5.1: *Invited Paper:* Energy Efficient Flexible Reflex™ Displays

Albert M. Green, Erica Montbach, Nick Miller, Donald Davis, Asad Khan, Tod Schneider, and J. William Doane
Kent Displays, Inc., 343 Portage Blvd., Kent, Ohio 44240, USA

Abstract: *We report on inherently low power, flexible, reflective, bistable cholesteric liquid crystal displays, with the Reflex™ brand. Several novel application spaces are discussed and their low power impact, including; Reflex™ electronic skins and pressure sensitive writing tablets. Web processing of Reflex™ displays will also be discussed and how this represents a paradigm shift in display manufacturing.*

Keywords: Bistable, cholesteric, flexible, phase separation, lamination, full color, roll to roll manufacturing

Introduction

Recently, there has been a significant amount of interest in bistable, reflective devices for several reasons including simple device structure, sunlight readability, and long battery life. Due to the absense of a backlight reflective displays are inherently low energy consumming devices. The cholesteric liquid crystal display (ChLCD) technology by Kent Displays Inc., [1,2] recently branded as Reflex™, not only offers the typical advantages of a reflective display but also enables several low power applications that were previously impossible with other display technologies.

Kent Displays has highlighted the "no power" atribute of their Reflex™ displays since they first entered the market more than 10 years ago, Figure 1. Just recently, low energy consumption has become a greater focus of not only the display industry but the world. The "no-power" feature of Reflex™ displays offers increased energy efficiency by only requiring power when it is being updated, resulting in increased energy efficiency.

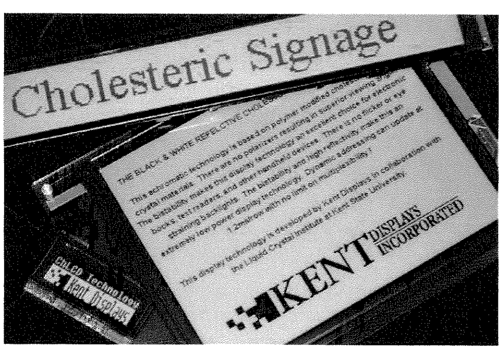

Figure 1. Typical Reflex™ displays have required power only when driving since first offered.

Reflex™ displays are a perfect fit for roll to roll manufacucturing due to the simple, yet elegent, structure of two flexible substrates, a liquid crystal / polymer dispersion and an absorbing backcoat. Roll to roll manufacucturing has the promise of low cost and high volumes due to a reduction of handling and the continuous web transport of displays at a rapid rate.

Roll to Roll Processing

Kent Displays is installing a roll to roll production line for manufacturing liquid crystal displays. This line will unwind a roll of plastic film coated with a transparent conductor, such as indium tin oxide or conducting polymer, and perform the necessary process steps to effectively convert the roll of film into a finished display. The equipment will be housed in a climate controlled ISO Class 7 cleanroom. The production line was built in the USA to Kent Display's specifications and has gone through several levels of testing to validate its design and operation. Manufacturing on the production line will start in Q4 2008.

The production line does not produce waste water or chemicals requiring treatment but rather utilizes a closed loop system for process cooling. Environmentally friendly UV curable materials and processes are used throughout the manufacturing process. UV curing lowers air pollution, as well as the energy required to treat exhausts by dramatically reducing solvent vapor production compared to more conventional thermal curing processes.

Applications

Several applications have been enabled by the Reflex™ display technology that were previously not possible with other technologies. Some examples of these applications are; pressure sensitive writing tablet displays, displays with solar cells, Reflex™ electronic skins, USB flash drive displays, and smart card displays. Each application gives the consumer a low power device.

Figure 2. Flexible Reflex™ writing tablet display will be available in the market in December '09.

Utilizing the "zero power" feature of the Reflex™ technology, writing tablet displays only consume energy when the display is erased, Figures 2 and 3. Since the writing tablet display is switched to the bright state by the pressure applied by the operator, the display need only switch to the lower voltage focal conic state to erase.[3] This means that the display electronics need to generate one voltage to drive the display and erase any written image to the dark state (focal conic state). As such, the drive electronics can be a simple, single level DC to DC conversion. The erase cycle for the writing tablet display is shown in Figure 4. This low power drive system enables the writing tablet displays to be powered by small watch type lithium-ion batteries which are desirable for consumer product designs due to size, weight, and price. Although these small coin cell batteries, such as the CR2016 and CR2025, typically are rated at small microamp current loads, they prove suitable for burst operation as required by the writing tablet displays.

The writing tablet energy consumption is found using equation (1) and the current and time in Figure 4 along with the battery electrical potential of 3 volts.

$$E = U \int I(t) \cdot dt \qquad (1)$$

Where E is the amount of electrical energy due to a current, U is the electrical potential difference in volts, I is the current, and t is the time for which the current flows. The energy consumed when erasing a 237cm^2 writing tablet (Figure 3) is approximately 8.4mJ. The capacity of a typical CR2016 coin cell is 90mAh at 3V, or 972 Joules. Thus, a CR2016 battery could in theory provide 116,000 erases for a 237cm^2 writing tablet. However, the CR2016 rating is based upon a much different load model, 100μA continuous discharge, where the writing tablet requires higher current for short bursts of time. Actual experimentation shows that the system is capable of an impressive 49,000 erasures before battery failure. At ten erases per day, the writing tablet will function for over 13 years.

Figure 3. Flexible Reflex™ writing tablet display only requires power when the written notes are no longer needed and are erased.

Recent advancements in commercial micro-controller products and peripherals have enabled products that are much closer to zero power in stand-by mode. Although "zero power" displays (bi-stable) have been in the market place for several years, only recently have supporting electronics been able to push quiescent, stand-by currents closer to zero. For example, the sleep current of the writing tablet products can be as low as 0.1μA. This is actually within the same order of magnitude of a typical lithium-ion battery self-discharge rate of 1% per year. A first order approximation of standby time projects a 48-year life for the product. The writing tablet displays shown in Figures 2 and 3 will be sold with one coin cell battery and the battery compartment will be sealed, meaning one battery will last the entire product life!

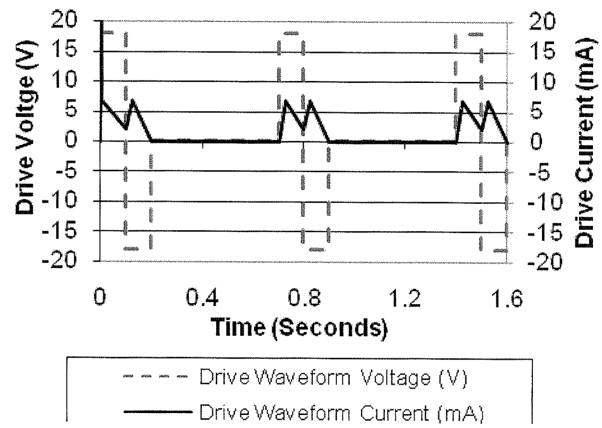

Figure 4. Drive waveform voltage and current for a 237cm^2 Reflex™ writing tablet display product. Illustrating the voltage and current consumed from a 3 volt source.

Figure 5. Reflex™ display including a solar cell behind the display. The solar cell not only powers the display but also generates enough additional energy to charge other devices.

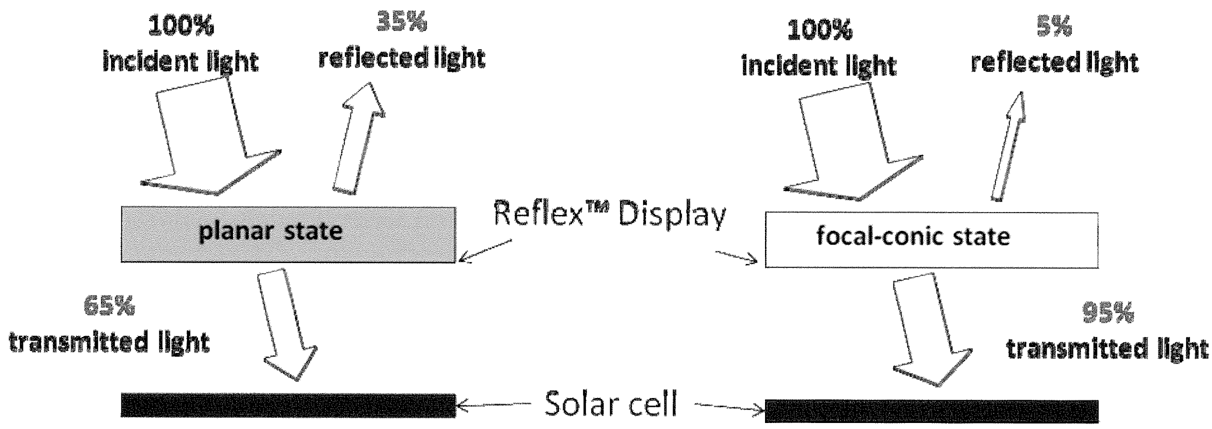

Figure 6. Illustration showing that in both the reflective (planar state) and the dark (focal conic state) states the solar cell behind the Reflex™ display receives enough light to continue storing energy.

A distinguishing feature of the Reflex™ display technology is its compatibility with photovoltaic cells. When integrated with a solar cell, Reflex™ displays have the ability to harvest energy. This pushes the display from a zero energy-consuming category into a positive energy device. Systems have been demonstrated operating entirely upon energy harvested from the integrated solar cell / display device. An example of this is shown in Figure 5.

The combination of a display and solar cell is a natural integration since only a selective portion of incident light is reflected by the Reflex™ display device.[4] A solar cell integrated behind a Reflex™ display absorbs any light transmitted through the display creating contrast for the dark state (see Figure 6), which is typically provided by paint on the back of the display. A Reflex™ display and solar cell can share highly valuable real estate in the device by allowing the solar cell to be placed behind the display, making it invisible to the user. This is especially valuable for portable systems where size and battery consumption are critical design considerations.

Reflex™ electronic skins are another example of a low power application enabled by the Reflex™ display technology. These electronic skins can cover an electronic device allowing the consumer to choose the color of that device for ultimate personalization, Figure 7.

The Reflex™ electronic skin consists of three display layers stacked up, red, green, and blue, as shown in Figure 8.[5,6] The conductor used on each substrate is unpatterned conducting polymer and is coated on both sides of the two interior substrates. Power is only required when the display is being switched and the Reflex™ electronic skins can be driven using the existing batteries in a device with little change in the overall device power consumption.

Figure 7. Flexible Reflex™ electronic skin. Consumers can have ultra personalized color without draining precious battery life.

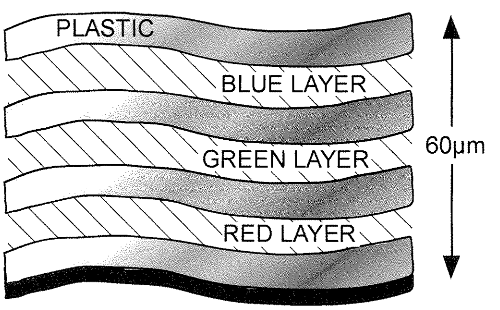

Figure 8. Flexible Reflex™ electronic skin cross section.

Other applications enabled by the Reflex™ display technology are a graphical display for a USB flash drive and a smart card display. A flash drive only recieves power when connected to a computer; therefore, the display must be reflective and bistable, Figure 9. There are several embodiments for smart cards, however, a reflective, bistable display is required for the versatility of having the battery in a fixture separate from the display, Figure 10. In addition, smart cards require flexible displays. Reflex™ displays can be multiplexed allowing both of these applications to have graphics displays without requiring thin film transistors on plastic.

Figure 9. Reflex™ displays enabled customers to utilize a graphics display in a USB flash drive.

Figure 10. Flexible Reflex™ smart card display allows versatile card design. Since Reflex™ displays only require power upon changing the image the battery can be located in the card or on an external card fixture, only powering the display when swiped.

Conclusions

Reflex™ displays offer unique applications that are enabled by the low power consumption, bistability, and reflective color inherent to the technology. In addition, the ability to manufacture displays in a roll to roll process is a paradigm shift for the display world. This type of continuous web processing makes these displays easily manufacturable and represent a significant departure from the standard batch type manufacturing. The potential high volume manufacturing due to web processing lowers the market entry barrier and takes advantage of the elegant, yet simple display architecture. The low cost display materials in combination with the roll to roll processing make numerous display designs possible and feasible.

New application spaces have been identified and opened up because of the Reflex™ display technology. These applications can offer very long display life using just one coin cell battery, energy harvesting devices using photovoltaics, and ultra personalization without a significant penalty to the overall power consumption of the consumer device.

Acknowledgements

We would like to thank the State of Ohio and the Research and Commercialization Project for their grant support. Also, we would like to thank the entire team at Kent Displays for developing and building great displays.

References

1. D.-K. Yang, J. W. Doane, *SID Intl. Symp. Digest Tech. Papers*, **23** 759 (1992).
2. D.-K. Yang, J. L. West, L.-C. Chien, J. W. Doane, *J. Appl. Phys.*, **76** 20 (July 1994).
3. T. Schneider, G. Magyar, S. Barua, T. Ernst, N. Miller, S. Franklin, E. Montbach, D. Davis, A. Khan, J. W. Doane, *SID Intl. Symp. Digest Tech. Papers*, **39** 1840 (2008).
4. N. M Miller, X. Y. Huang, R. Armbruster, F. Nicholson, et al. 2003: Ultra Low Power Black and White Cholesteric Display with COG and Solar Array, *SID Symp. Digest,* 34, 1446-1449.
5. J. W. Doane, D. Davis, , A. Khan, E. Montbach, T. Schneider, I. Shiyanovskaya, *Proc. Intl. Disp. Research Conf.,* **26** 9 (2006).
6. D. Marhefka, N. Venkataraman, A. Khan, F. Nicholson, T. Ernst, J. W. Doane, *SID Intl. Symp. Digest Tech. Papers*, **39** 810 (2008).