# E Ink Displays

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## Abstract

The ideal electronic book includes characteristics of prints and displays; the legibility and portability of print with the variability and dynamics of electronic displays. An interesting question is to ask whether the fundamental technology will come from the display world (SID) or the image world (IS&T). The first-out-of-the-block candidates come from the display world, particularly liquid crystal technologies. The main effort has been to make LCD displays as thin, light, durable, and low power as possible.

Consider the problem from another direction. Print technologies are wonderfully legible, light, durable, and low power, but what can be done to make the content variable? A number of ideas have been proposed. For instance, consider the possibility of moving a xerographic image in and out of view: say with rotating or electrophoretic toner particles! Consider the possibility of electrochromic technologies where the "printed image" is switchable by oxidation or reduction of dyes.

This talk describes the work at E Ink Corporation where materials similar to xerographic liquid toners and electrophoretic displays are combined with polymeric encapsulation to give devices with the optical qualities of prints as well as the addressability of electronic displays. The excellent optical properties arise from the scattering and absorptive properties of pigments and the variable content arises from the ability to move the pigments into and out of view.

## The Argument

Consider inventing the electronic book. The goal is a device that is as much book-like as possible, lightweight and readable in a variety of conditions (the "bed-bathroom-beach" criterion) as well as capable of being updated electronically, preferably remotely.

Deductive problem solving starts with what we now have, devices that meet the latter criteria, e.g., the portable PC or portable display device like a Palm Pilot. All the information we would ever wish can be downloaded and displayed conveniently. The challenge is to improve the form factor. First, electronic displays are difficult to see in a variety of lighting conditions. Second, they require a lot of power. Third, they are heavy, inflexible, and fragile.

Now if we were brainstorm possible solutions we would come up with a list of enabling technological advances. Let's tackle the harder problems first. How do we invent a low power, light, flexible, and rugged display? The good news is that many, many people are working on these particular problems. The bad news for the inventor is that many, many people are already working on these particular problems. Possibly, we can expect that low power will be achieved with the slower update needed for electronic book – avoid video speeds. This reduces the problem to inventing a display that is light, flexible, and rugged. The obvious idea is to look at polymeric materials to replace silicon based materials. And this is exactly the essence of the research at many academic and commercial R&D laboratories around the world. Hardly a day goes by that doesn't have some announcement in the technical or popular press about a significant advance towards polymeric electronics.

The instinctive problem solving starts with known display technology and looks for a route to the electronic book. Let's consider a "deductive" approach. The "logic" goes something like this:

- First, to create an electronic book, assemble electronic pages with the necessary electronic connections. In principle, not a problem.
- Second, to create electronic pages, assemble electronic pixels onto a substrate. Also not a problem, in principle.
- Third, invent the electronic pixel. The main problem.

We know two necessary properties of the electronic pixel. It should be about 100 µm in size (for adequate resolution) and it must reversibly switch between a light state and a dark state with an external signal, probably electronic.

Before we start inventing electronic pixels, compare the research program required to invent electronic pixels with that required to invent polymeric electronics. At the very least, the work will be entirely different, and that's interesting, especially for invention.

Now, let's invent electronic pixels. Take any printed material. Imagine each spot to be a pixel and try to imagine how to "switch" that spot.

One example is to consider a xerographic print, which, to a certain approximation, is composed of black polymer dots. To "switch" the polymer dot you might try to invent some mechanism to pull it back into the paper fiber, out of sight. Or, re-inventing the Xerox Gyricon, make the polymer dot dark on one side and light on the other and "switch" it by rotation. Imagine using a small electric signal to oxidize or reduce a dye to control the image. Imagine a small flexible plastic mirror that could be moved to reflect or deflect incident light. Once you have picked your favorite electronic pixel, then it's on to make the electronic page and then the electronic book. Done!

## A Proposition

E Ink has made a choice. The electronic pixel we invented is a small capsule, about 100 microns in diameter, that holds a dispersion of pigment particles in oil. The particles are charged and can be moved to and from the viewing side of the capsule with an electric field. (See Figure 1.) This dispersion is similar in composition to liquid toners. The major difference is that we design dispersions that can be switched millions of times rather than once as in liquid immersion development. The microcapsules are coated on a substrate to form an electronic page or display.

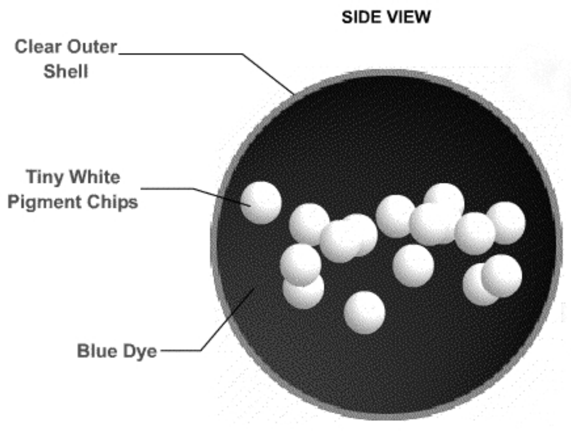


*Figure 1. An electronic pixel – encapsulated electrophoretic ink..*

Considerable work was done several decades ago on electrophoretic displays (EPDs). The physics of EPDs is similar to layers of our encapsulated pixels. A hydrocarbon dispersion of pigment is placed between two electrodes and an electric field is used to move particles to and from the viewing electrode. (See Figure 2.) Both EPDs and our encapsulated pixels have some important optical properties. They are both reflective, which means that they are easily read over a broad range of lighting conditions and they are easily read over a broad range of viewing angles. They are both essentially electrostatic, which means that a fixed amount of electric charge moves them from one state to another. This makes these displays low power.

About the same time that EPDs were being developed so were liquid crystal displays (LCDs). Today we see LCDs everywhere and EPDs almost nowhere. This is true for two important reasons: the pigment particles in an EPD almost always have a higher density than the continuous phase and the particles will settle with time even when the density difference is quite small. EPDs also suffer from electrohydrodynamic instabilites (similar to Bénard instabilities). When adjacent imaging electrodes are addressed oppositely, the electric field lines are distorted and particles tend to gather in small eddies. This imaging defect is unacceptable. (See Figure 2.)

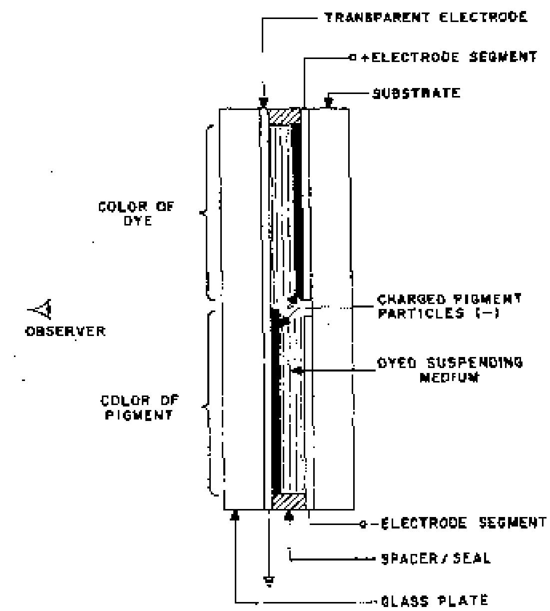


*Figure 2. Electrophoretic display (EPD).*

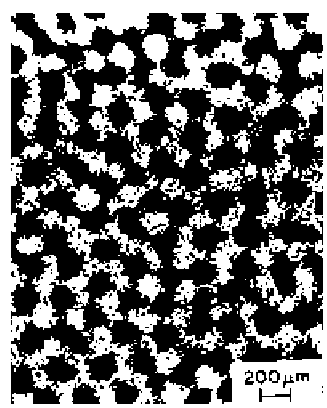


*Figure 3. Defects due to electrohydrodynamic instabilites.*

What we discovered was that encapsulation of the volume of dispersion in microcapsules solved both these problems. First, the pigment particles can settle, but only up to the edge of the capsule wall. The next addressing signal brings them back into position. (See Figure 4).

Second, the electrohydrodyanamic instabilities are suppressed because the small capsule size prevents large scale concerted motion. Additionally we discovered that the limit of resolution is not the capsule size, but smaller. Parts of the capsule can be addressed to one state and parts of the capsule to another. (See Figure 5.) And, of course, since capsules themselves can be dispersed in a liquid, they can be coated on a flexible substrate and dried. The counter electrode can be laminated to the dried layer without the need for spacers since the capsules themselves are self-spacing. This maintains the flexibility and lightweight of the display. On towards electronic pages and then electronic books!

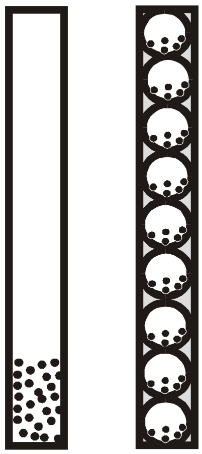

*Figure 4. Sedimentation in an EPID and in encapsulated electrophoretic inks.*

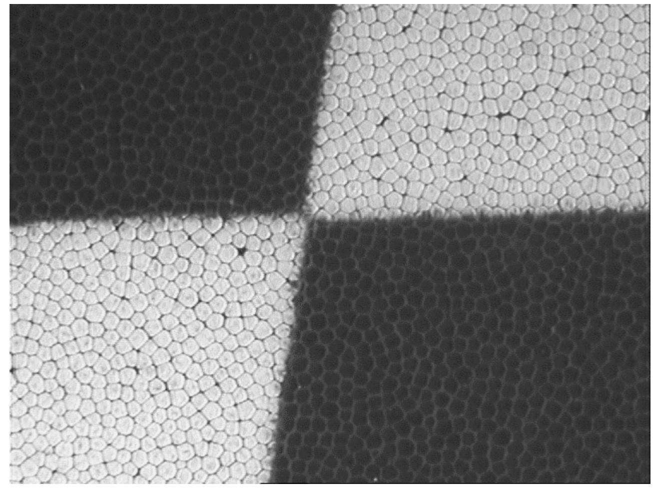

*Figure 5. Resolution of encapsulated electrophoretic inks compared to capsule size.*

## Conclusion

The proposition is that a fertile path to electronic paper and electronic books is to develop electronic pixels first and then to “assemble” them into electronic pages and then into electronic books. This proposition is confirmed by the invention of encapsulated electrophoretic inks. General ideas are suggested for other possible solutions, and these may arise naturally out of print technologies ubiquitous at NIP17.