



Transparent Electroluminescent (EL) Displays

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Abstract

This report covers the design and applications of transparent electroluminescent (EL) displays. The display emits amber color light (typical 110 cd/m²) in both front and back directions. The panel has transmission (85%) close to that of a pane of glass. It can be used as an overlay on other information displays, such as automotive gauges and posters. It can also be used with negative optics as projected from far away. The panel can be made as a curved surface, or any other predefined shape, including holes. There are many applications that this exciting new technology can fit.

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Introduction to Transparent Electroluminescent Technology

Non-transparent inorganic thin film electroluminescent (TFEL) technology was developed in the mid-1980's mainly by Planar Systems and Finlux, - which was later acquired by Planar. Sharp in Japan was also a primary developer of TFEL. In the late 90's Denso Corporation started to produce transparent EL displays for automotive applications.

Conventional non-transparent TFEL technology incorporates thin layers of phosphors that are emitting light under strong electrical fields. The typical phosphor used is ZnS:Mn. The voltages are supplied between cross electrodes, in which the front electrode is transparent. The common material used for the transparent electrode is Indium Tin Oxide (ITO). The rear electrode of conventional EL displays is made of metal. An advantage of having metal behind the illuminating layer is that it can capture a lot of the light that the phosphors are emitting to the back side. This concept is very good for indoor applications, and can increase the light output almost by a factor of x2. For outdoor applications the rear electrodes are causing a major problem, since they are like a mirror and reflect a lot of the ambient light. This is reducing the contrast ratio of the display. A new type of proprietary light absorbing electrodes was developed by Planar to solve this problem. This technology is called Integral Contrast Enhancement (ICE, or ICEBright™).



Figure 1 – Samples of transparent EL, ICEBright™ EL and Multi-color EL displays

At that time, TFEL technology was the dominant type of flat panel display, and is still used for many applications. Most people are familiar with the heart monitors in hospitals that have an amber color. Many of the first laptops incorporated TFEL panels as well. During the years, the LCD technology became more advanced and overcame some of its limitations. While EL had a significant cost advantage before, LCD has also become more cost competitive.

Today many applications that need robust displays, operating instantly in extreme environments of temperatures, vibrations, and wide viewing angles, are still using TFEL panels. TFEL, despite its limitation in color range, continues to be the technology of choice for many demanding display applications.



Figure 2 - Examples of transparent EL display. A mirror surfaced EL display is in the background

In this paper we will explore new TFEL developments, where the rear electrodes are replaced with transparent material to make the whole panel totally transparent. An example is shown in Figures 1 and 2. This development has many potential applications, which cannot be accomplished with non-emitting displays, such as LCDs.

Transparent Electroluminescent Display Design

Standard Thin Film EL display design

Thin Film Electroluminescent (TFEL) displays are based on depositing insulating layers and light emitting phosphor layer between transparent and metal electrodes as shown in Figure 3. Typically a thin film EL display is built on 1.1 mm thick soda lime glass substrate (size 195 mm x 265 mm) and encapsulated with 1.1 mm thick cover glass. The specific method developed and being manufactured by Planar Systems is the Atomic Layer Deposition (ALD). This method gives very uniform, well controlled and pin-hole free thin film layers, and extremely robust insulating films.

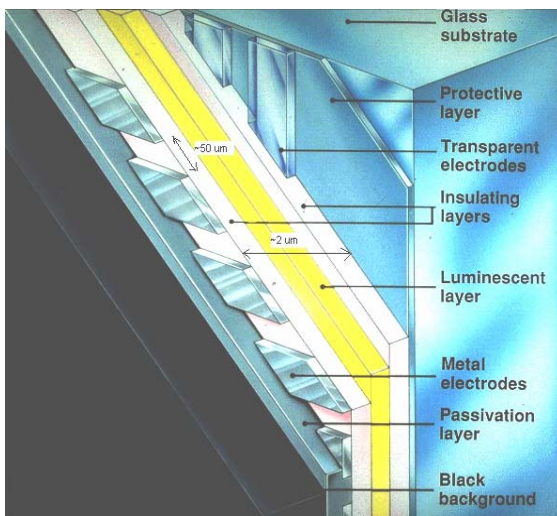


Figure 3 - Thin film electroluminescent (TFEL) display in matrix display configuration

Light is generated by exciting Mn atoms in ZnS phosphor with electrons moved by the applied AC voltage (Figure 4). The exciting voltage can be sinusoidal or pulse waveform. It is applied in a multiplexing method between the column electrode on one side, and the row electrode on the other side of the phosphor (Figure 5). Each time when the voltage surpasses the nominal threshold voltage of about 200 V, a short light pulse with less than 1 ms decay time constant is generated and thus brightness is roughly proportional to the driving frequency.

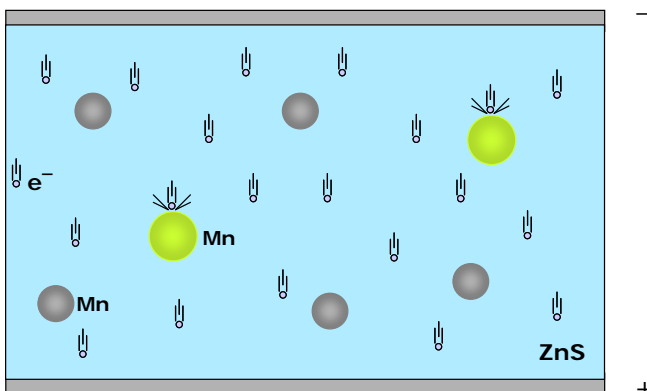


Figure 4 - Light emission by exciting Mn atoms with electrons in ZnS phosphor

In typical matrix display applications driving frequency can be up to 250 Hz. In seven-segments type of displays (direct driving without multiplexing) even higher frequencies are used. The high voltage pulses are generated by the driving electronics of a TFEL display. The display power interface is typically 5 and/or 12 Vdc for easy system design.

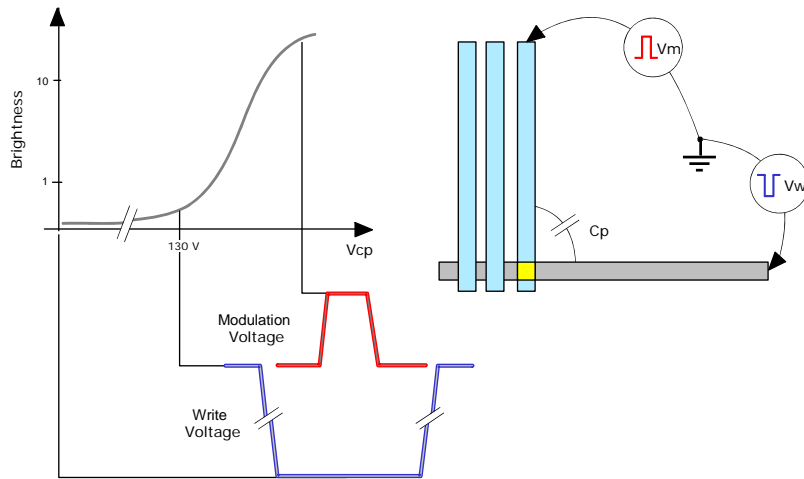


Figure 5 - Driving a matrix electroluminescent display with AC voltage

Standard EL display is using ZnS:Mn as the phosphor layer and the resulting light emission spectrum is yellow (Figure 6) with a peak at about 580nm. Some other colors could also be developed depending on the color requirements, by changing the phosphor type.

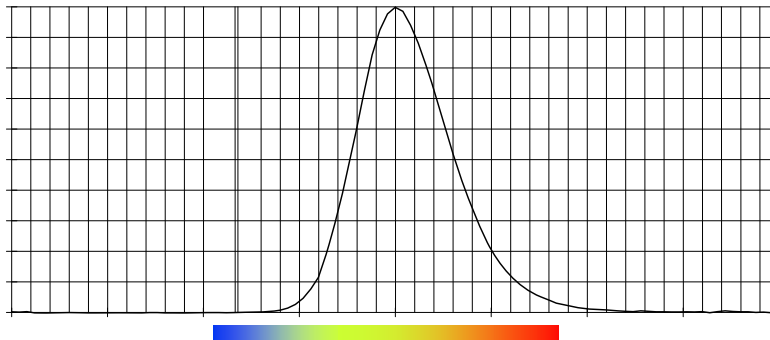


Figure 6 - EL phosphor (ZnS:Mn) light output spectrum

Due to the true solid state structure, various beneficial characteristics are achieved. Electroluminescent (EL) displays are extremely rugged with wide temperature range (-50 C...+85 C, limited by the driving electronics), long lifetime > 100,000 hrs, wide viewing angle (> 160 degrees), rapid display response within the full temperature range (< 1 ms) and good contrast.

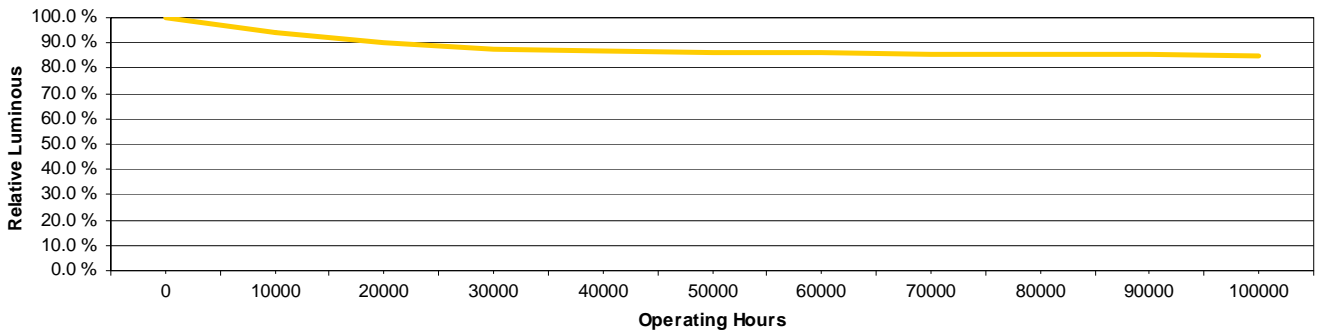


Figure 7 – Luminance stability of TFEL display (actual use)

Transparent EL display technology

Transparent electroluminescent displays are constructed using the standard EL display structure by replacing the metal rear electrode with a transparent electrode (e.g. ITO) and removing the rest of the non-transparent layers from the display structure. In order to maximize transmission, there is a need to match the layers index of refraction to the adjacent layers. The schematic cross section structure is shown in Figure 7.

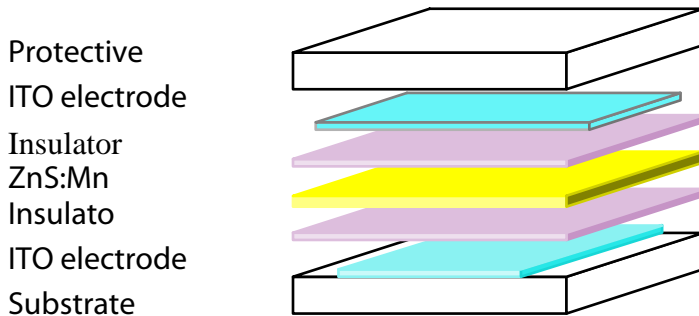


Figure 8 - Schematic cross section of transparent TFEL

The other important parameter in optimizing the layers of transparent EL is reducing the “halo effect,” which is caused by internal reflections when the layers index is not matched. This is also called light piping in optical systems. The light reflected is bouncing between the layers, and finally escapes by scattering effect down-stream away from the emitting pixel. This effect is mostly noticeable in transparent EL, but can be controlled. The criteria for measuring the effect are the distance from the pixel at which there is no visible light escaping, when looking with a microscope. As shown below, we were able to reduce the range of the halo effect by optimizing the layers and switching to a non-scattering phosphor. Another method to reduce the halo is to coat the outer surfaces with anti-reflecting materials (AR-coating).

Another important topic is the need to make the phosphor layer smooth to minimize scattering of light. During the initial development phase standard phosphors were used and the transmission was only about 75%. A development of smoother phosphor films improved the transmission to 84%.

There is a great complexity to make the electrodes transparent, while maintaining high conductivity similar to the metal electrodes. During the development of this project, there were several steps to get proper parameters. Higher conductivity is also a key parameter to reliability of the panel under severe environmental tests, including extended operation under high temperatures.

The transparent display driving electronics is similar to the standard EL displays. The interconnection to the edge electrode pads can be done for example by using tape automated bonding (TAB) for column drivers and heat seal to PCB to connect the SMT packaged row drivers. Also other interconnection schemes can be considered.

Test Results and Optical Behavior

A good demonstrator of the transparent TFEL technology was a quarter VGA (320 x 240) display with row and column pitch of 0.360-mm and total electrode fill factor of 74%³. This display was driven with a split screen architecture, in which the display is multiplexed as two separate 120 line displays. 160 output TCP (Tape Carrier Package) drivers on separate PCBs are interconnected to the transparent display by using flexible PCB for the interconnection. The same technology is used for interconnecting the panel to the row drivers. The logic circuits, the dc/dc converters and the circuitry needed to generate the voltage pulses for driving the TFEL panel are located on a separate circuit board connected to driver boards with a flat cable. A photo of this panel is shown in Figure 8. The transmission behaviour of this panel is shown in Figure 9.



Figure 9 - A quarter-VGA transparent electroluminescent display

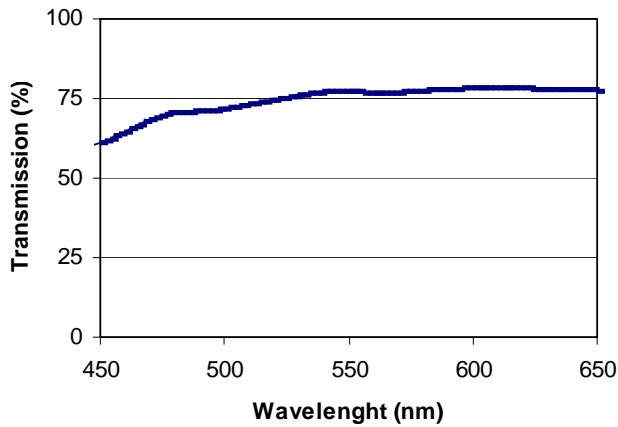


Figure 10 - The transmission spectrum of the quarter VGA display panel

The three major types of phosphor processes were labelled: (a) Standard (scattering), (b) Mid-scattering, and Non-scattering. Table 1 is a summary of the main optical properties achieved with the three different ZnS:Mn recipes implemented on quarter-VGA displays.

	Standard	Mid-scattering	Non-scattering	
Diffuse reflectance	1.73	0.82	0.32	%
Specular reflectance	7.6	7.4	9.0	%
Transmission	75.1	85.0	84.0	%
Halo contrast	10.64	15.50	16.07	
Halo half length	19.5	21.4	14.6	pixels
OFF-luminance	0.32	0.23	0.35	Cd/m ²
ON-luminance	155.7	124.4	109.1	Cd/m ²
1/8 ON -luminance	171.5	150.1	127.9	Cd/m ²
Contrast ratio at 0 lx	488.16	604.11	321.39	
Contrast ratio at 500 lx	51.57	82.28	129.70	
Contrast ratio at 1500 lx	19.12	31.00	59.81	
Contrast ratio at 25000 lx	2.13	2.90	5.28	
Contrast ratio at 50000 lx	1.56	1.95	3.15	
Lattice contrast	1.3	1.1	1.0	
Power @25% pixels on	8.2	8.1	11.1	W

Table 1 - Optical characteristics of a transparent EL display with 3 phosphor recipes @ 247 Hz

The table above illustrates a significant improvement of the transmission for the non-scattering phosphor relative to the standard process (84% vs. 75%). Further improvement in the overall transmission could be achieved by anti-reflection coating on both outside surfaces of glasses. This can add about 7.5% to the transmission. The new non-scattering process also lowered the diffused reflectivity (0.3% vs. 1.7%) and has less scattered light from lit pixels

(halo half length reduced from 20 to 15 pixels). However, there is some loss of luminance relative to the standard process (109 vs. 156-cd/m²). Nevertheless, due to lower reflections, the high ambient contrast ratio at 50000 Lux (4647 fC – outdoor conditions) improved from 1.6:1 to 3.1:1. The high ambient behavior is plotted in Figure 12.

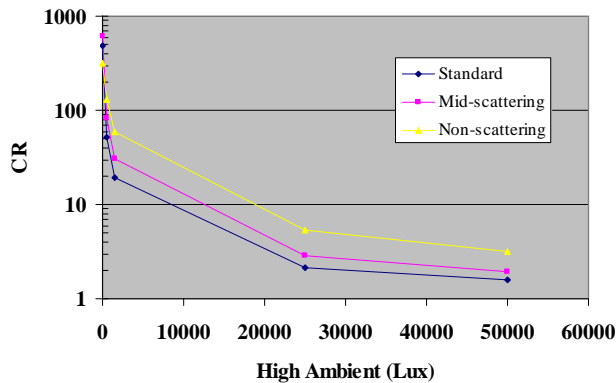


Figure 11 - High ambient contrast ratio (CR) of three recipes of transparent EL displays

A contrast ratio (CR) above 2:1 is easily legible, and above 3:1 is very comfortably readable for alpha-numeric characters. At outdoor conditions, it is most important to reduce diffused reflections as much as possible. As mentioned, further improvement can be done with anti-reflection (AR) coatings on the outer surfaces.

The appearance of the non-scattering is much improved compared to the standard process. Although the luminance at darkroom is lower, the halo effect is reduced and the high ambient contrast ratio (CR) increased. A small study of human factors was done in parallel. This study was a cognitive evaluation where the user reaction times for the changing information on the display was tested. In the tests for a specific application the first generation transparent EL panels showed that the luminance was too high under typical office conditions. And the surprise was that the reaction times to changing information of the panel improved under higher illumination conditions.

Another system was constructed for human subjective evaluation of the display readability. A group of observers evaluated the three display types shown in Table I. In all selected measures, the new non-scattering display type was found more pleasant and more readable than the first-generation scattering display type.

Potential applications for transparent EL displays

Transparent displays find use in applications where space is at constraint and there is a need to provide the users with a dual set of information. For example the idea to use a transparent TFEL display in front of the analogue meters in the car dashboard has been known for some years 1

Heads up display applications can utilize transparent TFEL ideally (Figure 11). Although direct sunlight will wash out the display as the sun shining through the display would be too bright for any emissive display technology, many times the information on a heads up display is also available in the “normal” instruments of the car. Figure 12 demonstrates how the halo effect is significantly reduced, and the display with the no-scattering phosphor has very high transmission.



Figure 12 - Transparent EL used in a demonstrator of a heads up display

Transparent displays enable exciting designs for both professional and consumer use e.g. in applications where the transparent display helps the viewer to localize objects behind the screen. Symbols or messages can also be superimposed on top of other information displays.

Some projects have been started with customers who have chosen transparent EL to differentiate their product with a unique visual appearance.

In Figure 13 we see the transparent display with a mirror behind it, which can give new options and optical effects for potential uses.



Figure 13 - Transparent TFEL display with a front surface mirror provides new options and effects

Engineers and designers can take advantage of the ability of the TFEL glass to withstand high temperatures (up to 600 °C) to bend the glass in a curved surface **after** the display has been processed. This also opens possibilities to process the TFEL display, without protective glass, in the customer's premises at high temperatures. In Figure 14 we have examples of prototypes of new concepts that were made to show the flexibility.



Figure 14 - Demonstration of curved transparent electroluminescent display

Figure 15 is showing that the transparent display can be embedded in other materials, such as silicone, which can produce uniquely shaped and watertight displays.



Figure 15 - Prototypes of transparent EL displays showing volume structure displays

Summary

TFEL technology provides unique opportunities to realize a transparent, rugged and reliable light emitting graphic display that maintains excellent readability both in extreme temperatures and in different lighting conditions. Transparent thin film EL is an intriguing display technology with many potential applications.

We explored the basic design characteristics; the key parameters to achieve good optical behavior are optimized thin film layers and non-scattering phosphors. ALD thin film deposition technology provides the robust insulating layers to allow the use of transparent ITO electrodes on top of the device structure. With the improved non-scattering film, the high ambient contrast ratio improved to a good legible level at ~ 50000 Lux, and the transmission improved to 84%.

Applications for transparent display technology include automotive overlay displays, gaming, home appliances and any other application where there is a need for superposition of information on other displays. The ability to make the transparent displays on curved surfaces or contract them in a volumetric transparent set-up gives additional dimension to product and equipment designers. Other unique features of the solid state structure of TFEL displays are the possibility to drill holes in it and the availability of radius bends.

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