
Electrophoretic Displays

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Abstract

Electrophoretic displays offer high brightness and contrast across the full range of viewing angles, an “ink-on-paper” appearance, and image stability. These attributes make electrophoretic displays an attractive candidate for portable devices that require easy readability in a variety of lighting conditions from indoor to bright sunlight without consuming much power. This chapter reviews the early development of electrophoretic displays and the challenges to commercialization, as well as the current electrophoretic display state of the art.

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Introduction

An ideal electronic paper display offers ink-on-paperlike optical attributes including the high contrast and brightness considered important for comfortable long-term reading and high comprehension and easy readability in a variety of conditions from office lighting to bright sunlight, consumes power sparingly for long battery life in portable devices, and is durable or even conformable or flexible. These attributes are desirable for incorporation into portable devices and especially for devices that are intended for long-term reading such as electronic book readers.

A number of imaging film technologies have been considered as candidates for electronic paper displays. Because emissive displays consume significant power and commonly used types wash out in bright sunlight, top electronic paper candidates are non-emissive. The dominant display technology, the twisted nematic display, does not offer high brightness in its non-emissive (reflective or non-backlit) form primarily due to the optical polarizers that are required to achieve optical contrast. Higher reflectance has been sought among reflective display technologies that do not employ polarizers. Within the class of liquid crystal displays, dispersions of liquid crystal droplets in a polymer matrix or bi-continuous polymer and liquid crystal dispersions give electric field-switchable scattering through manipulation of the anisotropic liquid crystal refractive index (see chapter “► [Liquid Crystal Polymer Composite Materials for LCDs](#)”). The scattering power of such films is limited by the small refractive index anisotropy, typically about 0.2 at best. Thin cholesteric liquid crystal films return light to the viewer through Bragg reflection off the periodic twist structure (see chapter “► [Cholesteric Reflective Displays](#)”).

Particle-based imaging films offer the promise of very high reflectance. Particles can be chosen that give a much higher refractive index contrast than achieved by the refractive index anisotropy of the liquid crystal technologies just mentioned. For example, titania particles offer a refractive index of 2.6 versus that of 1.4 for simple oils. In addition to high scattering, particle-based displays offer near-Lambertian scattering which gives them a paperlike appearance and constant performance across a full range of viewing angles. One early type of reflective particle display developed at the Xerox Corporation (Sheridon and Berkovitz 1977; Sheridan et al. 1997; Sheridan 2005) was called “Gyricon” and was based upon bichromal balls held in oil cavities in a polymer sheet. The bichromal balls are composed of particle-filled polymer; one hemisphere contains light-scattering particles and the other light-absorbing particles. These spheres have a permanent electric dipole aligned along the bichromal axis of rotational symmetry, so an electric field can be used to rotate these spheres between a state where their white hemispheres are facing the viewer and the opposing orientation where their black hemispheres face the viewer.

Another type of particle-based display is the electrophoretic display. Many groups have pursued electrophoretic displays of various forms. Common to electrophoretic displays is that pigment particles in an oil-based liquid or air translate under the force of an applied electric field. This chapter reviews electrophoretic displays that employ through-film switching where particles are moved primarily toward and away from the viewing surface to achieve optical contrast. “In-plane” electrophoretic

technology, where optical contrast is achieved through moving particles primarily laterally to the viewing surface, is reviewed in chapter “► [In-Plane Electrophoretic Displays](#).” Through-film switching electrophoretic displays are by far the most prevalent type of commercial reflective electronic paper displays today.

Early Development of Electrophoretic Imaging Films

Electrophoretic display imaging films were first developed in the 1970s, concurrently with the development of the twisted nematic display (Evans et al. 1971; Ota et al. 1973; Dalisa 1977; Amundson 2005). These electrophoretic displays used particles with a high refractive index in a dyed, oil-based fluid film. This “electrophoretic fluid” is held between a front and back electrode (Fig. 1). A voltage applied to the back electrode pushes the particles toward the viewing surface to achieve a white, reflective state. An opposing voltage pulls particles away from the viewer, so that light is absorbed by the dye before being reflected back to the viewer, giving a black or colored state, depending on the absorption spectrum of the dye. In this way, contrast is achieved by applying voltage pulses. A large refractive index contrast

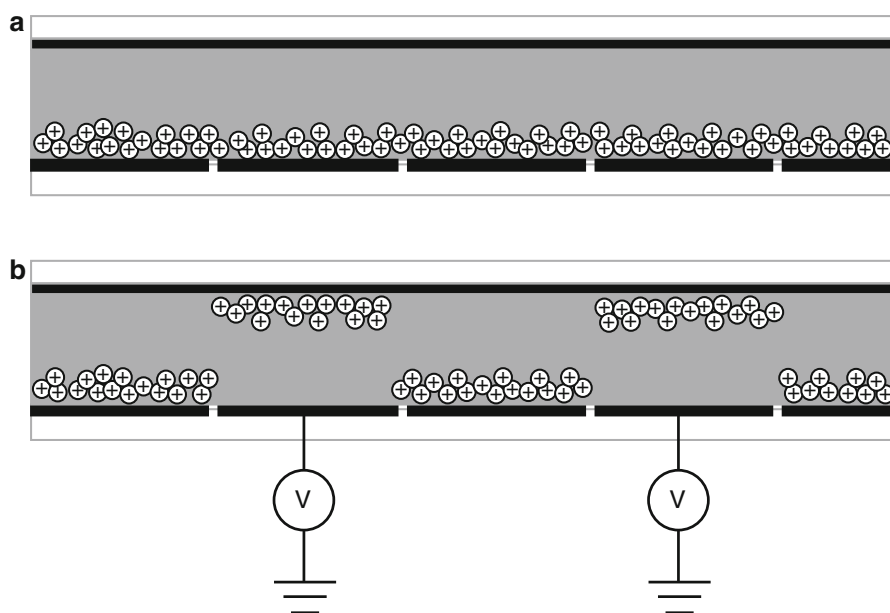


Fig. 1 A cross section of a thin electrophoretic film containing white scattering pigment particles in a dyed fluid. In (a), the display appears *dark* or *colored* (viewer is above the display) because the pigment is behind the dyed fluid. A voltage is applied to two pixels in (b), driving the pigment over those pixels to the *front* of the display. These pixels appear *white* because the pigment is in front of the dyed fluid

between the electrophoretic particles and their surrounding fluid is important because the white state is achieved through backscattering of ambient light, and the intensity of light-scattering scales roughly as the square of the refractive index contrast between the scattering particles and their surrounding fluid. The white scattering particle size is chosen to be on the order of the wavelength of visible light or to contain scattering structure on that length scale in order to maximize the light scattering. Properly designed, the electrophoretic films can give a much brighter white state than reflective liquid crystal films because liquid crystal films (except for certain cholesteric liquid crystal films) require light-absorbing polarizers in order to achieve optical contrast. Also, because scattering is used to achieve the bright state, these displays offer high contrast across the full range of viewing angles and an appearance similar to that of ink on paper.

The electrophoretic particles and their liquid medium must be carefully prepared for successful electrophoretic function. The particles must have a charge in order to move in response to backplane voltages. Many types of particles develop a natural charge in a fluid medium through ionization of surface species or preferential adsorption onto the surface. However, it is preferable to impart a charge to the surface through controlled surface functionalization. For example, ionizable species can be attached to particle surfaces whereby either the cation or anion is preferentially solvated, leaving behind the complementary charge on the particle surface. In addition, particle surfaces must be treated to avoid particle agglomeration or particles sticking to other surfaces. Surface treatment is most often achieved through chemical attachment of polymer brushes or physisorbed surfactants. These surface polymer assemblies must be sufficiently dense and of sufficient extent to create a steric hindrance to close particle approach, for irreversible association through van der Waals attraction occurs if the particles are brought close enough for van der Waals attraction energy to overwhelm thermal energy.

While the twisted nematic display technology was successfully developed into commercial displays during the 1970s, development of electrophoretic films was hindered by several observed failure modes. Despite the fact that humans have used dyes since prehistoric times, dyes are commonly unstable and degrade over time. Under switching voltages, the electrophoretic particle swarm would not switch uniformly but form “roll-cell” instabilities that leave an observable texture on the display surface. Particles would migrate laterally to electrode edges through a dielectrophoretic force, or gravitational force could cause particles to settle to one side of a display held vertically.

The failure modes due to lateral migration, “roll-cell” patterns, migration to electrode edges, and settling under gravitational force can all be reduced to subcritical length scales by subdividing the fluid reservoir into an array of cells on the order of tens to a hundred microns wide. Hopper et al. (Hopper and Novotny 1979 and Blazo et al. 1982) described a microcell structure made from photo-patterned ribs of photoresist material. The microcells were filled with an electrophoretic fluid (Fig. 2). All extant electrophoretic displays utilize microcapsules or microcells to eliminate long-range lateral migration.

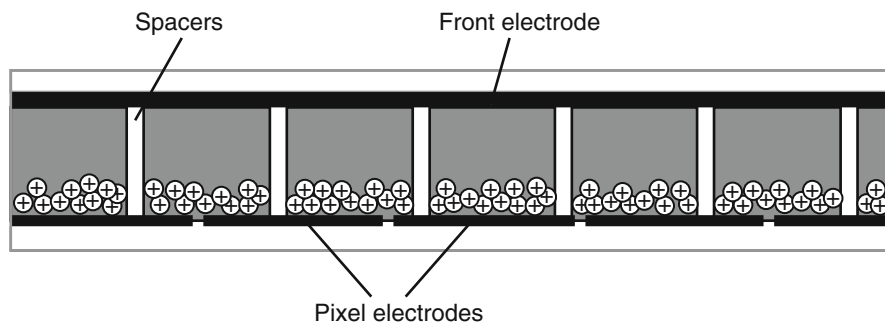


Fig. 2 A series of ribs extending vertically in the display contain particle populations and limit lateral migration of pigment

Image Stability, Power Consumption, and Driving Schemes

When properly formulated, electrophoretic films exhibit image stability, whereby the display holds its image even in the absence of an electric field. Image-stable displays require a very different driving paradigm than monostable displays such as twisted nematic displays. A twisted nematic film requires continuous application of a voltage with amplitude chosen to maintain a graytone; in the absence of a driving voltage, a displayed image will vanish. An image-stable display requires a voltage only to change a graytone (location of the pigments), and, in the absence of a driving voltage, an image will persist. The waveforms required to transition from one graytone to another are illustrated in simplified form in Fig. 3. Because an image-stable display requires power only to update an image, for displays that are not continuously updated, the power savings can be considerable.

Electrophoretic displays can be driven in direct drive or active matrix addressed in a straightforward fashion. Some formulations offer a threshold voltage sufficient to allow passive-matrix addressing (Ota et al. 1973; Amundson 2005; Ota et al. 1975; Lewis et al. 1977). One method for achieving an effective threshold voltage through backplane design is to employ a control grid structure (see Fig. 4). The physical action is analogous to vacuum tube operation. Particles behind a control grid electrode are shielded from a switching electric field. Once the control grid voltage falls below a critical value, the particles experience a switching electric field (Singer and Dalisa 1977; Murau 1984). In yet a different scheme, Blazo (Blazo 1982) describes a photo-responsive electrophoretic display by stacking a photoconductive layer in series with an electrophoretic film between front and back electrodes. In the absence of light, the photoconductive layer is highly resistive and protects the electrophoretic film from a switching voltage. Exposing specific areas of the display to light renders the photoconductor in those areas conductive, and so the electrophoretic film in those areas experiences a switching electric field. In this way, an image is created in response to light exposure.

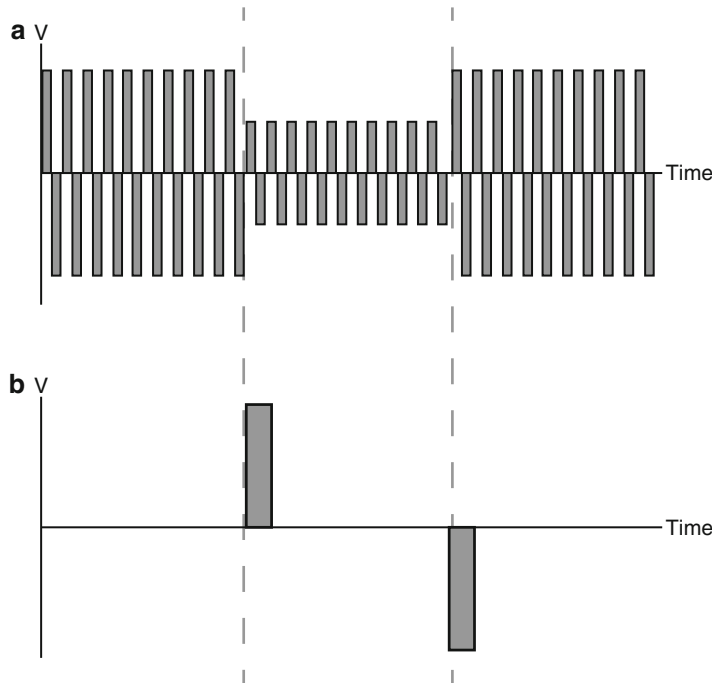


Fig. 3 Representation of drive voltages required to achieve an image sequence where one begins in one optical state, transitions to another optical state (*at the first dashed line*), then back to the original optical state (*at the second dashed line*). (a) shows a sample waveform for a twisted nematic display, and (b) shows a sample waveform for an image-stable electrophoretic display

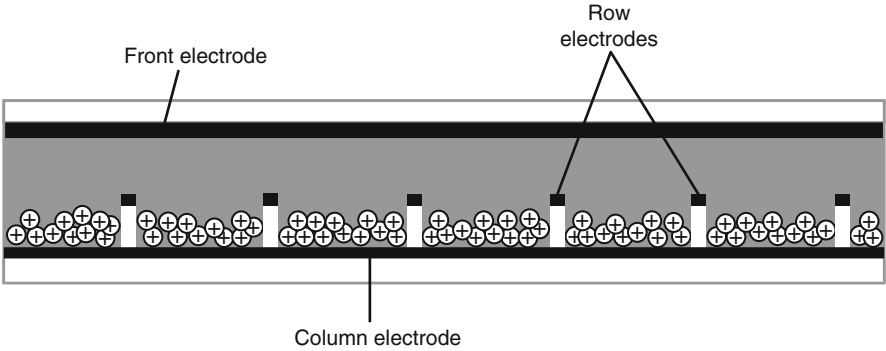


Fig. 4 Control grid structure for driving electrophoretic films. In this image, the pigment is trapped in electrostatic potential wells because of a voltage difference between the row and column electrode. Reversing the voltage bias between row and column electrodes releases the pigment to be moved toward the front in response to a voltage on the front electrode

Speed and Optical Performance Reciprocity in Electrophoretic Films

In this section, the relationship between the electrophoretic film design and properties and the response time is explored, based upon a very simple model for response time. By way of starting point, electrophoretic films that utilize scattering particles for the bright state and dyes for the dark state typically need to be on the order of tens to a hundred microns in thickness. At voltages on the order of tens of volts, these films switched between optical extremes in tens to a few hundreds of milliseconds. Here, we review basic factors that determine the switching speed. In a fluid, charged particles reach a terminal velocity in response to an applied electric field very quickly (typically, in well under a microsecond). Therefore, one can ignore inertial contributions to particle motion and express the electrophoretic motion through the terminal velocity:

$$v = \mu * E \quad (1)$$

where μ is the electrophoretic mobility and is determined by the balance between the Coulombic pull and viscous fluid drag. Derivations of the electrophoretic mobility can be found in Morrison and Ross (2002) and Probst (1994). An expression for the electrophoretic mobility was first developed by Smoluchowski:

$$\mu = \zeta * \varepsilon / \eta \quad (2)$$

where ε and η are the dielectric constant and viscosity of the surrounding fluid. ζ , the zeta potential, is the electrostatic potential at the shear plane around a particle. (The shear plane is an idealized representation of the dividing surface between fluid entrained by a particle and fluid that flows around a particle. Typically, the shear plane is near the outer reach of a polymer brush stabilization layer of a particle.) The zeta potential arises from the charge of the particle and can be approximated by

$$\zeta = q * \lambda_D / \varepsilon \quad (3)$$

where q is the particle surface charge density and λ_D is the Debye length in the surrounding fluid. Equations 2 and 3 can be combined to give an electrophoretic mobility of

$$\mu = q * \lambda_D / \eta \quad (4)$$

The time to switch an electrophoretic display film can be approximated by the distance traversed by the particles, h , divided by their electrophoretic velocity v . The electrophoretic velocity is simply the electrophoretic mobility times the applied electric field strength E , and the applied electric field is approximately the applied voltage drop, V , across the display cell divided by the cell gap h . This gives an approximate switching time of

$$T_{\text{switch}} \sim h/v = h/(\mu * E) = h^2/(\mu * V) = h^2 * \eta/(q * \lambda_D * V) \quad (5)$$

From this equation arising from a very simplified model for an electrophoretic display, we can see how the switching speed depends on the particle surface charge density, the fluid properties, the cell gap, and the drive voltage.

Electrophoretic films, unlike twisted nematic films, can be switched between two graytones at a variety of drive voltages, as one would expect from Eq. 5. From these first principles, one may estimate that the switching speed scales as the square of the cell gap divided by the drive voltage, once the particles and fluid properties have been fixed. The interest in faster response drives a cell design to thinner dimensions. The desire for higher contrast gives an opposing drive to thicker films. Likewise, there is reciprocity between switching voltage and response speed.

Recent and Present-Day Electrophoretic Displays

Microencapsulated Electrophoretic Displays

The proliferation in the 1990s of portable devices that incorporate displays renewed interest in electronic paper display technologies. By this time, the twisted nematic liquid crystal display technology was mature and successful, yet non-backlit twisted nematic displays performed poorly in brightly lit conditions and especially in direct sunlight. A growing opportunity existed for a display technology that would enable easy readability in both indoor and outdoor conditions while not consuming much battery power. Based on early work at the MIT Media Laboratories, the E Ink[®] Corporation was founded in August 1997 and began the development of a commercially viable microencapsulated electrophoretic film (Comiskey et al. 1998). The film was composed of microcapsules that contained dyed oil and highly scattering, charged particles. In the current process, microcapsules are coated onto an indium tin oxide (ITO)-coated plastic sheet that served as a transparent front plane of a display. This film, called a “front-plane laminate,” is then laminated to a backplane, and an edge seal is applied to protect the imaging film from the environment to form a display cell (Fig. 5).

Several years after the particle-dye formulation was developed, E Ink developed a dual-particle electrophoretic imaging film, such that it did not require the use of dyes. The dual-particle formulation is used today. In the dual-particle formulation, the white state is achieved through highly scattering particles just as with the particle-dye systems. The dark state is achieved through the use of light-absorbing particles that have the opposite charge as that of the scattering particles. A voltage of one sign draws the scattering particles to the front surface to give a white state, and the opposite voltage draws the light-absorbing particles to the front surface to give a black state. Colored pigments can also be used to achieve a colored state instead of either state. A dual-particle film is more challenging to formulate because two sets of particles must be made to have opposite charges and both must be surface treated to avoid particle agglomeration. However, a dual-particle formulation, illustrated in

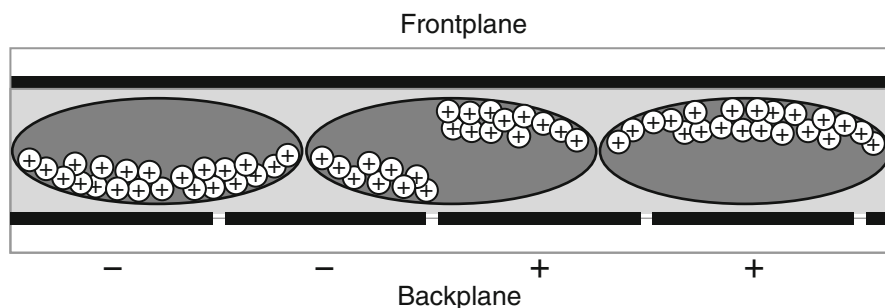


Fig. 5 Illustration of a microencapsulated electrophoretic display. The microcapsules are coated onto a front plane (*top*) with an ITO common electrode. The backplane electrodes are represented in cross section below. In this example, a positive voltage pushes light-scattering pigment toward the viewer and a negative voltage pulls the pigment toward the backplane

Fig. 6 A side-view schematic of a microencapsulated electrophoretic display film that contains two types of pigment particles and a microscopic image of such a display from the E Ink Corporation

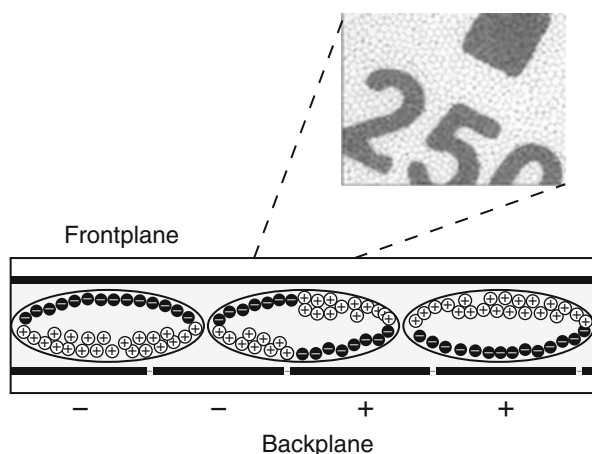


Fig. 6, offers significant optical advantages and eliminates the need for dyes, which are generally not long-term stable to light. A dual-particle formulation also avoids “dye tainting” of the white state that arises in dye-based systems. White-state tainting occurs when backscattered light from multiple scattering events off of white pigment passes through the dyed oil between the scattering particles (Fig. 7) and is absorbed by the dye. Tainting can be reduced by decreasing the dye concentration, but then the oil reservoir must be made thicker in order to reach the optical saturation necessary for a good dark or colored state. Since the speed of transition scales roughly as the square of the thickness of the film (see Eq. 5), this increase in thickness rapidly decreases the speed of the imaging film. As a result, there is reciprocity between white-state quality and switching speed. This reciprocity can be made less severe using a dual-particle formulation. A dual-particle formulation eliminates the need for a dye, and so light can be reflected back to the viewer by scattering off of the white pigment without dimming by light-absorbing entities (Fig. 7).

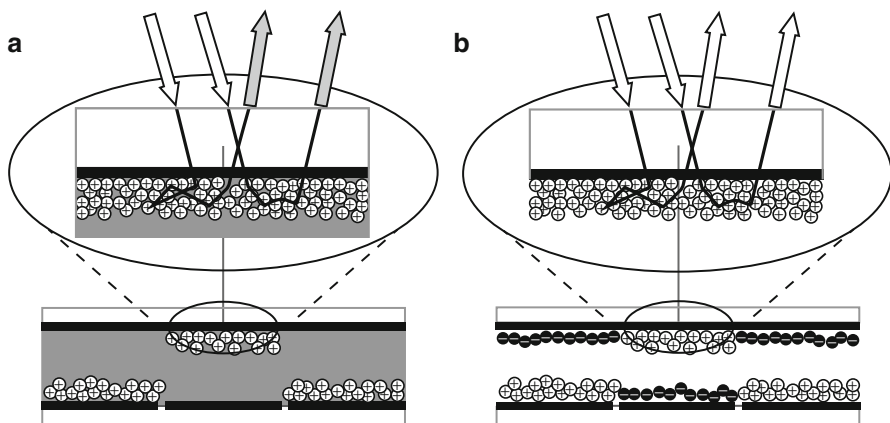


Fig. 7 The white state is achieved through multiple scattering off of white scattering particles in (a) a particle-dye electrophoretic film and (b) a dual-particle electrophoretic film. In the particle-dye system, interstitial dye taints the reflected light

The E Ink “front-plane laminate” can be laminated to a variety of backplanes to make various display types. E Ink’s first products were direct-drive displays and were made using both rigid and flexible backplanes; the pixels in these displays were switched between dark and light optical states. E Ink later developed grayscale rendering and commercialized a wide variety of active-matrix displays. E Ink’s first commercial, active-matrix display was used in the Sony® Librie® that was launched in April 2004 (Amundson 2005). The Sony Librie incorporated a 6-in. SVGA E Ink display that rendered images in 2-bit grayscale. This was the first electronic book reader using an electrophoretic display. Since the introduction of the Librie, numerous companies have made electronic readers using E Ink display modules. Currently, these electronic reader displays render images in 4-bit grayscale. Examples are shown in Fig. 8a, b. Prototype E Ink signage displays are shown in Figures 8c, d.

In order to successfully integrate electrophoretic imaging films into active-matrix display modules, several modifications had to be made from the typical electronics for driving liquid crystal displays. The active-matrix backplane and source and gate drivers had to be modified to support ± 15 -V drive, which was the preferred driving voltage. The display controller also required considerable redesign. Electrophoretic films are not driven to maintain an optical state but instead are driven to change the optical state. This means that, in order to render a new image in an efficient manner, the display controller should hold in memory the current image as well as the new image. Based upon the current and new image, the voltage sequence suitable for achieving the transition from the current to new graytone for each pixel is extracted from controller memory and applied to the appropriate pixel.

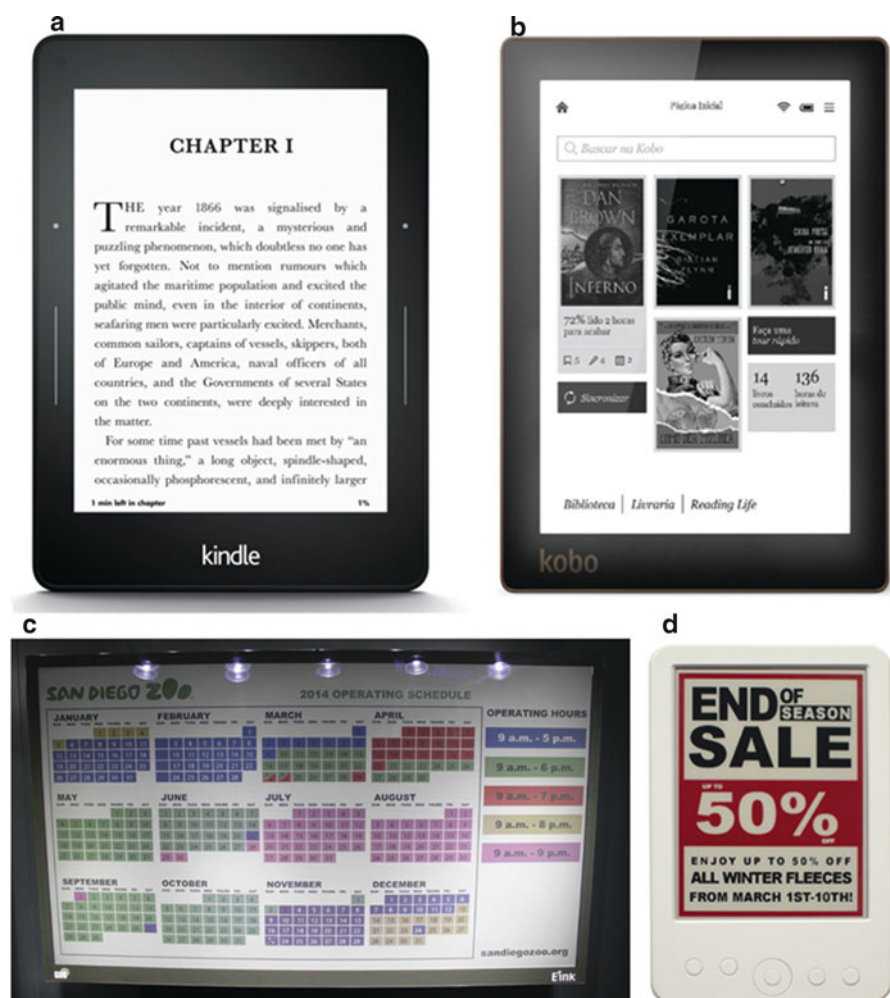


Fig. 8 Examples of commercial and prototype devices using E Ink electrophoretic displays. (a) A commercial Kindle® Voyage® eReader, (b) a commercial Kobo® Aura HD eReader, (c) a prototype 32" public information display, and (d) E Ink Spectra™ electronic shelf label display

Microcell Electrophoretic Displays

Microcellular electrophoretic films were fabricated in the late 1970s and early 1980s using photoresist patterning to form the microcell walls (Hopper and Novotny 1979; Blazo 1982). The microcell walls block lateral migration of the pigment particles. The SiPix® Corporation (acquired by E Ink in 2012) developed a continuous process

Fig. 9 A Micro Cup[®] electrophoretic film constructed with an embossed rib pattern and cells filled with an electrophoretic fluid and then sealed with an overcoat is shown in (a) top view in (b) cross section

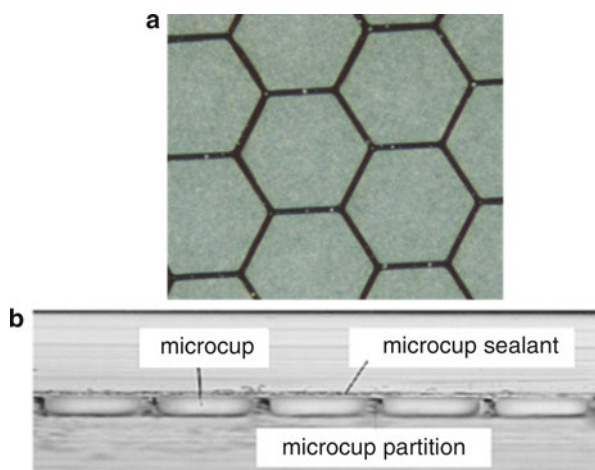


Fig. 10 An E Ink Spectra display using the SiPix microcell structure and *white*, *black*, and *red* pigments



for manufacture of microcell electrophoretic displays. An embossing wheel is used to form microcups in a deformable polymer layer coated over an ITO-coated display front sheet, followed by hardening of the polymer. Embossing, filling of microcups with electrophoretic fluid, and cup sealing are done in one continuous process. A microscopic image of a microcell electrophoretic imaging film is shown in Fig. 9.

The in-line coating process allows for spot color. SiPix has demonstrated displays where one region contains an electrophoretic fluid with one dye and another region contains an electrophoretic fluid with another dye. This allows one region to be switched between white and one color and another region between white and a different color.

In 2013, E Ink announced a three-pigment system using the SiPix microcell structure and with white, black, and red pigments. Initial applications are retail signage and electronic shelf labels. The displays show white, black, and red reflective states. A Spectra sign is shown in Fig. 10.

Air-Gap Electrophoretic Displays

The velocity of electrophoretic particles in a fluid medium is proportional to the electric driving force and inversely proportional to viscous drag. The electrophoretic velocity is therefore roughly inversely proportional to the fluid viscosity, all else being equal. The appeal of an air-gap electrophoretic display, one in which charged particles move through air instead of a liquid phase, is a high electrophoretic mobility for achieving high switching speeds as well as potential high reflectivity due to the large difference in index of refraction of the particles versus air. One may note that the viscosity of simple fluids is typically on the order of 1 cP, while the viscosity of air is around 0.02 cP. Based upon this, one may expect about two orders of magnitude speed increase in air-gap electrophoretic films compared to fluid-based versions. A challenge to keeping this speed advantage, however, is achieving similar particle charging to that in fluid-based systems. The well-established methods for charging particles in aqueous fluids, ionization of dissociating species on the particle surface, and nonaqueous media, through micellization of dissociating ions on the particle surface, are unavailable in a gas-phase system.

A microcellular, air-gap electrophoretic display was developed through collaboration between the Bridgestone[®] Corporation and the Department of Electrical Engineering at Kyushu University in Japan (Hattori et al. 2003). A key for successful implementation is avoiding particle sticking to each other or to walls of the microcells and electrode surfaces. This is especially challenging in an air-gap system, because of strong van der Waals attractions in air. Bridgestone and Kyushu University reported the development of a “liquid powder” electrophoretic particle that exhibits extremely low association forces (Hattori et al. 2003). Figure 11 shows a demonstration of liquid powder. A liquid powder (Fig. 11a) and an ordinary powder (Fig. 11b) are poured onto a horizontal platform. The ordinary particle

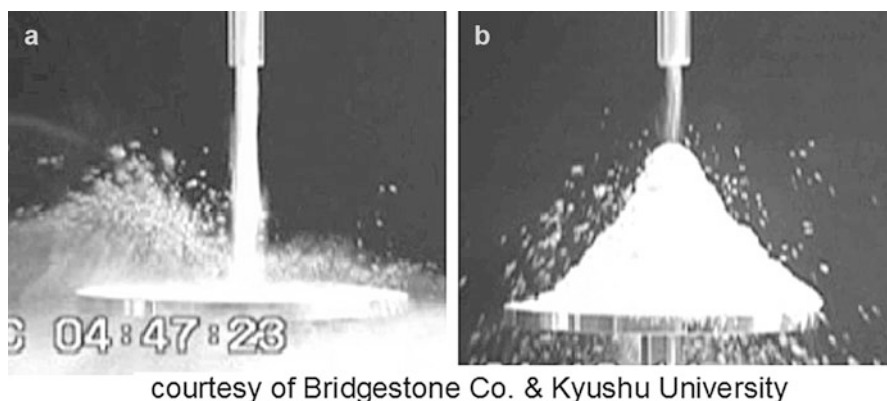
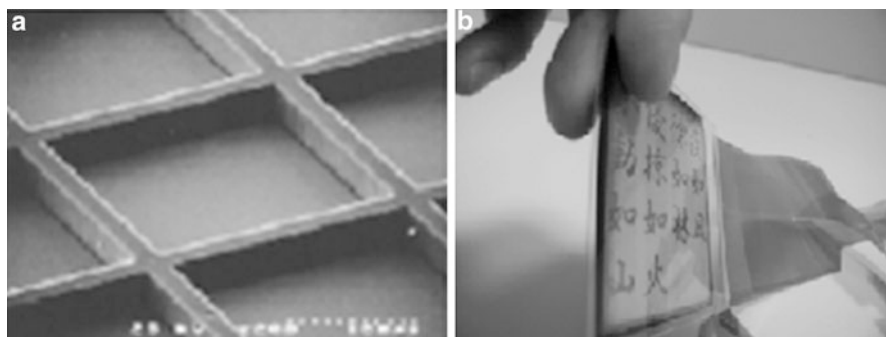


Fig. 11 (a) Electronic Liquid Powder[®] made by Bridgestone and (b) an ordinary powder poured onto a platform. The ordinary powder forms a pyramidal pile owing to interparticle associations. The absence of a pile in (a) is indicative of very low interparticle association forces (Reprinted from Amundson 2005)



courtesy of Bridgestone Co. & Kyushu University

Fig. 12 A microscopic image of a microcell structure made by Bridgestone is shown in (a). (b) shows a 160×160 passive-matrix display on a plastic substrate made by Bridgestone and Kyushu University (Reprinted from Amundson 2005)

forms a pile with a particular angle of repose that is an indicator of forces of particle association. The “liquid powder,” on the other hand, does not form a pile. This is a reflection of extraordinarily low association forces. Bridgestone and Kyushu University placed white and black “liquid powder” particles in an open-top microcell array and then applied the top substrate to form an electrophoretic cell. Despite the low particle association forces, the particle-particle and particle-wall forces are sufficient to impart a sizable threshold voltage, and so these displays can be driven using a passive addressing scheme. Switching of these displays required 70–100 V, presumably owing to the size of the threshold voltage. Individual pixels switched in about 0.2 ms with a 70-V drive voltage. Given the very fast switching speed, one can achieve relatively fast updates even with the row-by-row nature of the passive-matrix driving scheme. Hattori et al. (2003) reported a 67 ms update time for a 160×160 display. They also reported grayscale rendering through partial addressing. Figure 12 shows a microscopic image of a microcell structure and a 160×160 passive-matrix display made by Bridgestone and Kyushu University. A prototype display module is shown in Fig. 13.

While the fast speed of an air-gap electrophoretic display is appealing, “liquid powder” displays suffered drawbacks. The driving voltage needed to be very high to overcome the attractive forces between particles and substrates, and this complicates driving electronics. Another challenge of air-particle displays is the high-speed collisions that can damage the pigment surfaces and limit display lifetime. In 2012, Bridgestone ceased their commercialization of their air-gap electrophoretic display.

Flexible Electrophoretic Displays

Display flexibility offers several advantages. At the base level, a flexible display, even in an unflexed configuration, offers durability. Glass-based displays become increasingly more delicate and difficult to protect as the size of the display increases.

Fig. 13 A 100dpi, QVGA passive-matrix, commercial display module made by Bridgestone and Kyushu University. This display module measures 83×62 mm



A flexible display, on the other hand, is much more durable and less likely to break if, for example, a handheld device is dropped or bent. The durability also allows the device to be designed without the additional size and weight required by protective features demanded by glass-based displays. Actual conformability allows displays to be applied on curved surfaces, and full flexibility enables yet a much larger universe of applications.

Electrophoretic films are ideal candidates for incorporation into flexible displays. E Ink “front-plane laminates” are themselves flexible, and the microcapsules or microcups provide a solidity that maintains the display integrity during flexion. For non-flat displays, the full viewing angle optical performance is especially valuable. As a consequence, E Ink displays have been used in most development efforts directed toward flexible displays over the past decade. Flexible display technology and development are discussed in more detail in chapters “► [Flexible Displays: Attributes, Technologies Compatible with Flexible Substrates, and Applications](#)” and “► [Flexible Displays: Substrate and TFT Technology Options and Processing Strategies](#).”

E Ink’s first involvement with flexible displays started in 1999 through the collaboration with Bell Laboratories, Lucent Technologies (Rogers et al. 2001). This collaboration resulted in the creation of the first fully flexible electronic paper active-matrix display (Fig. 14). The backplane was manufactured using rubber stamping for defining molecular photoresist monolayers and used organic semiconductors in the pixel transistors, on a plastic substrate. The E Ink front-plane laminate was laminated to the plastic backplane to form a flexible display.

From this low-resolution concept demonstration, E Ink has progressed to commercial manufacture of flexible, high-resolution active-matrix displays. Examples of devices that incorporate E Ink flexible displays are shown in Fig. 15.

The thin and lightweight Sony Reader shown in Fig. 15a would have been quite fragile had it been made with a large glass-based display. The all-plastic display allows for a very light weight; the entire device weighs only 6.8 oz (193 g) and is

Fig. 14 The world's first flexible, electronic paper display made using a flexible, active-matrix backplane and E Ink's front-plane laminate. The backplane was fabricated using rubber stamping and organic semiconductors. The display has a resolution of 16×16 pixels (Photograph by CJ Gunther)

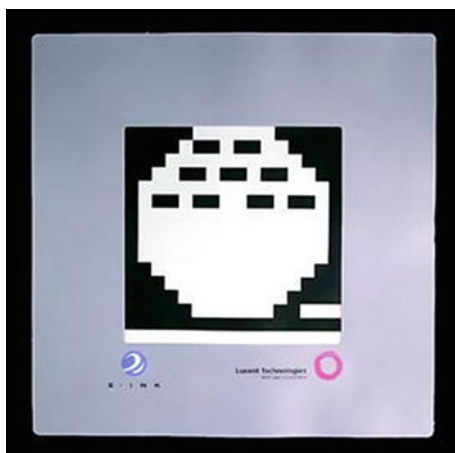


Fig. 15 Examples of devices that incorporate flexible E Ink displays. (a) Sony Reader with a 13.1" flexible display, (b) a YotaPhone[®] made by Yota[®] with an E Ink screen, (c) an E Ink Digital Hour Clock Watch made by Phosphor[®], and (d) a Sony SmartBand[®] Talk. The E Ink displays in the latter three devices are curved for improved ergonomic design

very rugged. The E Ink screen on the YotaPhone (Fig. 15b) enables a low-power, daylight readable display and is curved to enable a better fit into the palm of a hand. The displays in the watch and wristband (Fig. 15c, d) are curved to better fit around a wrist.

Summary

In the “second age” of electrophoretic display development, starting in the late 1990s, electrophoretic display technology has been developed to fulfill a desire for electronic paper, a role not well filled by the dominant liquid crystal display technology. These displays offer good reflectivity over a full viewing angle, and their Lambertian scattering characteristic imparts an “ink-on-paper” appearance, which is attractive for long-term reading. Their ability to hold an image in the absence of applied power and voltage makes this technology attractive for use in portable devices and enables readers that can last as long as 2 months without battery recharging. Electrophoretic displays have been integral to the recent commercial success of electronic books. They have also been used in handheld medical devices and displays in the retail environment and as indicators on electronic devices such as USB memory sticks where their zero-power image stability is essential.

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