9-4: Flexible Active-Matrix Electrophoretic Display With Integrated Scan- And Data-Drivers

Atsushi Miyazaki, Hideyuki Kawai, Mitsutoshi Miyasaka, Satoshi Inoue, and Tatsuya Shimoda
Seiko Epson Corporation, Technology Platform Research CenterFujimi281, Fujimi-machi, Suwa-gun, Nagano 399-0293, Japan,
Tel: +81-266-62-8445, Fax: +81-266-62-8998, Email: miyazaki.atsushi3@exc.epson.co.jp

Abstract

A newly developed flexible active-matrix (AM-) electrophoretic display (EPD) is reported. The AM-EPD features: (1) low-temperature polycrystalline silicon (LTPS) thin film transistor (TFT) technology, (2) fully integrated scan- and data-drivers, (3) flexibility and light-weight realized by transferring the whole circuits onto a plastic substrate using SUFTLA™ (Surface Free Technology by Laser Annealing/Ablation) process.

A large storage capacitor is formed in each pixel so that driving electric field can be kept sufficiently strong during a writing period. Two-phase driving scheme, a reset-phase which erases a previous image and a writing-phase for writing a new image, was chosen to cope with EPD's high driving voltage. The flexible AM-EPD has been successfully operated with a driving voltage of 8.5 V.

1. Introduction

In recent years, as more and more electronic documents are distributed through computer networks such as the Internet, a demand for an electronic paper, an electronic display with paper-like features, has been rapidly increasing. Consequently, there have been a number of studies reported on such kinds of display devices, [1,2] and electrophoretic displays (EPDs) [3] have been proven to be one of the most promising candidates. Based on the electrophoresis phenomenon of charged pigment particles suspended in a dyed solvent, EPDs exhibit such desirable features as good optical characteristics and bistability, all of which are ideal properties for the e-paper application. However, they at the same time possess intrinsic problems of the lack of a well-defined threshold and the requirement of a high driving voltage. Therefore it has been long thought to be impossible to drive EPDs with a passive matrix (PM) addressing. However, recently some successful attempts for PM addressing have been reported[4]. Nevertheless, due to EPDs' slow response, addressing the entire panel with PM scheme takes too long, practically unbearable, especially in case of ultra-high-resolution panels such as e-papers. We, therefore, believe that active-matrix (AM) addressing is the most suitable when EPDs are used for e-papers, and have developed and reported an AM-EPD using the low-temperature polycrystalline silicon (LTPS) thin film transistor (TFT) technology. [5]

In this paper, we report an AM-EPD with newly designed pixel circuits and integrated scan- and data-drivers, using LTPS-TFT. We also successfully fabricated the panel onto a flexible plastic substrate utilizing SUFTLA™ (Surface Free Technology by Laser Annealing/Ablation) process.

2. Microencapsulated EPDs

Our materials and preparation method for microencapsulated electrophoretic displays (MC-EPDs) have been already reported in detail elsewhere. [6,7] Briefly, first TiO_2 particles are suspended in a dyed solvent using dispersant and ultrasonic vibration. Secondly the suspension is enclosed into Gelatin/Gum Arabic microcapsules by using the complex coacervation method. Next a water solution containing the microcapsules is added with a binder, and coated onto a base film using a blade coater. Then the water in the solution is evaporated by heating. The capsule-coated sheet is called EP sheet. Lastly the EP sheet is laminated on a TFT circuit substrate.

3. Electrophoretic Display

Writing images on the MC-EPDs is performed by impressing an electric field across the suspension between two electrodes. Figure 1 shows the principle of driving MC-EPDs. When an electric field is applied between electrodes, TiO_2 particles are attracted towards one or the other side depending on the polarity of voltage due to the electrophoretic phenomenon. Therefore, white colored dots can be seen when the TiO_2 particles are attracted to the front of the display, and conversely blue colored dots can be seen when an opposite polarity of voltage is impressed.

Figure 2 shows data concerning contrast ratio of MC-EPDs for the time under DC voltage between

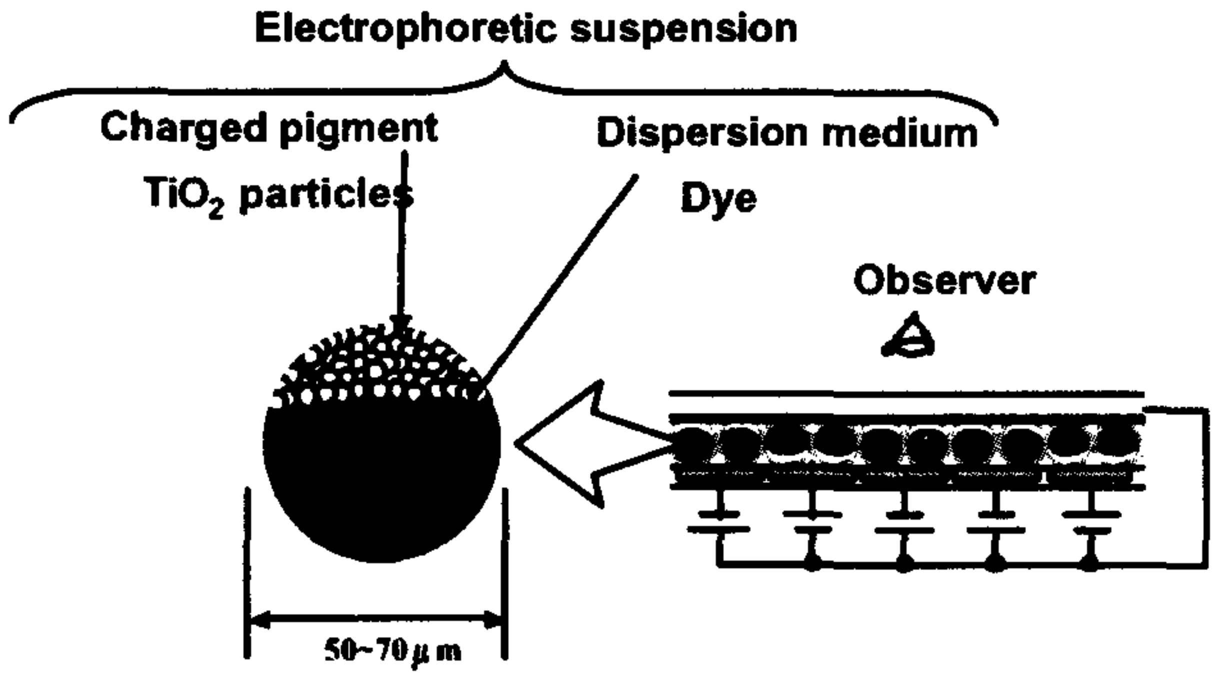

Figure 1 Schematic cross section of microencapsulated EPD.

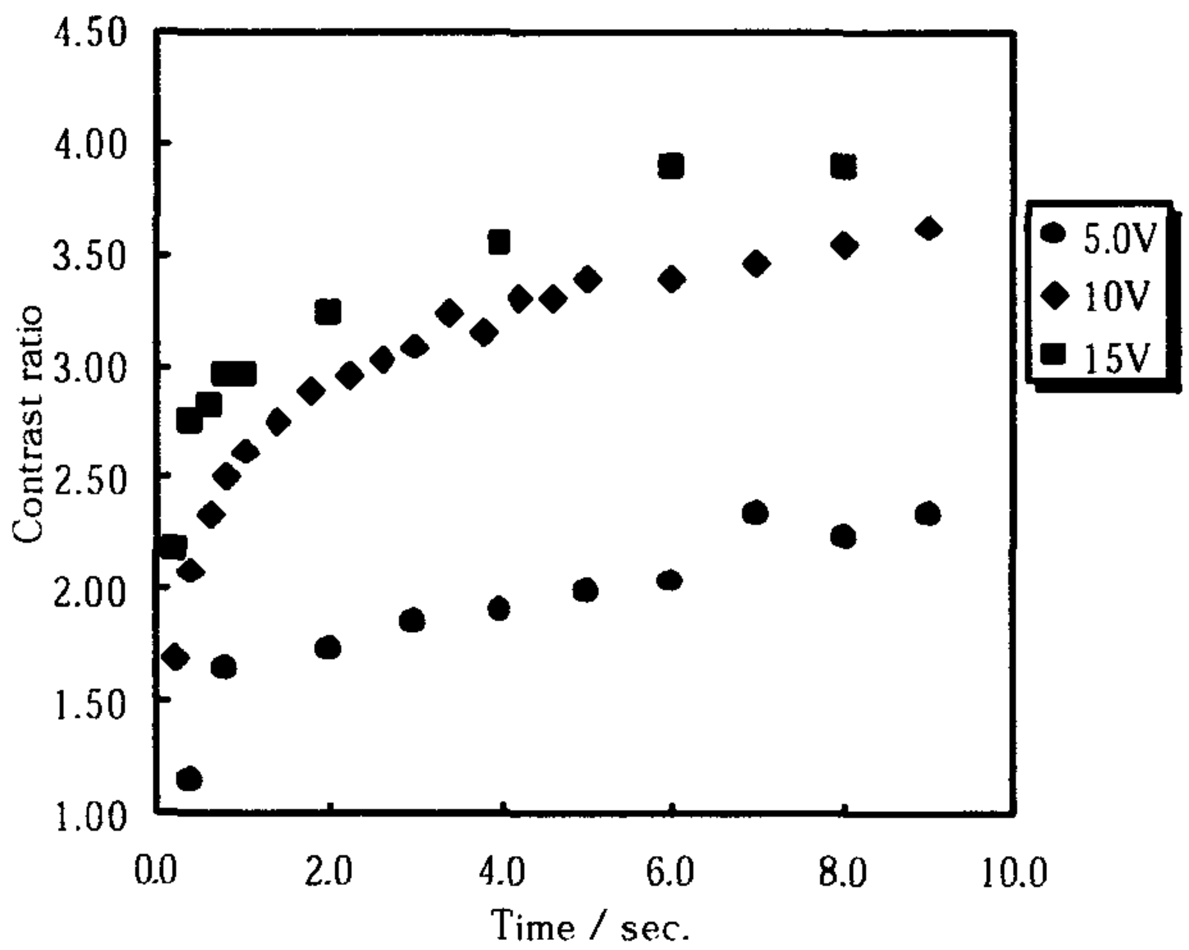

Figure 2 Display properties of MC-EPD.

electrodes. When a voltage 15 volt was impressed directly across the microcapsules for 400 milliseconds, a contrast ratio of 2.8 was obtained. It was found that electrophoretic suspension requires much longer response time than other display materials such as liquid crystal.

4. LTPS TFT AM-EPD

Figure 3 shows the pixel circuit of the AM-EPD. The pixel is composed of a switching TFT and a storage capacitor. Since a response time for an EPD is very long as shown in Figure 2 and the driving voltage has to be kept sufficiently high during the writing period, the capacitance of the storage capacitor is required to be large enough. The value of the capacitance was determined considering leakage current and pixel size.

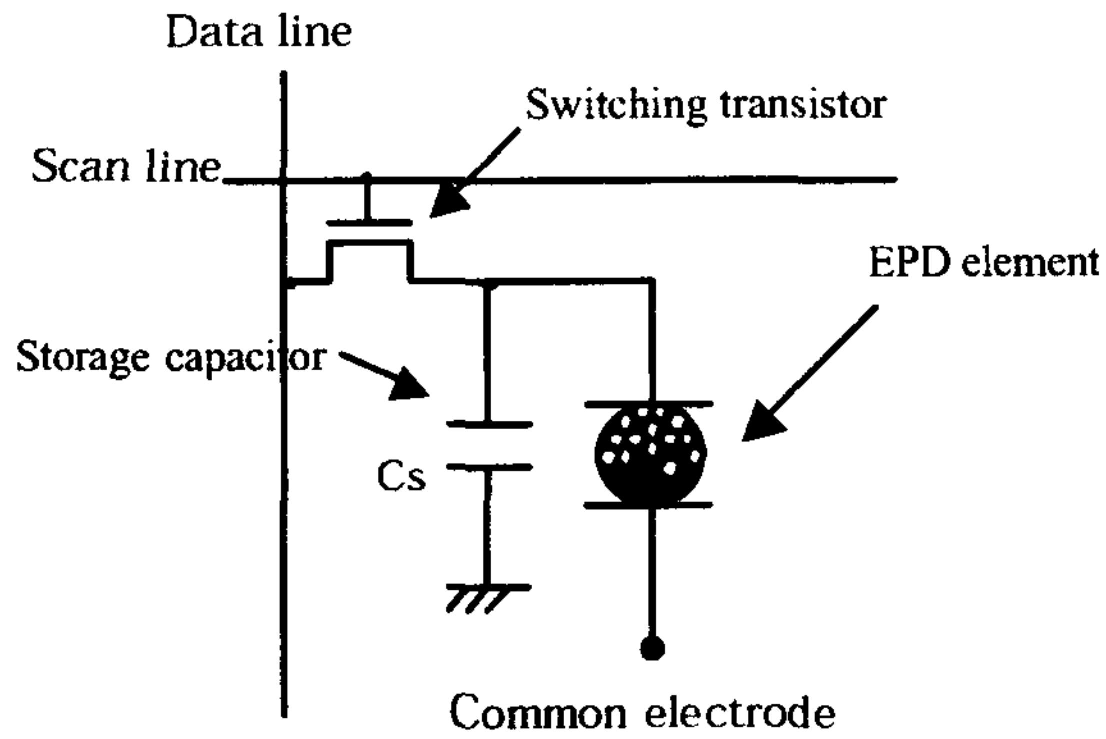

Figure 3 Pixel circuit of the TFT-EPD.

Potential that was stored to the storage capacitor would be discharged through a switching TFT or EP materials on pixel electrode. Leak current of the switching transistor is estimated at 10^{-10} A level, and EP material's leakage current is estimated at 10^{-12}A level. Therefore we concluded leakage current was subjected to characteristics of the switching TFT not EP material.

Unlike transmissive displays like LCDs, EPD device is a reflective display, so a storage capacitor can be formed throughout the entire pixel area. This gives advantages when a large capacitor is necessary.

We designed the capacitors to possess specifically about tenfold capacity ratio against to the capacitance of EPD material.

The block diagram of the panel is schematically shown Figure 4. The scan- and data-drivers are integrated around the pixel area on the substrate and their functions are the same as used in TFT-LCDs.

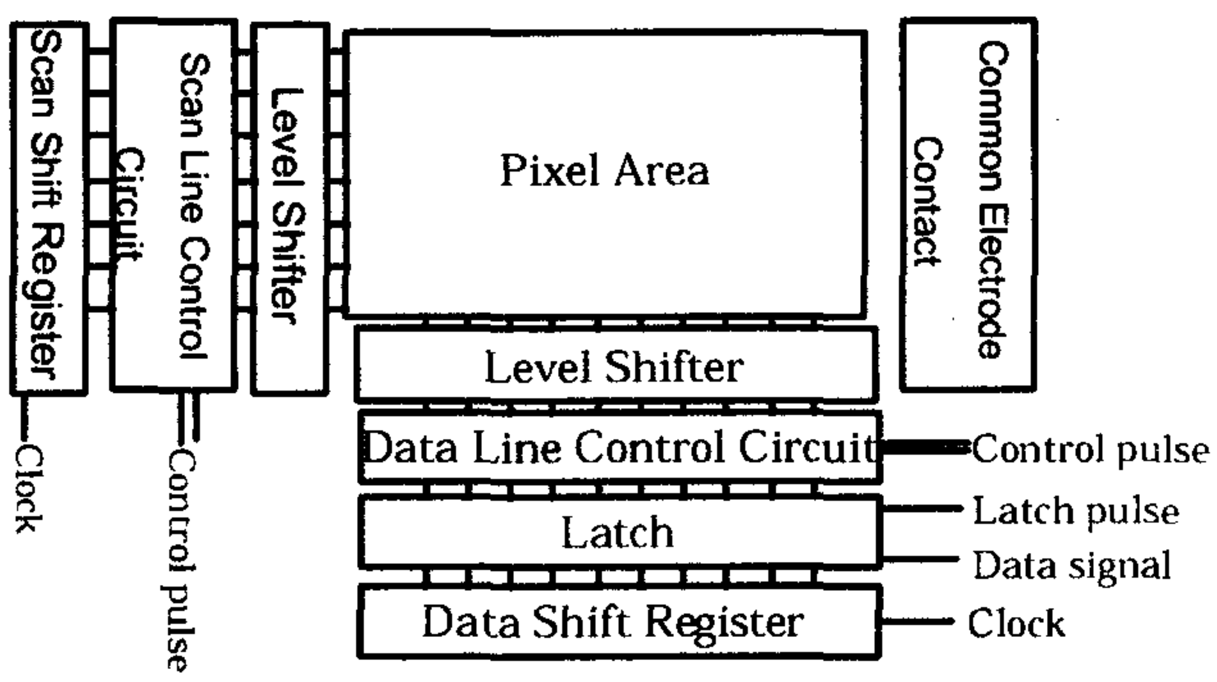

Figure 4 Block diagram of the AM-EPD.

Because EPD writing time takes long as described above, we chose a line-at-a-time mode in order to avoid cross-talk problem. Using the two techniques of large storage capacitors and a line-at-a-time mode has been proven to shorten the addressing time of displayed images.

During a gate line is selected by the scanning driver, a data-driver applies the data signals into the pixel circuits connected to the selected gate line. The output pulse of the sift register in data-driver is stored in the latch. After sampling all the data signals for the selected gate line, a latch pulse is input and the data signals are transferred into the display area through the level shifter.

Figure 5 illustrates driving waveforms to address the AM-EPD. We utilize a "two-phase driving" scheme[4] because EPD requires high driving voltage whereas LTPS-TFT has a tendency to get degraded when driven at a high voltage. Briefly, in the scheme, one writing sequence consists of two phases, a reset-phase and a writing-phase, and the potential of the counter-electrode is dynamically switched between these phases. In order to shorten the reset-phase period, we placed scan- and data line control circuits in the drivers, as shown in

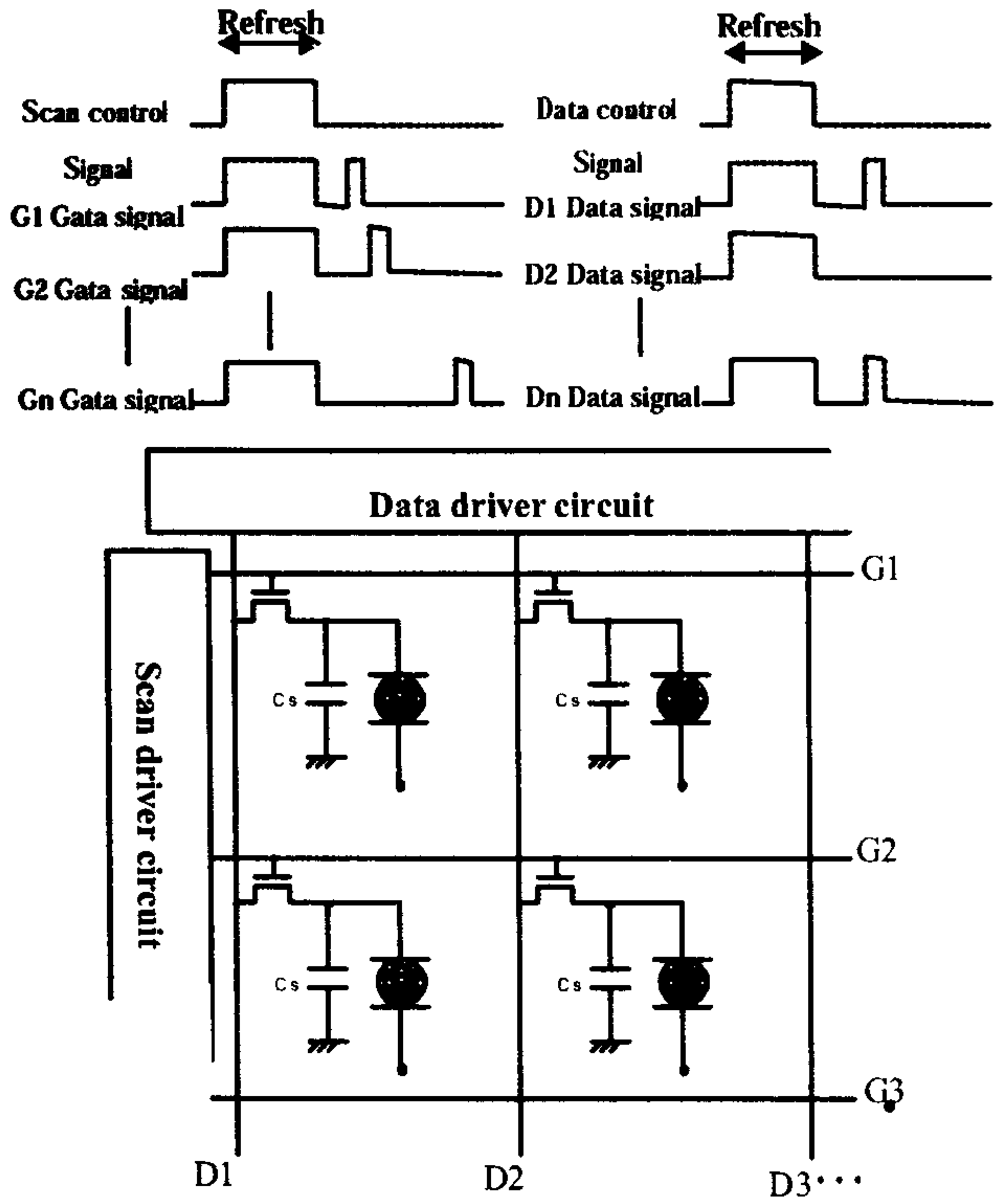

Figure 5 Driving waveforms for the AM-EPD.

Table 1 Specification of AM-EPD.

Display Area	84 × 61.5 mm
Number of Pixels	24 × 176 pixels
Pixcels pitch	350 μm (73 dpi)
Operation Voltage	8.5 V
Driver	bult-in.

Figure 5. The control circuits force all the scan and data lines to be either level, high or low, according to the control pulse inputs regardless of outputs from the shift registers.

As a result, the entire image can be erased at once.

The specifications of the AM-EPD are summarized in Table 1. It has an 8.4 × 61.5 mm^2 display area in which 24 × 176 pixels are arranged.

Figure 6 shows photographs of AM-EPD devices formed onto glass and flexible substrates. Flexible substrate was formed by SUFTLA process that enables the transfer of TFTs or TFT devices from the original substrate to any substrate.[8, 9] Fabrication sequence for AM-EPD device is described below. First, an EP sheet was prepared by coating electrophoretic materials onto a PET film with an ITO layer. The thickness of the EP sheet was about 155μm. Lastly, the EP sheets were laminated onto glass and flexible plastic substrates.

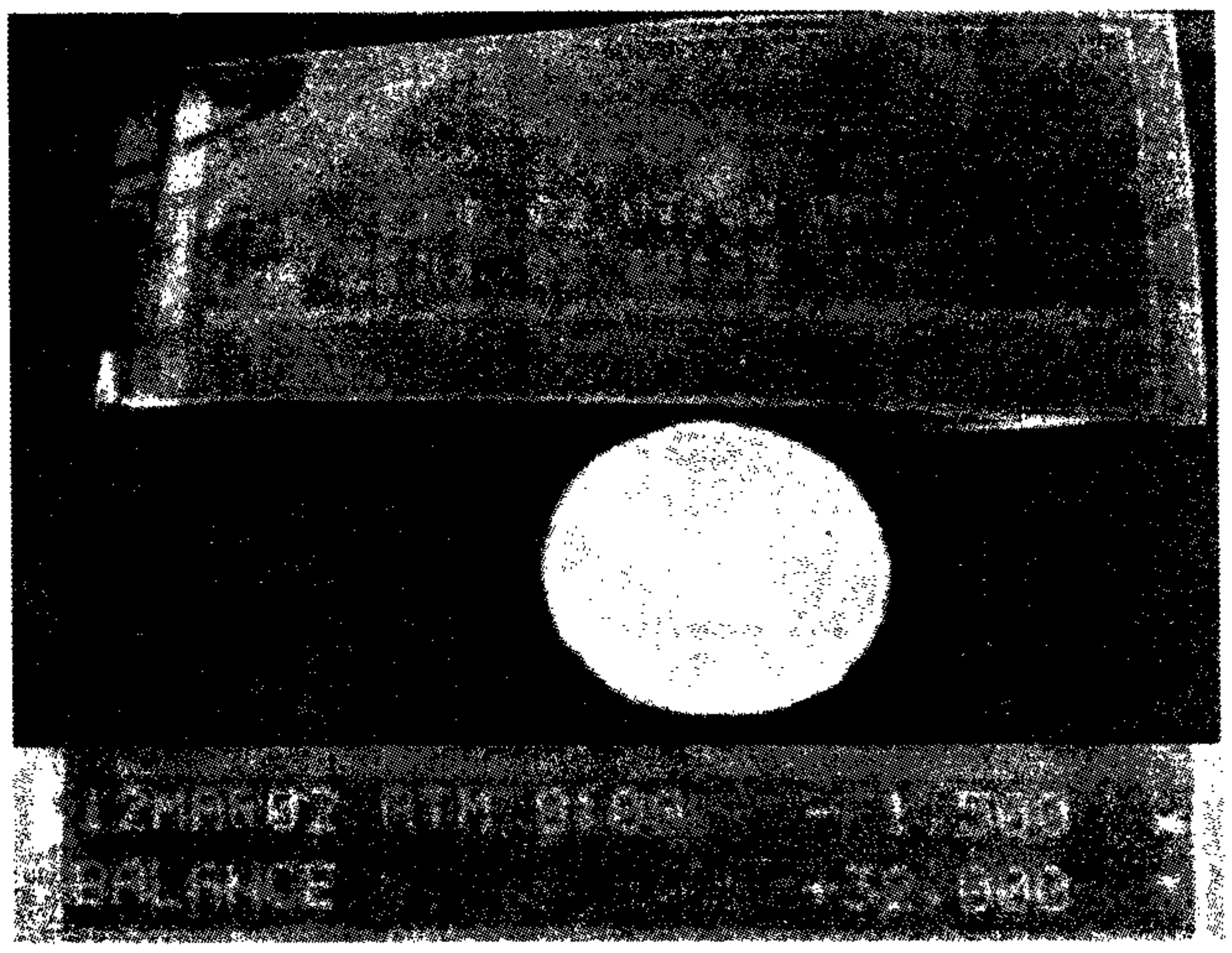

Figure 6 Photograph of displayed AM-EPD.

Total thickness of the glass panel and the plastic panel were about 855 or 375μm, respectively. It was confirmed that the AM-EPD could retain displayed images, even after power supply and data signals were cut off. The AM-EPD has also been successfully operated with a driving voltage of 8.5 volts.

5. Conclusion

We have fabricated an AM-EPD with integrated scan- and data-drivers on a flexible substrates using low temperature poly-Si TFT technology and SUFTLA process. Our AM-EPDs were driven 8.5 Volts, and the displayed images were retained even after cutting off the power supply and data-signals. In consequence, our display device exhibits very low power consumption. The flexible AM-EPD device showed tremendous potentiality of the combination of SUFTLA and MC-EPD in the manufacture of thin, lightweight, flexible electronic display devices, such as e-papers.

6. Acknowledgment

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