



# Low-Cost Display Technology Utilizing Thick Dielectric Electroluminescent (TDEL) Devices on Glass Substrates

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## Abstract

Low cost and space efficient vehicular displays remain largely unsatisfied due to complexity of fabrication for current display technologies. We report on a novel display technology in which inorganic electroluminescent devices are formed on glass substrates with utilization of low cost printing of a rear thick film dielectric layer and metal electrodes.

## Introduction

View angle, durability, contrast in bright lighting, and cost are several of the key issues for vehicular displays. Thin film electroluminescent (TFEL) displays<sup>1</sup> have garnered niche markets in vehicular display usage due to their superior ruggedness. However, reduced display cost and improved performance is required in order to broaden vehicular usage of TFEL technology. We report on a thick dielectric electroluminescent (TDEL) display technology which has the potential for low cost EL vehicular displays formed on glass substrates. We also report on the latest embodiment of TDEL technology which incorporates a black thick film dielectric layer (BDEL). A diagram of a full-color BDEL display is shown in Fig. 1. Ease of BDEL fabrication is achieved while maintaining the superior readability of TFEL displays.

## TDEL Device Operation

The fundamental operation of TDEL display devices is similar to AC-EL devices (Fig. 2). A bipolar pulse voltage is applied to the capacitively driven device. During continued AC operation at 60-240 Hz, the high capacitance

dielectric layer(s) current-limit electrical breakdown of the 0.5 to 1 $\mu$ m thick phosphor layer. The electrical breakdown of the phosphor layer results in light emission through hot-electron impact excitation of luminescent atoms such as rare earth or transition metals. Sufficient hot carrier generation requires the use of a wide-band-gap semiconductor (ZnS<sup>1</sup>, GaN<sup>2</sup>) host material for the luminescent atoms. Unlike TFEL, only a single thick dielectric is required for TDEL. Furthermore, in contrast to TFEL dielectrics deposited by atomic layer epitaxy, such as Al<sub>2</sub>O<sub>3</sub>:TiO<sub>2</sub>, TDEL devices allow for low cost and high-yield screen printing of a thick film dielectric layer. The reduction in fabrication cost associated with this thick BaTiO<sub>3</sub> dielectric layer is coupled with superior dielectric performance (Table 1). Current TDEL devices utilize GaN<sup>2</sup> phosphor technology which exhibits a maximum brightness of 40 cd/m<sup>2</sup> at 1 kHz excitation. Full color GaN phosphors advantageously exhibit very low threshold voltages (~1/3 that of ZnS phosphors) with brightness values as high as ~30 cd/m<sup>2</sup> at 120 V biasing. In addition to our continued progression in GaN

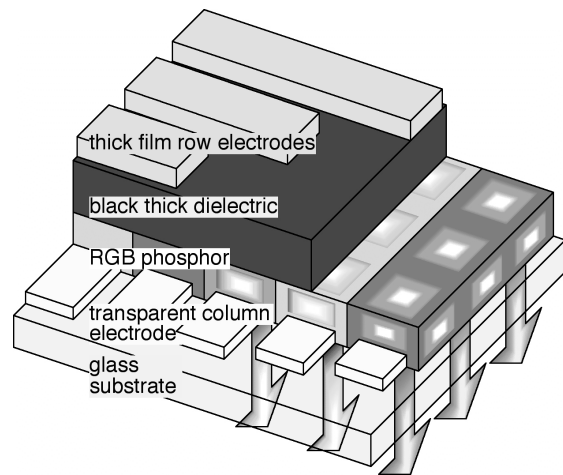


Fig. 1 BDEL display structure.

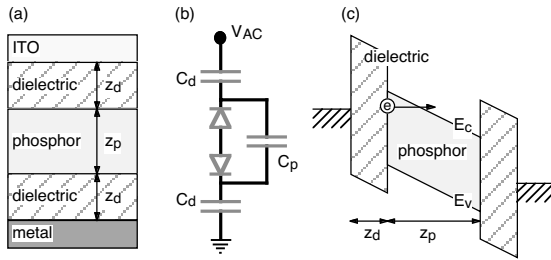


Fig. 2 Structural (a), simple circuit (b), and band (c) diagram of AC EL device operation.

phosphor technology, implementation of efficient (~100-300 cd/m<sup>2</sup> at 60-240 Hz biasing) oxide (and potentially sulfide) phosphors should also boost the maximum BDEL display luminance.

### TDEL Fabrication

The simplicity of fabrication for a TDEL display is unmatched by other rugged emissive display technologies. Film deposition requirements for AC-EL technologies are listed in Fig. 3. Fig. 3a details TFEL fabrication, which requires defect free, entirely thin film fabrication. The recent discovery and advancement<sup>3</sup> of inverted thick dielectric EL (I-TDEL) display technology (Fig. 3b) has overcome many of the scaling and cost limitations of TFEL displays. I-TDEL technology is being pioneered by i-Fire Technologies for HDTV and vehicular display use. Although I-TDEL technology is very promising, fabrication on an opaque ceramic substrate and the need for dielectric planarization add undesired cost and complexity to display fabrication. Therefore, TDEL on glass technology (Fig. 3c) is being developed at Extreme Photonix in order to combine the distinct advantages of TFEL and I-TDEL technology into a single display device. For customized small graphics monochrome displays, a significant manufacturing cost reduction for TDEL technology can be achieved by large batch processing of the TDEL display except for rear thick film metal electrode. With use of a large area transparent indium-tin-oxide (ITO) front electrode, any graphic display design can be implemented by

Dielectric	$\epsilon_r$	$E_b$ (MV/cm)	$t$ ( $\mu\text{m}$ )	$\epsilon_r / t$	$V_{th}$ (V)
SiO <sub>2</sub>	4	8	0.2 (x2)	10	125
BaTa <sub>2</sub> O <sub>6</sub>	23	4	0.3 (x2)	38	71
Al <sub>2</sub> O <sub>3</sub> :TiO <sub>2</sub>	18	6.0	0.2 (x2)	45	68
BaTiO <sub>3</sub>	1000	~0.1	20 (x1)	50	66

Table 1 A comparison of thin and thick film dielectrics. The thickness and multiplicity of each dielectric layer(s) is representative of that required for reliable device operation.  $V_{th}$  corresponds to the threshold voltage (~1 MV/cm) required to generate light emission from a 500 nm phosphor layer ( $\epsilon_r \sim 8$ ) in an AC EL device.

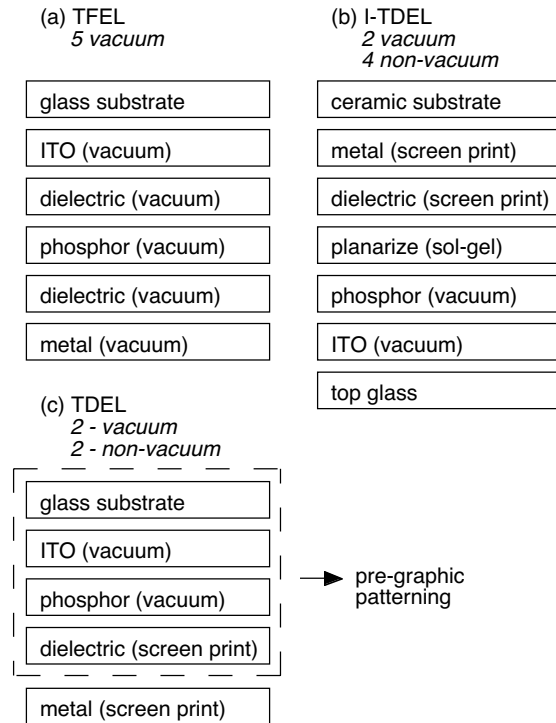


Fig. 3 Flow diagrams of the film deposition needs for monochrome AC-EL display technologies. 3(b) is an inverted AC-EL structure since light emission through the substrate is not possible.

Format (rowxcolumn)	2" diag.	4" diag.	6" diag.
(120x160)	254 -f-	508 ■p■	762 ■p■
(240x320)		254 -f-	381 -f-
VGA (480x640)			190 -f-

Table 2 Resolution capability for full-color TDEL display technology set at ~80% fill factor. For example, a 6" diagonal VGA format is possible using thick film patterning of the rear row electrode. Fodel® is a DuPont photo-patterned thick film technology.

low cost and rapid re-tooling of the rear metal screen printing mask. TDEL technology does require high-strain point glass due to the high temperature firing cycle of the thick dielectric layer. However, TDEL technology can tolerate slight glass defects and allows for use of low cost (~\$1 U.S. for 5"x5") industrial grade (1.5K lux scratch inspection) high-strain point Corning 1737 glass. This is economically preferred over the 2-3X more costly display grade (5-10K lux) glass.

Video rate operation is inherent to passive matrix addressed AC-EL displays. Since the very small thin film features associated with active matrix technology need not be utilized, issues with glass substrate shrinkage are greatly reduced. Furthermore, TDEL display technology can achieve excellent resolution capability using industry standard ITO patterning on glass and thick film patterning for the rear metal electrode. The patterning resolution of the rear thick film metal electrode determines the ultimate display resolution (Table 2). Full color TDEL display patterning is possible up to VGA format (480x640) for as small as 6" diagonal displays. Ease of scaling TDEL technology to larger display sizes is expected due to standard ITO patterning on glass substrates and thick film screen printing for the dielectric and rear row electrode. As a result, we are exploring TDEL for applications such as >30" HDTV.

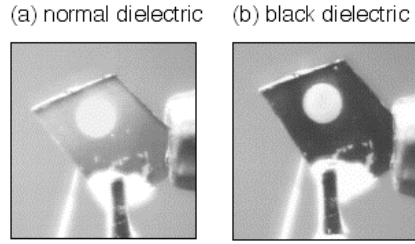


Fig. 4 Photographs of TDEL and BDEL devices in 140 lux lighting with 120 V 1 kHz applied bias. The BDEL device in (b) was fabricated from the same TDEL device first tested in (a).

### TDEL Vehicular Displays

Vehicular displays require very low light reflectance from a display due to bright sunlight operating conditions. An advanced high contrast embodiment of TDEL technology is that of black dielectric EL (BDEL) shown in Fig. 4. BDEL relies on a proprietary high permittivity thick dielectric film which strongly absorbs visible light. BDEL technology retains all the advantages of TDEL technology mentioned above, while allowing for very high display contrast. Furthermore, implementing BDEL technology is a nearly zero-cost screen-printable contrast enhancement technique. Unlike the ~50% luminance decrease associated with use of polarizing films, the *entire* display back plane is rendered black with only a ~10-20% luminance decrease from TDEL. The low reflectivity of the black dielectric is primarily diffuse which significantly reduces display glare. A contrast comparison of CRT, LCD, TDEL and BDEL technology is shown in Table 3. The data was measured under standard display operation and office lighting conditions. BDEL technology is one aspect of our larger Chroma Layer™ technology. Chroma Layer™ not only allows for black but also for a color display back plane. Using the same near-zero cost fabrication the display back plane can be rendered any custom color (except white which is undesirable) for vehicle interior color matching. However, for

Display	L(on)	L(off) 140 lux	Contrast
CRT	140 cd/m <sup>2</sup>	4 cd/m <sup>2</sup>	35:1
LCD	110 cd/m <sup>2</sup>	2 cd/m <sup>2</sup>	55:1
TDEL	100 cd/m <sup>2</sup>	5 cd/m <sup>2</sup>	20:1
BDEL	90 cd/m <sup>2</sup>	2 cd/m <sup>2</sup>	45:1

Table 3 Comparison of display brightness and contrast measured under office lighting (ceiling lighting / vertical display screen) with an illuminance of 140 lux. No additional contrast enhancement (such as polarizers for CRT) is required for BDEL in order to achieve contrast ratios of 50:1 at 100 cd/m<sup>2</sup> brightness.

vehicular displays the colors should be limited to dark hues in order to maintain adequate display contrast. Similar color rendering or contrast enhancement could be achieved through use of a Luxell Corp. multiple thin film interference filter<sup>4</sup> at the rear of a TFEL display. However, this approach is more complicated/costly than BDEL and is not compatible with the advantages of a screen printed thick dielectric layer.

The use of ultra-stable oxide and nitride materials, and the absence of polymeric materials, vacuum, or gases makes TDEL ideal for operation in harsh environments such as vehicular displays. The expected operational temperature range of -45 to 85°C is determined only by the limitations of the driver electronics. Current TDEL 60 Hz operational lifetimes exceed 1000 hrs at 95% brightness. Operational lifetimes of 20,000-50,000 hrs are projected for TDEL displays. Important for vehicular console displays, a wide view angle of 180° is inherent to a TDEL display.

## Conclusion

TDEL technology possesses many attractive features for vehicular display usage. TDEL displays have the potential for low cost manufacturing, high contrast, superior temperature range, and low-cost small graphics customization. With future advancements in TDEL brightness, such displays are an excellent match to vehicular display operation.

## References

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<sup>2</sup> A. J. Steckl, J. Heikenfeld, M. Garter, R. Birkhahn, and D. S. Lee, "Rare Earth Doped Gallium Nitride – Light Emission from Ultraviolet to Infrared", *Compound Semiconductor* **6** (1), p. 48 (2000).

<sup>3</sup> S. Grossman, *Electronic Design*, "Electroluminescent Display Triples Brightness to 150 Candelas/m<sup>2</sup>", p. 25, May 1 (2000).

<sup>4</sup> J. A. Dobrowolski, B. T. Sullivan, and R. C. Bajcar, "Optical interference, contrast-enhanced electroluminescent device", *Applied Optics*, **31** (28), p. 5988 (1992).