order to determine its cause and to establish means for eliminating it. So far, attempts to completely remove the rim by ultrasoneration in various solvents have been unsuccessful. Preliminary tests indicate that the rim can be removed by milling for about 2 1/2 minutes at a 60° angle, without adversely effecting the row or column electrodes. Redeposition is known to be effected by the angle of milling. We are now evaluating the results of tests in which the angle of milling was varied between 10° and 35°. Initial results look negative.

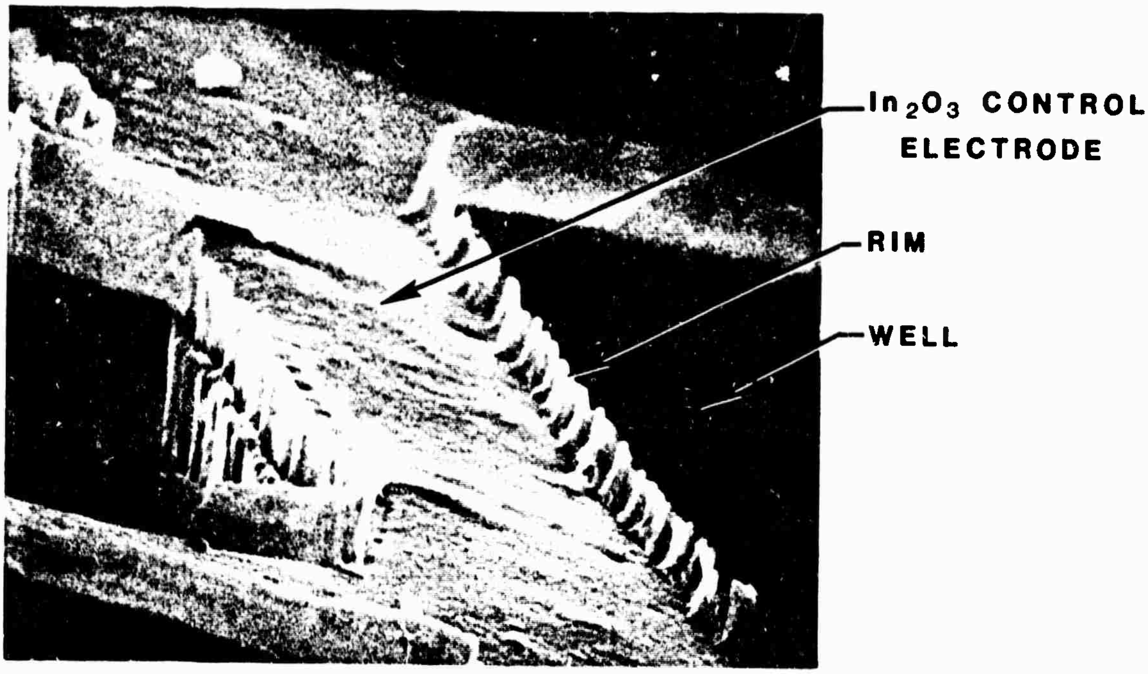

Figure 1: Photograph of SEM image of edge rim.

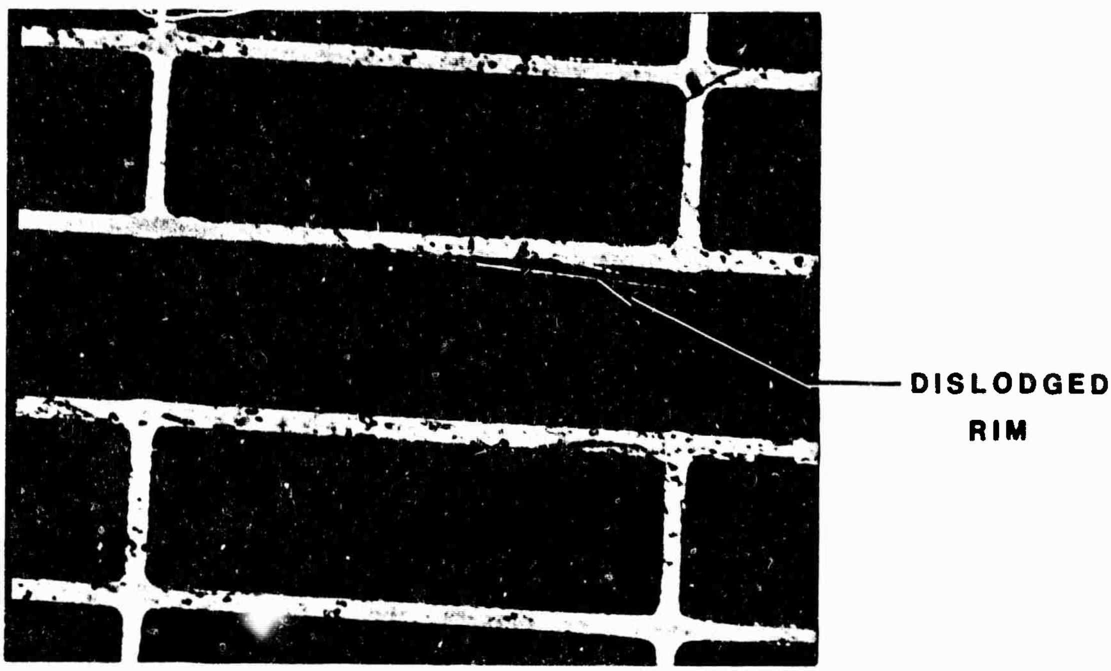

Figure 2: Dislodged edge-rim material.

Since the edge rim seems to be associated with the lift-off photoresist, it might be eliminated if this resist layer could be eliminated. This could be accomplished if the aluminum milling mask did not have to be removed. However, specular reflection from the aluminum would degrade the contrast in the displayed information. If a black layer (of In_2O_3 for instance) was deposited between the Mylar and aluminum, the desired result could be obtained without the problem of specular reflection. Black layers of In_2O_3 have been produced. One device was fabricated using this method; initial tests showed that it was substantially free of shorts. However, after the device was filled with suspension and tested under operating conditions, a number of shorts developed between the column electrodes and the row and anode electrodes. Since the suspension may have been contaminated, additional work must be done to determine if this is a viable fabrication technique.

2.3 Cell Fabrication

Until recently, the anode plate and control-electrode plate were sealed around the perimeter by hot-lamination of an epoxy-coated Mylar gasket. Occasionally, however, an excessive number of column-electrode opens had been noted. These opens are now known to be caused by cracks in the hard, brittle In_2O_3 control electrode which is supported only by the relatively soft (especially at the sealing temperature) Mylar. These cracks, shown in Figure 3, are of two types: a network of fine cracks directly beneath the Mylar gasket and a major crack just inside the Mylar gasket.

The cracks can be eliminated and the column-electrode opens prevented by using a room-temperature-curing epoxy for attaching the two plates. A Mylar gasket establishes the proper spacing, a fillet of epoxy is applied around the perimeter of the anode plate, and the epoxy is cured with the plates weighted to maintain the spacing. An additional benefit of applying aluminum

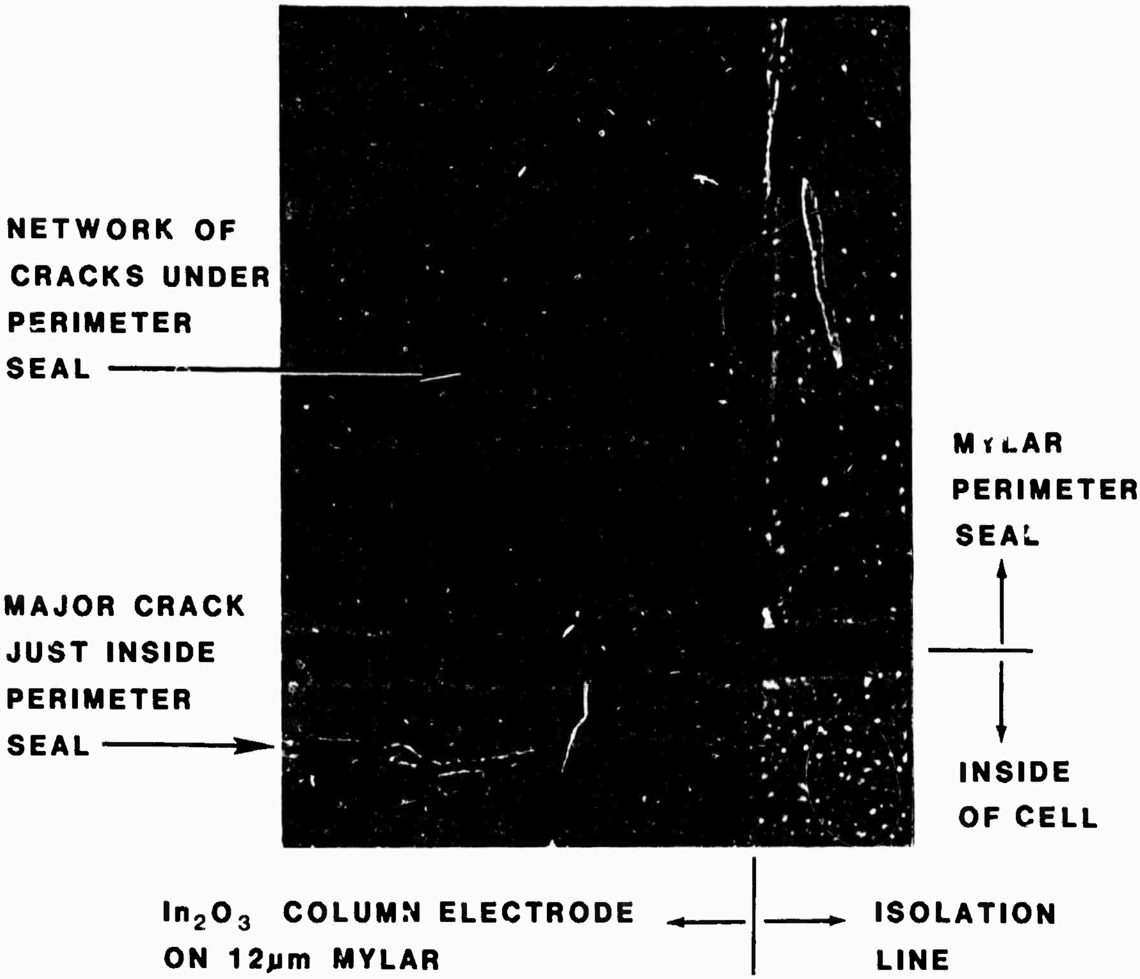

Figure 3: Cracks in In_2O_3 column electrode.

directly on black In_2O_3 is that the ductile aluminum is not expected to crack. Thus, the laminated seal may still be used.

2.4 Suspensions

The irreversible sticking of pigment particles to the electrodes is degrading the performance of the device. Particles adhering to the electrodes prevent the display from achieving minimum brightness in the off state, thereby reducing the contrast.

Efforts to eliminate sticking are being focused on treatment of devices with various chemicals prior to their being filled with electrophoretic suspensions. Adsorption of organic molecules onto the surface of indium oxide or glass is known to lower the surface-free energy of these materials and, thereby, reduce the tendency of other materials to adhere.

Several surfactants have been evaluated to reduce sticking of the pigment which occurs in untreated cells. A number of cells fabricated this way showed little or no sticking. Other materials, particularly fluorinated surfactants, are being evaluated as antisticking agents.

A method for screening of dyes has been developed. Thin layers of pigment are applied to glass plates from an aqueous slurry containing 1% polyvinyl alcohol. The dried layers are spotted with dye solution, and solvent is allowed to move over the spots. The ratio (R_f) of the distance the dye moves to the distance the solvent moves is a measure of the adsorption of the dye by the pigment. A ratio of 1 indicates no adsorption; lower values indicate adsorption of the dye. Dyes examined to date exhibit R_f values between 0.18-0.78.

3. DEVICE TESTING

Several devices have now been fabricated which are nearly free of shorts or opens; Figure 4 is a photograph of one of these devices. Shorts or opens accounted for only seven (7) faults in the 228 column electrodes and only one (1) fault in the 148 row electrodes. For test purposes, an already existing driver was used which required rotation of the display 90° from its normal orientation. Twenty-five (25) rows of 21 characters are displayed in a 9 x 7 position, thus utilizing the 228 x 148 available pixels. Eventually, as noted in Section 2, pigment sticking degraded the contrast.

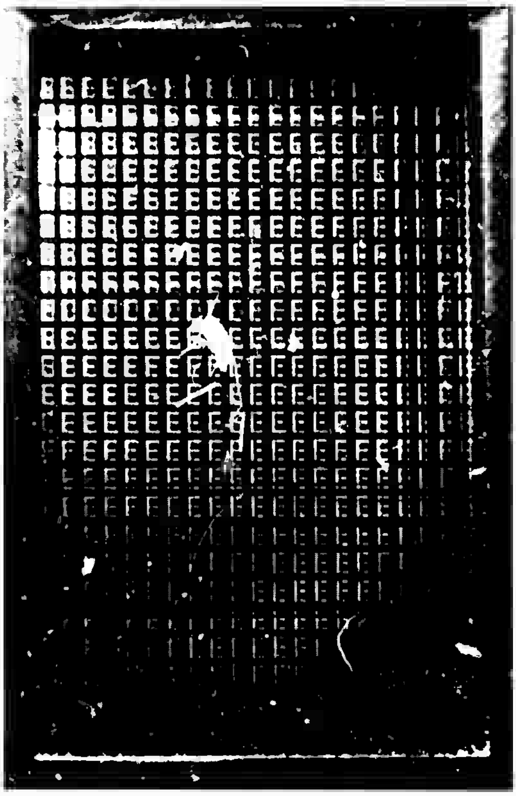

Figure 4: Letter E displayed on Phase I device.

Testing could not be completed on the other devices because shorts developed when the normal operating voltages were applied. We are actively investigating this problem, and two possibilities are receiving most of our attention, viz., contamination of the suspension, and the effect of redeposited material from the ion-beam milling operation.

4. DRIVE ELECTRONICS

To expedite demonstration of the Phase I device, a portable driver is being fabricated which does not require either a computer or microprocessor control. With this driver, each of the 64 standard ASCII characters will be sequentially displayed in all 512 character positions simultaneously. The driver will be self-contained, requiring only line voltage, and easily portable.

5. PHASE II

The design of the Phase II device was completed. Its 640 column electrodes and 384 row electrodes will allow 25 lines of 80 characters to be displayed in a 8 x 15 dot matrix. This format permits upper case, lower case with ascenders and decenders, and underlined characters to be displayed. With 100 lines/inch resolution, the active area of the display will be 6.40 in. by 3.84 in.

The drawings for the necessary photolithographic masks have been digitized and the pattern generator tapes prepared. A vendor with the capability to make these large-size masks has been found. Masks will be ordered when the correctness of mask plots prepared from the pattern generator tapes has been verified. An alignment/exposure system suitable for the larger Phase II device has been put into operation and is being used on the Phase I device. Because of the newly acquired alignment capability, the registration between the row and column electrodes has been improved, thus eliminating registration problems encountered in mounting the display to the fan-out board.

Because ion-beam milling may be less suited to the larger Phase II device, alternative techniques for forming the potential wells are being considered. One method is to use photopolymers rather than Mylar for the dielectric supporting the control electrode. The potential wells can then be formed by using an opaque control electrode. Figure 5 is a photograph of an SEM image of wells 14 μm deep in a photopolymer layer 20 μm thick. Note the good edge definition and near vertical shape of the walls. Additional work is needed to obtain the desired 12 μm thickness and the required thickness uniformity across the layer.

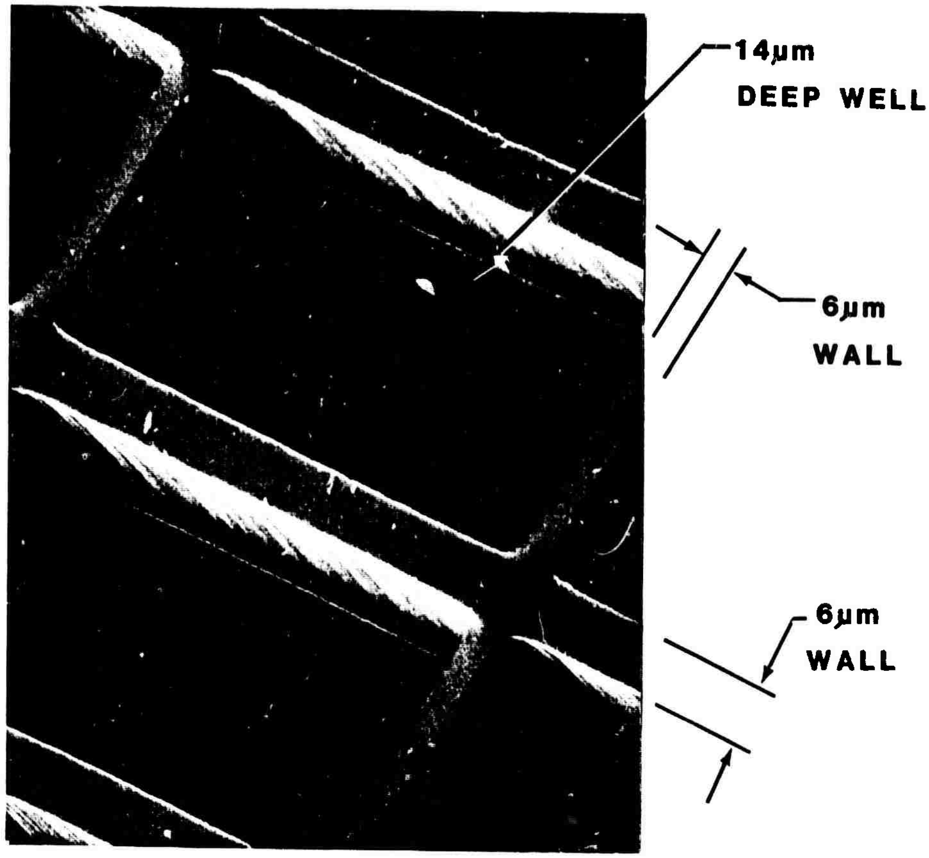

Figure 5: Wells 14 μm deep.

6. PLANS FOR NEXT QUARTER

a. Solve shorting problem in Phase I device and operate device with computer-controlled driver.

b. Complete portable driver.

c. Obtain Phase II photomasks.

d. Continue investigation of alternatives to ion-beam milling.

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