The Present and Future of Gyricon Electronic Paper Displays

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Abstract

The Gyricon technology, which was invented by Nick Sheridon at the Xerox Palo Alto Research Center, is a reflective, bistable, wide-angle viewable display technology which is manufacturable in web format on flexible substrates. It operates by embedding tiny bichromal spheres in a sheet of plastic; each hemisphere of the sphere is colored a different color and has an opposite charge. By embedding each sphere in its own cavity filled with silicone oil, the ball is free to rotate under the presence of an electric field. Depending upon the application, this field can be introduced by a circuit board laminated to the paper, from an active matrix array, or from a printer which deposits charge on the surface of the material. It enables potential applications which range from indoor and outdoor signs, to PDA displays, to fold out displays, to rewriteable, downloadable books and newspapers. This paper will explain operations of the technology, described technical performance, and show applications including a first commercial embodiment in the field of wireless, battery operated signs for the retail market.

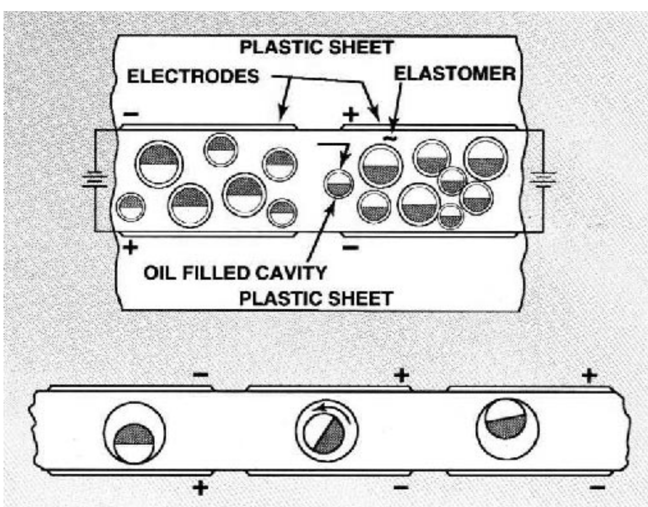

Figure 1. Basic Gyricon Operation

Introduction

Basic Technology Description

Figure 1 shows a cross section of the basic Gyricon display structure. It consists of a then layer of elastomeric material, in which are embedded bichromal spheres.

Each one of these spheres is located inside it's own cavity which is filled with silicon oil, allowing it to mechanically rotate. The bichromal spheres are built with one half one color (i.e. black), and one half white (i.e. white), with each half having a different permanent charge. In a stable situation, the balls gravitate to one side of the cavity and become attached to the side of the cavity. When an electric field is applied across the sheet of elastomer, however, it causes the ball to become unstuck from the cavity side and rotate to align with the field. After the ball has rotated, it settles again against the cavity wall and again becomes attached until the reverse electric field is applied. If an image wise voltage pattern is applied to the surface of the sheet, it thus induces an image related ball rotation, and the image is viewed by reflected light off the balls. The balls can be of different sizes, but are normally made between 30 and 90 microns, so that each piece of the image is made up of many balls, much like toner particles in a piece of printed paper.

Figure 2a shows one of the key steps in manufacturing technique for generating such paper. Molten polyethylene is allowed to fall onto the surface of a disk which is rotating at approximately 4100 rpm. The disk is heated to maintain the molten state of the polyethylene, so that the molten material flow to the edge of the disk where it spins off into space. After leaving the disk, surface tension pulls the molten material into spherical elements. These spherical balls harden in flight so that they are in a solid phase before reaching the walls of the chamber, where they are collected. By using black material on one side of the two-sided disk, and white on the other, the flows of the two materials meet at the disk edge and merge to form bichromal sphere. Through careful selection of pigments and additives which are put into the polyethylene material, the opposing sides of the balls are caused to have different permanent charge. The process runs continuously to generate bichromal spheres.

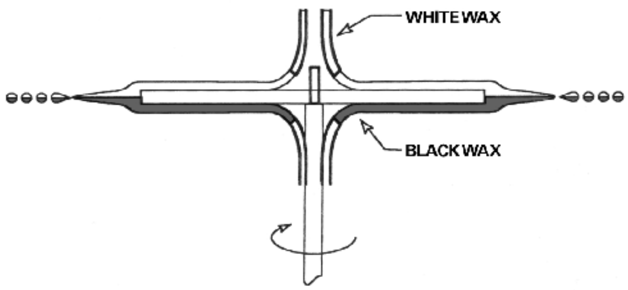

Figure 2a. Bichromal Ball Production

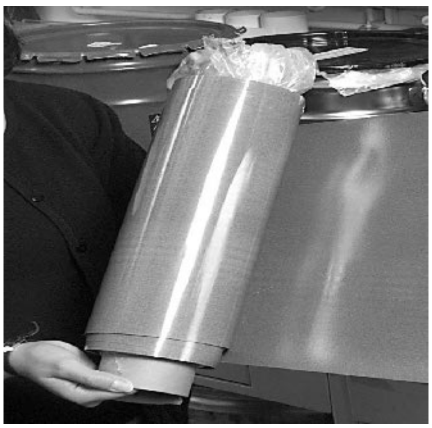

Figure 2b. Completed Roll of Sheet Material

The spheres generated are mixed with uncured elastomer and fed into a web fed sheet coater. The coated materials between 250 and 500 microns in thickness, is cured after coating and collected in the cured state onto a take-up roll. This produces a sheet of material with embedded balls. A roll of material produced this way is shown in Figure 2b.

Table I. Demonstrated Gyricon Performance

Metric	Demonstrated Performance
Whiteness	24%
Contrast	12:1
Ball Size	60 microns
Bi-stability	> 6 months
Voltage	+/- 50 V
UV	3 years for ASTM G 147
Operating Temperature	70C over 1000 hours
Handling	Robust to touch
Colors	B/W, R/W, G/W, B/Y, R/Y

In order to release the balls for rotating, the material is soaked in silicon oil, which causes the elastomer to expand (from 10-35% depending on the choice of material), generating a cavity around each bichromal sphere which fills with oil. To maintain the swelled material, the resulting swollen sheet is laminated between two other pieces of material to generate a finished piece of Gyricon media.

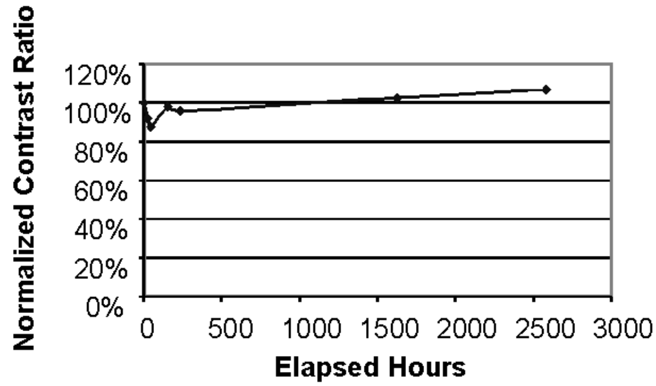

Figure 3. Gyricon Lifetime Data at 40C

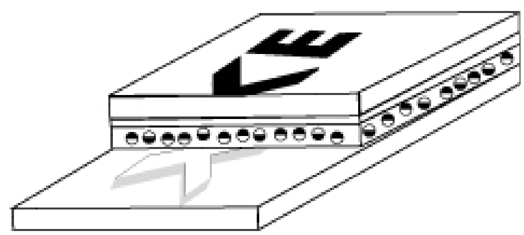

Figure 4a. Fixed Electrode

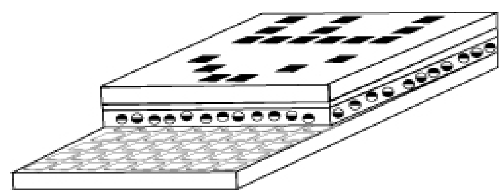

Figure 4b. X-Y Active Matrix Array

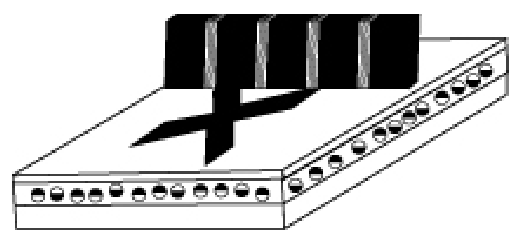

Figure 4c. Scanned Electrode Array

Table I shows a list of the basic material performance parameters which have been demonstrated with this material as a display medium. It's key features that make it interesting are the use of reflected light and bistability (which enable very low power battery enabled applications), it's wide angle viewability (like paper), it's flexibility (which enables interesting choices for display architecture), its unbreakability (it uses no brittle materials like glass), and its manufacturability in large sheets which leads to very low cost large displays. Figure 3 shows some sample lifetime data, which indicate the stability of the Gyricon display under the test of time and influence of UV irradiation.

Electronic Addressing

In order to use this material as a display, an image-wise voltage must now be imposed on the material to cause the balls to rotate. This can be done in several different ways. One way, as shown in Figure 4a, is to laminate the material to a circuit board which includes an image wise electrode pattern. In its simplest form this pattern consists of the overlapping elements from a set of multiple images, which are overlapped and segmented. When each segment is addressed, anyone of a number of multiple images can be generated. These images may be selections of graphic choices, or may be the overlapping members of a set of alphanumerics. Figure 5 shows pictures of a graphic sign generated in this way.

Figure 4b can expand this technique to use full active matrix of drives. In this case every pixel is actively driven and a fill pixilated image can be generated. Figure 5b. shows such an image. It should be noted that these images are done using standard printed circuit boards as the drive elements. Since the Gyricon materials is relatively thick, good image quality is produced even with a finite gap between the drive and material, or a certain amount of 3D topography on the drive circuit, making it easy to achieve a successful lamination.

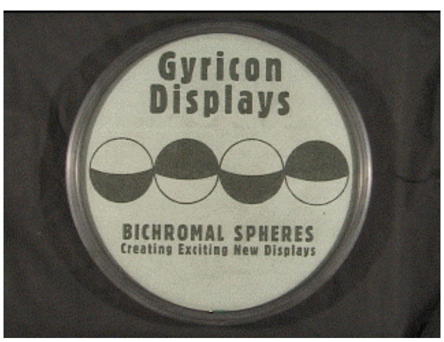

Figure 5a. Multi Fixed Image Display

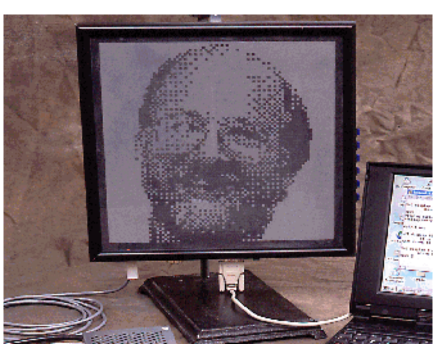

Figure 5b. Active Matrix Display

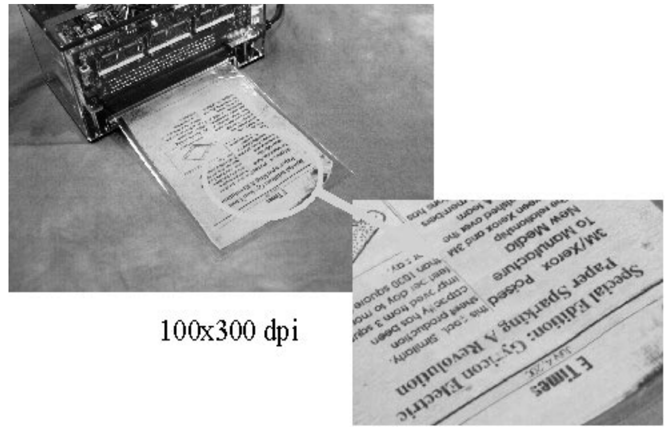

Figure 6a. Erasable paper printer

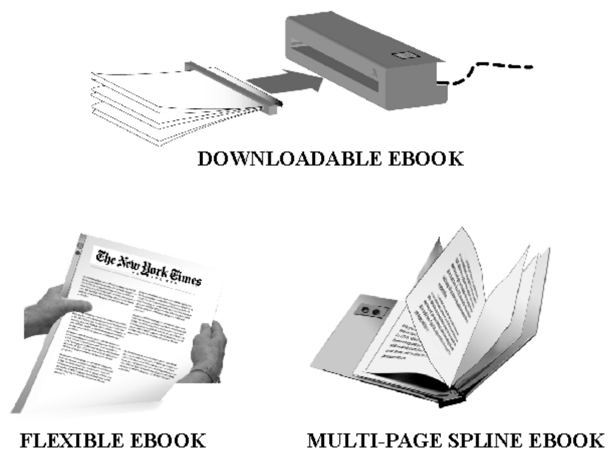

Figure 6b. Gyricon E-Book Configuration Options

Figure 4c shows a third way of using this material to generate a reprintable display. A circuit board is generated which has a linear array of electrodes located on one side, at a resolution matching the desirable resolution of a reusable printers. The architecture of the board is chosen to enable independent addressing of each one. The array is used as a printer so that the Gyricon material is swept across the circuit board in a printing motion, so that as the digital data on the board I changed, an image charge pattern is deposited on the surface of the material. This deposited charge causes the balls to rotate to align with the image. Since the display is bistable, the image remains 3 even after the charge has leaked off the surface.

As an example, Figure 6a shows a picture of an erasable paper printer using this technique, print the front page of a newspaper at a resolution of 100 dpi (in the circuit board axis) and 300 dpi in the cross scan direction. Such a system could be the first step in generating a reprintable newspaper, or future versions of polymer based active matrix electronics could be printed on the page to generate a downloadable electronic book, as shown in Figure 6b.

Current Applications

The applications of this technology in considering the Gyricon material as rewriteable paper, are quite broad, One can envision for the technology which range from retail signs, to hand held wand based printers, to expandable PDA displays, to reprintable and reimageable books. All of these applications are potential feasible and achieved with Gyricon material, but in each case involve development of associated electronic technologies to enable them. The retail signage market can take advantage of standard printed circuit board technology to enable generation of low cost highly viewable signs. The application to PDA displays requires development of the peripheral active matrix drive technology to enable fully pixilated displays. The use of foldout displays and reimageable books requires development of a very high density, very low cost, driver technology, likely to be polymer mtransigtos5rts which can be printed on the surface.

Figure 7. Gyricon Displays for Retail Solutions

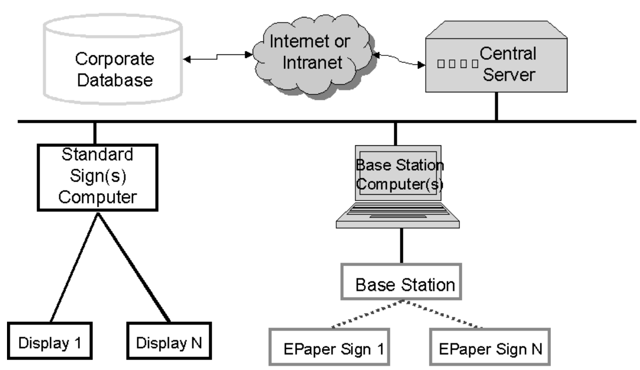

Figure 8. Wireless Retail Pricing Solution Using Gyricon Displays

As an example of the first application in the retail market, Figure 7 shows pictures of retail pricing and point of purchase signs built to enable a total pricing solution. These signs include Gyricon display material in both black and white and multicolor forms (i.e. green and white, red and white, red and yellow, etc.). These signs take advantage of the bistable characteristic of Gyricon display material to enable signs which are viewable in room light, low cost for very large signs, and battery operate performance with will enable produce versions to run for 2-3 years on three triple A batteries. They can be placed around retail stores and controlled through a wireless network , through an rf receiver and antennae in the base.

Figure 8 shows a diagram of the system solution which enables thousands of such signs to be placed around a retail store and controlled from the store computer (through wireless net) or from corporate headquarters (over the internet). This solution enable stores to gain timely control of their pricing, ensure that the signs are always connected to the point of sale database so that the customer is always charged the same price he sees on the signs, and enables timely implementation of price changes for weekend discounts, in response to competition, win response to changes in inventory, etc.

A network of such signs has already been installed in Macy's in Bridgewater, N.J. and is demonstrating its usefulness. The key to enabling such a solution is that the lower power requirements (due to bistability and use of room light for reading) enable these signs to be highly portable and require no installation of power or wire communication networks, giving the retailer the flexibility he requires to rearrange his store and conduct his business.

Conclusion

We have shown a new type of display material based on a broad distribution of rotating spherical particles, and have demonstrated its utility for application to make large retail signs. Future applications include electronic printing on erasable material, as well as electronic replacement for printed materials throughout direct application of transistor technology.

Biography

Dr. Sprague is the Vice President and CTO of Gyricon Media Inc., a spinout of the Xerox Palo Alto Research Center. Previous to this, Dr. Sprague has been at Xerox PARC since 1976 working in a variety of technical and management positions including Manager of Document Hardware Laboratory and Associate Research Center Manager, where he has worked in the fields of electronic reusable paper, ink jet printing, flat panel display, document scanning, laser printing, ionography, and optical data storage. He has won numerous Xerox awards including the prestigious "President's Award" for his work in ink jet printing and holds over 60 patents. Before coming to work at PARC, Dr. Sprague worked at the Itek Corporation. Dr. Sprague has a B.S. and a Ph.D. in Optics from the University of Rochester. He is a fellow of the OSA and SPIE.