Overview of Flexible Plasma Display Technology

Carol A. Wedding, Oliver M. Strbik III, Edwin F. Peters, JeffW. Guy, Daniel K. Wedding
Imaging Systems Technology
PO Box 352380 Toledo, Ohio 43635 USA
cwedding@teamist.com

Abstract: *There has been increasing interest inflexible displays and electronics. Flexibility is desirable because it promises low cost manufacture and offers new and emerging applications. A number of competing flexible display technologies are being developed including Electrophoretic, Organic Light Emitting Diode (OLED), and flexible LCDs. Plasma displays have also entered the flexible display arena. Three independent and unique approaches to flexible plasma displays are underway at the University of Illinois, Fujitsu, and Imaging Systems Technology. This paper will compare and contrast the three approaches.*

Keywords: Flexible plasma, Plasma-sphere, plasma tube, microdischarge, hollow cathode

Introduction

Definition of Flexible Displays and Electronics: Traditionally the display and electronic industry use substrates formed of rigid materials. The display industry traditionally uses glass substrates. Electronic components are often formed on silicon. These substrates are rigid and produce rigid electronic systems. Flexible displays and electronics differ from their rigid counter parts in they are formed from non-rigid materials. They can bend, conform, or roll. This definition may also include display and electronics that are essentially flexed only during their manufacture. [1]

Research and development is being conducted all over the world to develop flexible substrates, barrier layers, conductors, semiconductors, optical coatings, optically transmissive materials, and optically reflective materials, and optically emissive materials.

Both organic and inorganic materials are under investigation. Non-rigid materials currently being investigated for use as flexible substrates include various polymers, metal foils, and ultra thin glass. Conductive and semi-conducting materials used for electrodes, transistors and other elements includes electrically conducting polymers (PEDOT), nano materials (carbon nanotubes), polymers doped with conductive metals, and amorphous oxides (amorphous silicon).

Electo-optical material includes small molecule and large molecule organic light emitting diode, encapsulated electrophoretic, polymer dispersed liquid crystal, and chiral liquid crystal.

Rational for Developing Flexible Displays: Industry is motivated to develop flexible display and electronics for two basic reasons. Flexible displays and electronics will lead to new and emerging applications. Flexible displays and electronics promise low cost production methods. New and emerging applications include small hand held applications such as cell phones, ipods, RFID tags, and smart cards. Slightly larger emerging applications include ebooks, electronic paper wearable electronics. And finally, large applications include dynamic signage, conformable immersive displays for games and entertainment, and simulation and training.

Flexible displays and electronics provide opportunity for low cost production. First, traditional semiconductor process are eliminated. Many of the fabrication techniques now being developed for flexible displays make use of simple printing processes at room temperatures instead of various photolithographic techniques. Materials can be applied as an additive process instead of a subtractive process thereby lowering waste. Second, as the production of flexible displays and electronics matures, batch process, which is now used in the display and electronic industry will move to a roll-to-roll process. This is a complete paradigm shift from traditional semi conductor industry to processes traditionally associated with printing industry and plastic production.

Design Challenges for Flexible Displays and Electronics: The most significant design for flexible displays and electronics is to match the performance of the existing rigid display and electronic technology currently on the market. Many organic materials used for flexible displays and electronics are sensitive to moisture and oxygen. Exposure to oxygen and moisture shortens the life of the material. Substrates formed from polymer materials are permeable to oxygen and moisture. Thus they provide little protection. Additionally these materials tend to operate at slow speeds and higher voltages. They are also sensitive to temperature extremes.

There are a number of companies and consortiums working to develop flexible displays and electronics. Dozens of industrial giants are pursuing flexible displays, including Lucent, DuPont, 3M, Dow Chemical, Infineon Technologies AG, Matsushita Electric, Toppan, Sony, and Philips. [2]. Products are being introduced into the market. Alien Technology is one company successfully producing and selling RFID tags on flexible rolls. Sony is using eInk technology to produce the first electronic book, the LIBRIé.

Approaches to Flexible Display Technology: There are a number of flexible display technologies now under development including organic light emitting diode (OLED), Electrophoretic (E-paper), and flexible LCD, and flexible plasma. OLED differs from LED because OLED are not made from standard semiconductors materials. They are made from carbon-based molecules. E-paper is a reflective technology. Tiny microcapsules filled with electrically charged white particles suspended in colored oil. Voltage controls whether the white particles are at the top of the capsule (so the viewer sees white) or at the bottom of the capsule (so the viewer sees the color of the oil). Flexible LCDs are similar to the rigid LCDs except that they are formed using new materials that allow for low temperature processing. The challenge is to improve flexible transistors for the back plane and develop technology to keep the flexible substrates evenly spaced while the display is bent or curled. Flexible plasma displays are being developed using techniques to encapsulate the plasma gas when using a flexible substrate.

Flexible Plasma Displays

Flexible Plasma Display Design Challenges: As with all flexible display technology, the primary challenge is to mimic the performance of the conventional rigid display. Figure 1 shows a conventional plasma display. In a conventional plasma display, two substrates (4a and 4b) form a chamber for an ionizable gas (6) at selected pressures of 0.3-0.6 atmospheres. The two substrates are flat, rigid, and hermetically sealed. The crossover of each top row address electrode (1) with a bottom column electrode (2) defines a gas discharge display pixel (7). Dielectric layers (3a and 3b) are applied uniformly to each substrate to insulate the electrodes. Layers of other materials such as MgO and phosphor may also be applied. Barrier ribs (5) may be formed by a number of processes. Although Figure 1 illustrates a two-electrode conventional PDP structure, the display may also be a three-electrode surface discharge structure with one bottom column electrode and a pair of top row electrodes. The keys to mimicking the features of a conventional rigid plasma display are encapsulating the gas at the requisite pressure; maintaining purity of the gas and at the cell site; and maintaining cell geometry and spacing.

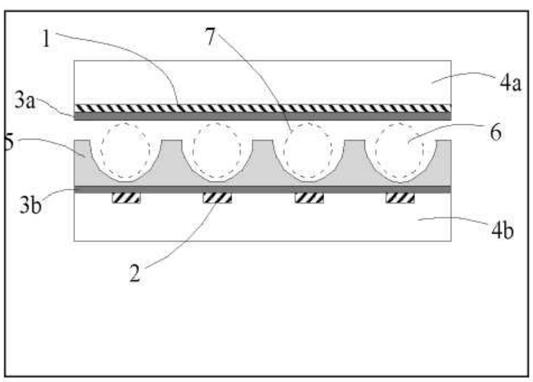

Figure 1. Conventional Plasma Display

Approaches to Flexible Plasma Displays: To address the challenges of making a flexible display, three unique approaches have been successfully demonstrated. The University of Illinois, Urbana Illinois, USA has demonstrated a flexible plasma display with hollow wells (called a microdischarge display). Fujitsu Limited of Kawasaki, Japan has demonstrated a plasma tube display. Imaging Systems Technology Toledo, Ohio, USA has demonstrated a flexible plasma display using hollow spheres (called Plasma-sphere^{T}M display). Each of these approaches is based on prior art plasma display architectures developed many years earlier. However, these past attempts were not technically or economically feasible at the time. Over the years, various improvements in technology have made these three approaches feasible and attractive.

Micro Discharge Displays

Structure: The University of Illinois microdischarge device is an open cell structure. It is flexible because the dimensions of the pixel are so small that they may be fabricated on polymer-metal foils. [3] The pixel dimensions of the microdischarge are on the order of 1-25 microns. Because of the inverse relationship of gas pressure and distance between electrodes, (as illustrated in the Paschen curve) the tiny pixels can efficiently operate at atmospheric pressure. Drive voltage of approximately 100 volts has been reported. Additionally the hollow cathode construction provides additional efficiency. Either direct current (DC) or alternating current (AC) voltages may be applied to the electrodes. Figure 2 shows the microdischarge structure. The microdischarge device (100) includes a first electrode (106), a second electrode (104) and a dielectric layer (108) between the first electrode (106) and second electrode (104). A cavity (102) is formed in the insulator (108). To ignite the plasma, a potential difference across the insulator (108) is established by a voltage source (110) connected between the first electrode (106) and the second electrode (104). The potential difference creates a discharge in the cavity (102) when a gas is present. The resulting light has emission spectra that are characteristic of the gas selected.

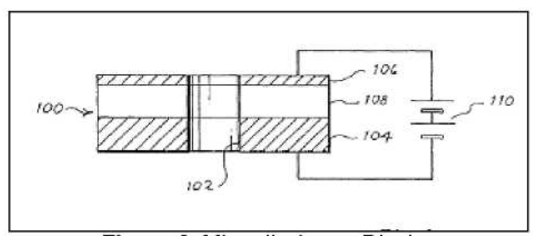

Figure 2. Microdischarge Display

Manufacturing Process: The concepts of hollow cathode have been known for over 30 years. Sperry Rand Corporation produced displays with a hollow cathode. [4] The University of Illinois's display is unique in that semiconductor and MEMs process are used to produce the features of the pixel. Plasma etching, ultrasonic machining, and UV laser ablation may be used to form the discharge volume of the cavity. The semiconductor and MEMs process allow for the machining of very tiny hollow cathodes. Flexible microdischarge arrays are fabricated in metal-polymer-metal foil. The foil thickness is approximately 30 microns thick. The hollow cavity can be as small as few microns. [5, 6]

Rational for Developing a Microdischarge Display: The microdischarge array has application in display and non display applications. They may be used as large or small displays. But this requires proper sealing and barrier protection to keep the gas pure. Other applications include: custom lighting, photodynamic therapy, gas chromatography, gas remediation, and micro lasers. [3]

Photodynamic therapy is a medical treatment that involves destroying harmful cells in the human bloodstream with IR light. Target cells are "tagged" with an IR light-absorbing molecule. IR light, pass through the skin and is absorbed by the tagged cell. This causes the tagged cell to be destroyed. The microdischarge array allows for a low cost disposable method of applying an IR patch to the skin. Another use of microdischarge devices is gas chromatography - the determination of the composition of a gas. The microdischarge array may be used for the remediation of toxic gases. Hazardous gas is flowed through the microdischarge cavities with a voltage potential applied to break down the gas into benign products. The microdischarge device is ideally suited for application as a microlaser. These microlasers can generate ultraviolet, visible, or infrared radiation that may be used in materials processing or atmospheric diagnostic applications.

Fujitsu Plasma Tube Displays

Structure: The Fujitsu tube display differs from the open cell structure of a conventional plasma display because the gas is confined to elongated tubes. [7, 8] The structure of the Fujitsu plasma tube display is shown in Figure 3.

The elongated display tube (1) encapsulates the gas. The tube is borosilicate glass with an elliptical shape in cross section. Phosphor (4) is disposed inside the tube. MgO is also deposited within the tube. The display electrodes (2), which extend in the direction of the major axis of the elliptical shape, are positioned on flexible top substrate (21). The top substrate and display electrodes are attached to the tubes with adhesive (5). The data electrodes (3) are positioned on bottom substrate (22). The data electrodes run parallel to the tubes. Electric discharge occurs when an alternating electric field is applied between two display electrodes forming a pair.

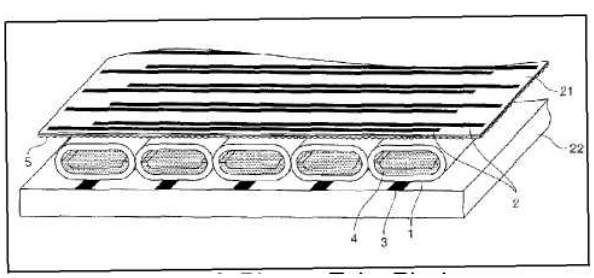

Figure 3. Plasma Tube Display

Manufacturing Process: The concept of encapsulating the plasma gas in elongated tubes is not new. This concept was practiced in the early '70s by several companies, including Owens-Illinois. [9] O-I called the tube display structure "capillary discharge". O-I disclosed forming the elongated tubes by drawing hollow core glass fiber. The capillary discharge structure was never fully commercialized. Presumably this structure was difficult to manufacture using the techniques known and practiced in the early '70s. Thirty years later, Fujitsu Limited revisited the plasma-tube concept. The now mature fiber optic cable industry provides a source of low-cost highly uniform hollow-core glass fiber. Fujitsu also discloses some interesting techniques for coating the inside of the tubes and maintaining purity. [10, 11] The long thin tube presents a technical challenge for coating the inside with phosphor, MgO, or other beneficial materials. Additionally the long thin tube is difficult to fully evacuate of contaminants that may affect performance. Fujitsu coats the inside of the tube using a select material mixed with a solvent. The viscosity of the solvent is controlled by heat. The tube is angled and heat is applied to the exterior of the tube to melt the solvent and move it down the tube. The tube is heated to burn off organics, evacuated, and backfilled with gas. Additionally each tube is equipped with a getter compartment, which is not part of the visible active area of the screen. The getter compartment provides a place for contaminants to collect during display operation.

Rational for Developing a Plasma Tube Display: Fujitsu recognizes that there is a practical limit as to how large a plasma display can be made. [12] The larger the display becomes, the more difficult it is to produce a display from a single substrate or form. A large display is more easily assembled from tiles or small component parts like an LED display. Additionally, the Plasma-tube display can easily accommodate many different sizes and aspect ratios by cutting tubes to length and by selecting the number of tubes. Finally, the plasma tube display may be bent, conformed, or rolled.

IST Plasma-sphere Displays

Structure: The Plasma-sphere PDP shown in Figure 4 is comprised of multiple microspheres (3c) that encapsulate the ionizable gas (6). Each microsphere comprises a dielectric shell material with highly uniform diameter and thickness formed with IST's proprietary processes. Because the pressurized gas is contained in a microsphere, the Plasma-sphere substrate (4c) is not required to be rigid and impermeable. It can be made flexible and a top substrate is not required. Additionally, because each Plasma-sphere defines the crucial parameters of gap and dielectric thickness, critical tolerances are not required for the substrate. Essentially, the critical parameters in a conventional PDP have been moved from the substrate to the less complex Plasma-spheres, resulting in greater flexibility. Plasma-spheres can be configured with gas pressures above one atmosphere, and with two, three, or more electrode configurations.

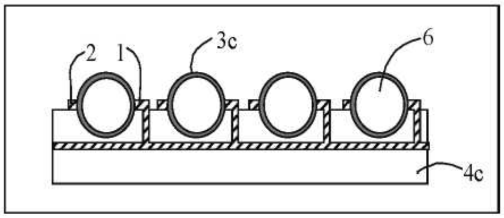

Figure 4. Plasma-Sphere Display

Manufacturing Process: Using hollow-spheres at each pixel site to encapsulate the gas is known in the prior art. In 1974 Sanders disclosed gaseous discharge display device in which separate and unconnected gas filled beads were embedded between conductors to form pixels. [13] Others have also attempted to produce gas filled spheres for displays. Although the production of hollow spheres is low cost and well known in many industries, standard hollow-sphere production methods are inadequate for the production of Plasma-spheres. IST has developed a proprietary manufacturing process which produces optically transmissive, uniform hollow spheres that are free of contaminants. With these processes, IST controls shell thickness to within a few microns and gas pressure to within one Torr. Microspheres are produced in a chamber that is devoid of human contact or intervention and thus clean room environment is not required. The microsphere yields are over 98%. The Plasma-sphere pixel elements are formed separately from the substrate. Because of the separation of processes, the substrate is not exposed to heat or reactive chemicals. The manufacture of the flexible substrate includes a roll-to-roll process instead of a batch process. Flexible substrates can be produced on wide web equipment using techniques and equipment such as those used in the paper industry. Mass assembly and inspection of Plasma-spheres on the substrate may be accomplished as part of a roll-to-roll manufacturing process. The technologies of these proprietary production techniques are simple when compared to those of conventional displays that require handling and cutting of large pieces of glass to form a pair of rigid substrates. Additionally, the Plasma-sphere arrays eliminate many of the other process steps used in the manufacture of traditional rigid two substrate plasma displays such as sand blasting, vacuum deposition, and gas processing. The elimination of these conventional process steps coupled with a roll-to-roll process offers automation and the advantages of high yield and low cost.

Rational for Developing a Plasma-sphere Display: The Plasma-sphere is an enclosed pixel structure. Each Plasma-sphere is physically and electrically isolated from its neighbors. The ionizable gas that is encapsulated inside the Plasma-sphere is isolated from the gas inside the neighbor pixels. This enclosed pixel structure is an important factor in the operating window of the Plasma-sphere array.

The Plasma-sphere is immune to charge spreading. Charge spreading occurs in open cell plasma displays when a pixel is overly energized and the ionized plasma from that pixel causes neighbor pixels to light. The enclosed pixel structure also leads to higher ON voltages. This leads to higher memory margins and the ability to use a higher voltage sustain pulse that increases the light output of the Plasma-sphere. The Plasma-sphere array also has increased brightness and efficacy. Like the plasma tube display the Plasma-sphere display allows for large area low cost and flexible displays. These displays may be used in stadiums, dynamic signage, simulation, and games and entertainment. The Plasma-sphere display has additional application in ultra bright outdoor signage.

Conclusion

There are strong research and development efforts in the area of flexible displays and electronics. Flexible displays and electronics are of interests to industry because of the potential for low cost manufacture and the opportunity to address new and emerging markets. Flexible plasma displays present a challenge because of the necessity to encapsulate the plasma gas. Traditionally, this was done with two rigid glass substrates. This challenge had been overcome using three very different display architectures. Each of the flexible plasma display architectures draw from ideas known and practiced in the past. Novel and modern manufacturing techniques now make these architectures feasible and economical. Unlike some of the other flexible displays technologies discussed, the flexible plasma displays do not require the development of new and exotic materials. The traditional glasses, phosphors, and gases have been successfully used to produce working flexible plasma display models. Flexible plasma displays will find application in large area signage, large area flexible applications, and some emergent non-display applications.

Acknowledgments

IST is pleased to acknowledge that the Plasma-sphere research and development was sponsored in part by the National Science Foundation (NSF), National Institute of Standards (NIST), and the State of Ohio.

References

1. *Flexible Flat Panel Displays*, Gregory Crawford, ISBN: 0-470-87048-6, July 2005 Wiley Series in Display Technology
2. *Philips Unveils Ultra-Thin, Flexible Display*, Charles Choi, FORBES.com Copyright 2004 by United Press International
3. United States Patent No. 6695664: Microdischarge devices and arrays
4. United States Patent No. 3662214: Gas Discharge Display Apparatus Utilizing Hollow Cathode Light Sources
5. United States Patent No. 6139384: Microdischarge lamp formation process

6. *Flexible microdischarge arrays: Metal polymer devices* S.-J. Park, C. J. Wagner, C. M. Herring, and J. G. Eden a) Applied Physics Letters Volume 77, Number 2 10 July 2000
7. United States Patent No. 6914382: Display Device Having Array Of Elongated Discharge Tubes
8. United States Patent No. 6677704: AC-Type Gas Discharge Display With Elliptical Discharge Tube
9. United States Patent No. 3602754: Capillary Tube Gas Discharge Display Panels And Devices
10. United States Patent No. 7049748: Display Device Employing Gas Discharge Tubes Arranged In Parallel Between Front And Rear Substrates To Comprise A Display Screen, Each Tube Having A Light Emitting Section As Part Of The Display Screen And A Cleaning Section Connected To The Light Emitting Section But Displaced From The Display Screen
11. United States Patent No. 7083681: Method For Forming Coating Film On Internal Surface of Elongated Tube and Unit for Forming the Same
12. United States Patent No. 6577060: Display Device
13. United States Patent No. 3848248: Gaseous Discharge Device Spheres