DEVELOPMENT OF AN ELECTROPHORETIC IMAGE DISPLAY

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The purpose of this work is to develop a 350 x 600 element X-Y addressed electrophoretic image display (EPID). The design and fabrication of a control-grid electrode supported by a Mylar dielectric has been investigated. Computer modeling is being used as a design aid, and ion-beam milling has been successfully used to fabricate the Mylar control-grid electrode. The Mylar dielectric is attached to the In_2O_3 coated substrate using heat and pressure alone or in combination with an epoxy adhesion promoter. Good seals, with occasional nonbonded areas, were obtained by heating the Mylar while applying pressure. Better seals were obtained when one side of the Mylar was coated with epoxy. Operating life-test results indicate no adverse interactions between the electrophoretic suspension and the Mylar/epoxy seal. Computer modeling of the electrostatic potential in the device is in progress.

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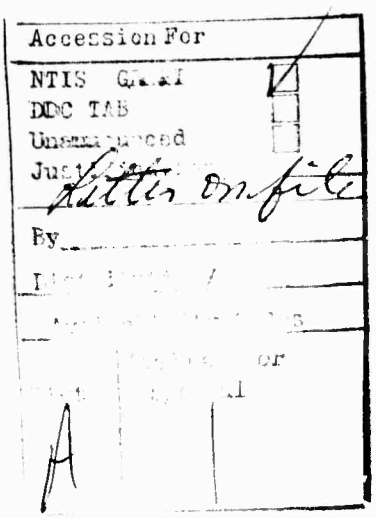
PREFACE

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; Ms. Beverly Fitzhenry, Chemist, is responsible for evaluation and testing of electrophoretic suspensions; Mr. Joseph Lalak, Electronic Engineer, is responsible for cell fabrication and technology.

This program is sponsored by the Defense Advanced Research 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 first Quarterly Technical Report covers the period from 1 August 1979 to 31 October 1979.



SUMMARY

The purpose of this work is to develop a 350 x 600 element X-Y addressed electrophoretic image display (EPID). The design and fabrication of a control-grid electrode supported by a Mylar dielectric has been investigated. Computer modeling is being used as a design aid, and ion-beam milling has been successfully used to fabricate the Mylar control-grid electrode. The lateral dimensions of the grid are delineated photolithographically. The Mylar dielectric is attached to the In_2O_3 coated substrate using heat and pressure alone or in combination with an epoxy adhesion promoter. The results are described in Paragraph 3.4, and an example is shown in Figure 1. Section 2 describes the Mylar sealing techniques developed. Good seals, with occasional nonbonded areas, were obtained by heating the Mylar while applying pressure with a platten which was coated with a release agent. Better seals were obtained when one side of the Mylar was coated with epoxy as described in Paragraph 2.2. Operating life-test results indicate no adverse interactions between the electrophoretic suspension and the Mylar/epoxy seal. Computer modeling of the electrostatic potential in the device is in progress. Section 4 describes models which can be used to calculate the potential along the axis of a potential well and to plot the equipotentials and device geometry. Figures 2 and 3 are examples of the output of these models. Further research will determine the maximum area which can be ion-beam milled uniformly and the appropriate dimensions of the device. No hardware of significance was developed.

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1. INTRODUCTION

During this first quarter, work was concentrated in three areas: sealing Mylar to indium-oxide-coated glass substrates; development of technology for fabricating Mylar control-grid structures; and implementation and modification of computer models of the electrostatic potential in the device.

2. MYLAR SEALING

2.1 Mylar Without Adhesion Promoters

The viewing side of an electrophoretic image display (EPID) is typically a glass substrate having a transparent electrode of In_2O_3 deposited on one side. A cell is formed by sealing two such substrates together around the perimeter and incorporating a spacer of suitable thickness to establish the desired gap between the cell electrodes. Mylar has been found to be suitable as both the spacer and the sealant.

Clean Mylar frames 50 μm thick have been sealed to In_2O_3 coated glass using heat and pressure alone, without the need for adhesion promoters. The sealing temperature is controlled at a point where the Mylar can flow slightly and bond to the In_2O_3. This has been done without adversely deforming the Mylar.

This technique is being adapted to the use of Mylar as the dielectric support for the control grid in the X-Y addressed EPID. The primary differences are that, since the depth of the potential wells will be about 5 μm to 20 μm, thinner Mylar should be used and only one side of the Mylar will be sealed to In_2O_3, leaving the other side available for deposition of the grid electrode.

Mylar 12 μm thick and up to 0.75 in x 0.75 in has been bonded to In_2O_3 coated glass substrates. This was accomplished by using a polished steel platten to apply pressure to the Mylar.

A thin film of synthetic oil was applied to the platten to prevent the Mylar from sticking to it. The residual oil is removed from the Mylar by solvent cleaning prior to grid-electrode deposition. No problems have been encountered with the adhesion of the aluminum grid-electrode.

Occasionally the bond between the Mylar and the In_2O_3 is not formed in certain small isolated areas, and this would interfere with proper operation of the device in those areas. Increasing the temperature and or pressure during sealing has improved the bonding. However, deformation of the Mylar is too severe under conditions necessary for complete bonding. Therefore, the use of epoxy to seal the Mylar to the In_2O_3 is being investigated. This is discussed in Paragraph 2.2.

Preliminary work has begun to determine the feasibility of sealing pre-electroded Mylar to In_2O_3 coated glass. Improved optical properties will be obtained in the final device if the reflective aluminum grid-electrode can be replaced by either an opaque, non-reflective electrode or, more desirably, by a transparent electrode. To this end, Mylar coated on one side with In_2O_3 has been obtained from Sierracin. This material is only available in 0.005" thickness with a thin, high sheet resistivity coating. However, we have demonstrated that this coating can occasionally survive the sealing process with modest increases in resistivity at the expense of perfect sealing. Consideration is being given to in-house deposition of In_2O_3 onto thinner Mylar. In this case, the In_2O_3 could be deposited after the Mylar is bonded to the substrate.

2.2 Epoxy-Coated Mylar

Work has begun to adapt a technique that was developed by the Philips Research Laboratories, Eindhoven, the Netherlands, for making epoxy-coated Mylar, to meet the needs of this program. The Mylar/epoxy seal can be made at lower temperatures (200°C vs. 250°C) than those used for making the Mylar seal and results

in a bond over the entire area without deforming the Mylar spacer.

An epoxy resin (Araldite AZ15) and hardener (#HZ15) from Ciba Geigy is mixed in a 10:3 ratio and dissolved in one part acetone to one part 4-hydroxy, 4-methyl, 2-pentanone. The Mylar sheet is dipped into this solution and then withdrawn at a controlled rate. Surface-tension forces control the thickness of the liquid layer. Evaporation of the solvent results in a dry (non-tacky) film of uncured epoxy about 1 μm thick. The coated sheet can be handled and cut to shape. Subsequent heating under pressure causes the epoxy to flow and then cure. This basic method has been applied successfully to two different requirements, viz., attachment of the control-grid dielectric and perimeter sealing of the device, as described below:

- Mylar 12 μm thick was coated with epoxy on one side only. Perfect seals 1 in x 1 in have been made to In_2O_3. A good bond was obtained at all points and the problems discussed in Paragraph 2.1 have been eliminated. This method could be used to attach pre-electroded Mylar with the expected benefit of less change in electrode resistivity.

- Mylar 50 μm thick was coated with epoxy on both sides. Frames were cut and used as perimeter seals for test cells. All seals were very clear, indicating good bonds, and passed boiling water and pull tests, indicating good strength.

A life test is in progress to determine the compatibility of the epoxy and electrophoretic suspension. Test cells with plain and epoxy-coated Mylar perimeter seals were filled with the same suspension. These cells have been operating for over 10^3 hours at $\pm$ 50 V, 2 Hz square wave with no failures in either group. This represents more than 1.5×10^7 switching operations. Thus, it appears that the epoxy chosen is compatible with the electrophoretic suspension. Further, there are no blemishes in the seals nor leaks in the cells, indicating that the solvents in the suspension have not degraded the seal.

3. MYLAR CONTROL-GRID FABRICATION

3.1 Background

Until recently, photoresist was used as the dielectric to support the control grid. It had the advantage that potential wells with vertical walls could be formed photochemically. However, the optical properties of the photoresist dielectric resulted in decreased brightness and contrast in the display. Therefore, Mylar has been chosen as the replacement for photoresist. Mylar is chemically very stable and has been used as a spacer/seal in EPIDs, is not attacked by the components of the suspension nor does it introduce contaminants, and has excellent electrical and optical properties.

3.2 Preparation of Test Pieces

An evaporation system with appropriate fixturing was set up for the deposition of aluminum grid-electrodes. Mylar 12 μm thick was sealed to In_2O_3 coated glass substrates using both methods described in Section 2. An aluminum layer about 6000 Å thick was deposited on the surface of the Mylar. Photoresist was then spun onto the Al surface and patterned with a grid mask. This left 5 μm wide lines with a spacing of 35 μm in one direction and 70 μm in the other. The 30 μm x 65 μm unprotected rectangles were subsequently removed to form the potential wells in the grid structure. Some difficulties in controlling and reproducing the fine 5 μm grid lines have been resolved.

3.3 Formation of Potential Wells

The chemical stability of Mylar makes it difficult to etch. Any isotropic etching procedure would result in undercutting of the grid electrode and in potential wells with non-vertical walls. For these reasons ion-beam milling was selected as the means for forming the potential wells. A Veeco miller with a nominal 3" diameter beam is being used.

The patterned substrates are first milled to remove the aluminum from the unprotected rectangles. Argon at a pressure of 2×10^{-4} torr is used with a 50 mA/cm^2 beam at 500 V. The photoresist thickness and milling rate, in argon, are such that all the unwanted aluminum is removed before the resist mask is consumed. This takes 30 minutes. The argon is then replaced by oxygen at 2×10^{-4} torr, and the beam current is maintained at 50 mA/cm^2 at 500 V. The milling rates in oxygen are high for the photoresist and Mylar; the milling rate in oxygen for aluminum is low. The remaining photoresist is removed (avoiding a subsequent stripping operation), and the potential wells begin to form. After about 60 minutes, 12 μm of Mylar has been milled away. By adjusting the angle of the rotating substrate table with respect to the axis of the ion beam, the profile of the walls of the potential wells can be controlled. An angle of 20° has been found to give the desired vertical walls.

3.4 Results

Figure 1 is a photograph taken with a scanning electron microscope of a portion of a cross section of an ion-milled Mylar control-grid structure. Several important features should be noted: the Mylar has been milled with the desired vertical walls, the aluminum grid has remained intact, and less than 1 μm of Mylar remains in the bottom of the wells. These initial results indicate the need to determine the effect of the residual Mylar at the bottom of the wells, and to find ways to minimize or eliminate it.

When a control-grid substrate with residual Mylar in the wells is observed dry in air, it appears milky. However, when it is wet with the solvent mixture used in the electrophoretic suspension, this milkiness disappears. This is due to the reduction in the difference between the indices of refraction of the Mylar and the surrounding medium.

Several simple three-electrode cells were fabricated from early test pieces and filled with suspension. Electrical shorts or

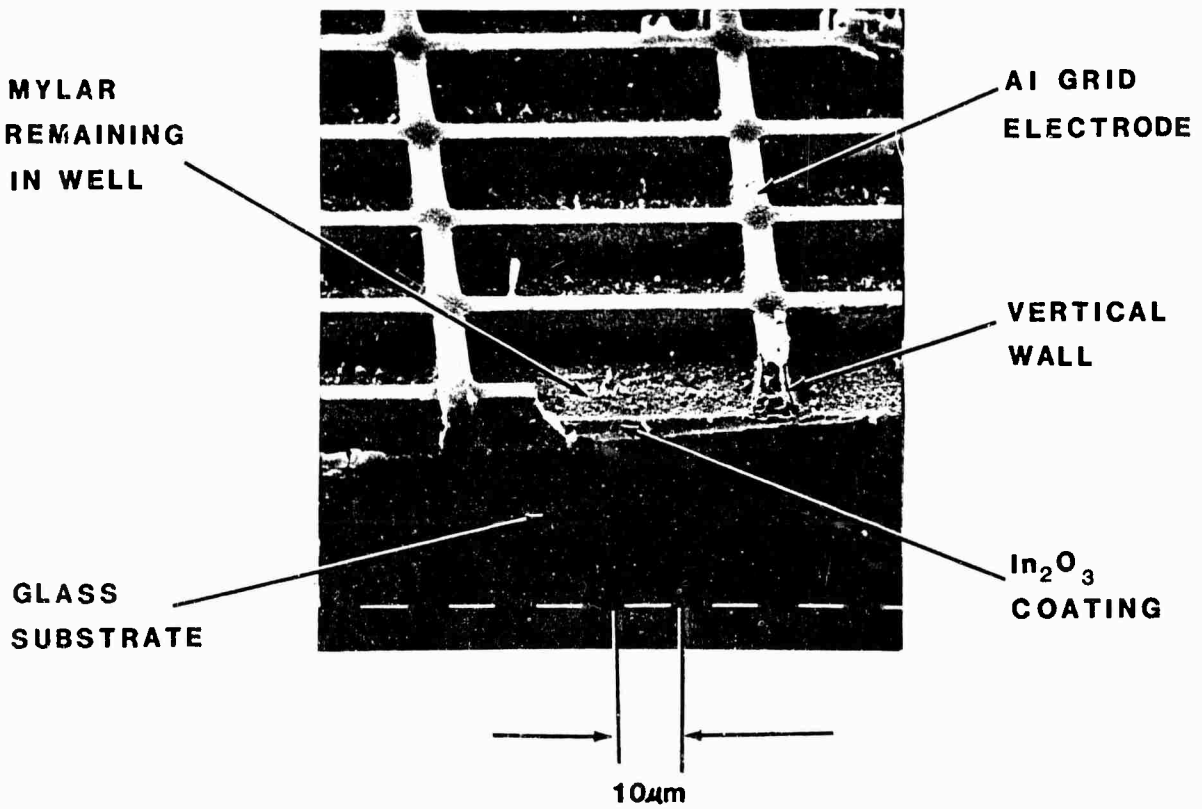

Figure 1: Photomicrograph of an ion-milled Mylar control-grid structure (viewing angle 58°).

opens of the grid electrode prevented total evaluation of these samples. However, it was determined that Mylar grid structures could be used and that the residual Mylar at the bottom of the wells had only a slight effect on the optical properties of the display.

Therefore, tests were made to determine the tolerance of the In_2O_3 at the bottom of the wells to the ion-milling conditions. In argon the In_2O_3 was removed in about three minutes. In oxygen, however, milling could proceed for nearly nine minutes before removing the In_2O_3. This will allow for some over-milling of the Mylar to ensure that all of it is removed from the bottom of the wells.

Work is in progress to determine the maximum diameter over which the Mylar can be completely removed while leaving sufficient In_2O_3 within the milled area.

4. COMPUTER MODELING

4.1 Potential Distribution Along Axis of Well

The performance of the control-grid EPID depends on the dimensions of the device. For a given thickness of the electrophoretic suspension, the length, width, and depth of the potential wells and the width of the walls separating the wells all affect the brightness and contrast of the display. In addition, the addressing potentials and writing time are related to the device dimensions. Large deep wells with narrow separating walls result in desirable optical properties. However, this would result in the need for large addressing potentials and slower operation.

Therefore, it is necessary to model the device so that optimum dimensions can be determined. This has been done by Singer and Dalisa (Ref. 1). Their Equation (1) on page 258 of this reference describes the electrostatic potential at any point within the device. We have solved this equation along the line equidistant to the walls of the well and have written a program for a personal computer which calculates the potential along the line of interest for different geometries and applied potentials. (It should be noted that the quantity V_c should be added to the above referenced equation and that the origin is on the center line of the wall at the bottom of the well.)

A potential plot reveals the magnitude and position of the potential minimum for the critical hold condition. The information from this simple model allows rapid investigation of a large number of device configurations. This model will be used to select several configurations for further study.

Ref. 1. B. Singer and A. Dalisa, "An X-Y Addressable Electrophoretic Display", Proc. of SID 18, 255 (1977).

Figure 2 shows the results of one such calculation. This is for a 30 μm wide by 12 μm deep well with a 6 μm wide wall in a device 50 μm thick overall. The grid potential is zero and V_A and V_c are 70 V and 30 V, respectively.

4.2 Two-Dimensional Equipotentials

The model discussed in Paragraph 4.1 does not take into account the dielectric constant of the wall or the suspension and neglects space-charge effects. Existing computer models (originally written for silicon devices) which include these details are being modified for use on EPIDs. These models are also two dimensional and can be used to plot equipotentials and the device geometry. Figure 3 is an example of the output of one such model in a preliminary stage of modification.

5. PLANS FOR NEXT QUARTER

a. Start design of Phase I device once the maximum usable area in the ion-miller is determined.

b. Obtain fixtures for sealing Mylar of the appropriate size and make seals.

c. Complete computer modeling and order photolithographic masks for selected design.

d. Test suspensions formulated for this application.

e. Fabricate devices (1" x 1") to test suspension performance.

f. Decide whether to deposit In_2O_3 as control-grid electrode.

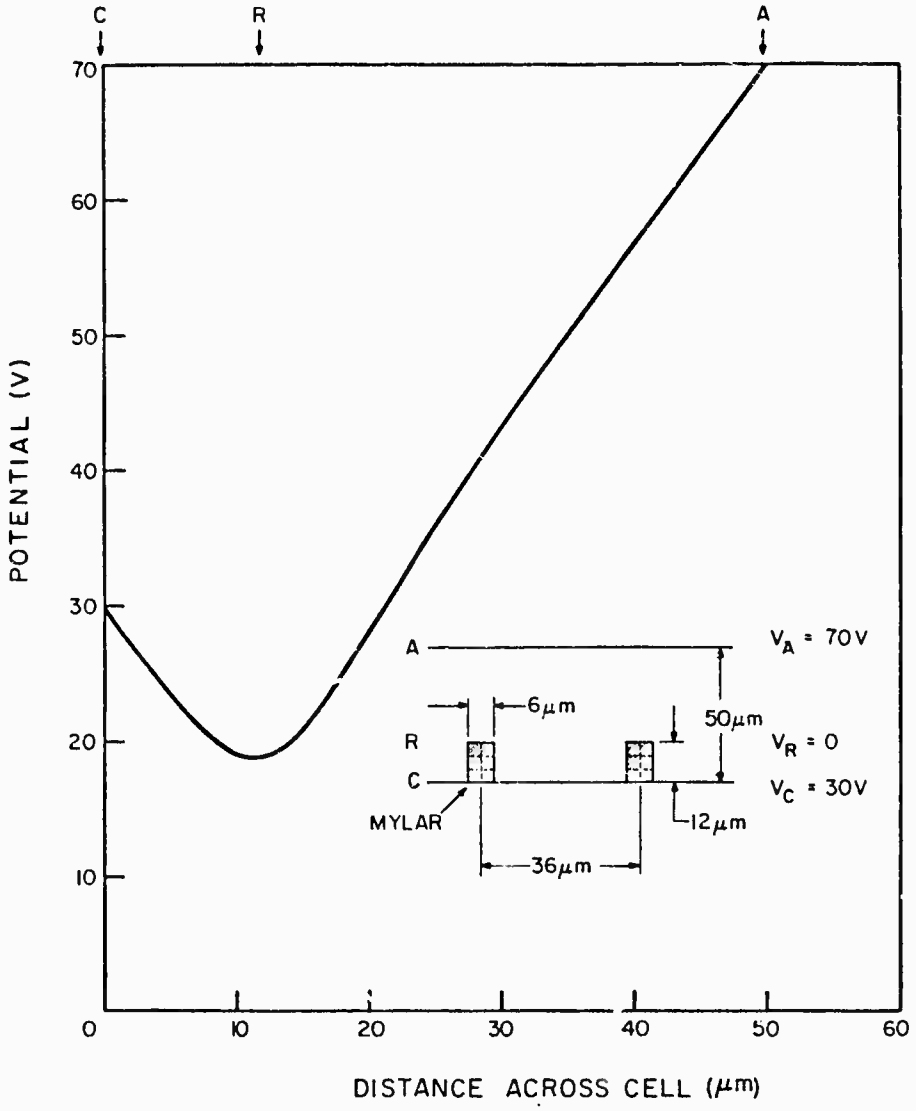

Figure 2: Electrostatic potential along line equidistant to walls of well.

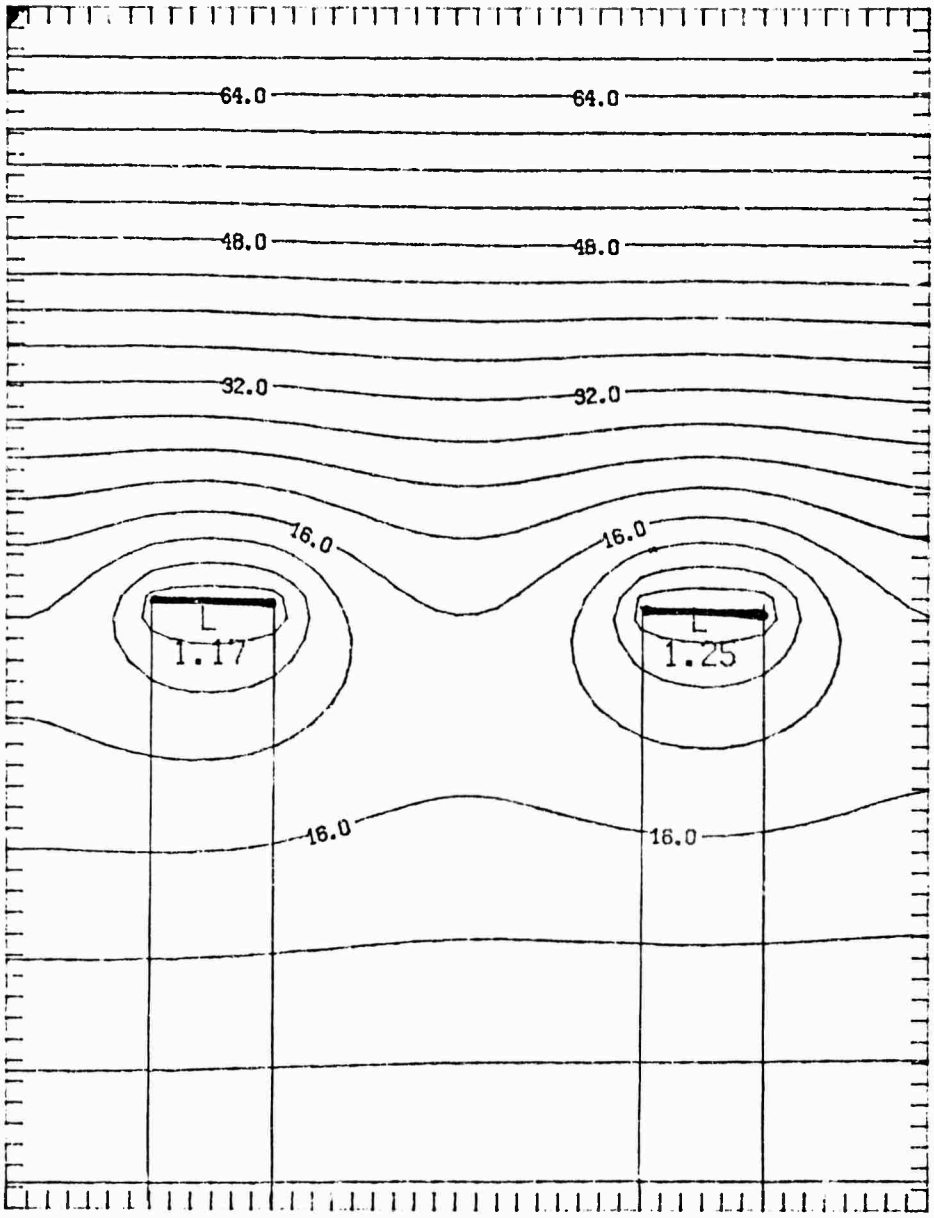

Figure 3: Equipotential contours for an EPID cell.

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