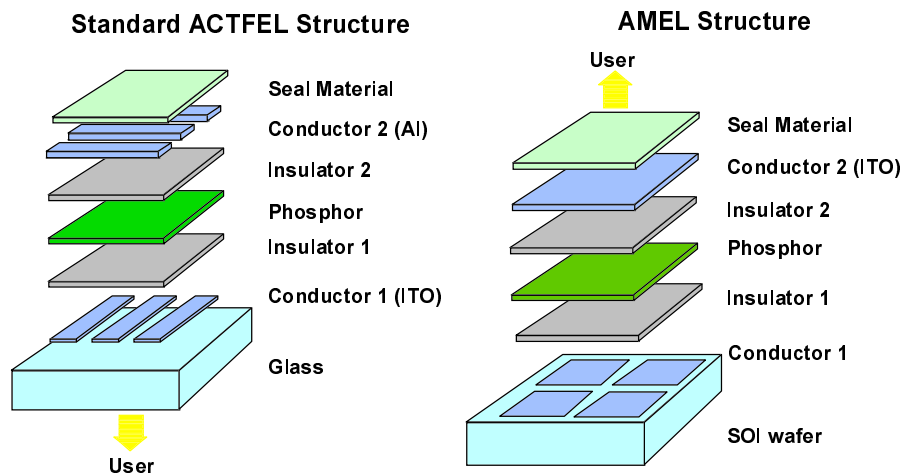


Active Matrix Electroluminescence

Active Matrix Electroluminescence (AMEL) technology is produced by the integration of IC and thin film EL (TFEL) technologies on a silicon wafer to produce a very small, very high resolution display. The AMEL device is realized by fabrication of the electronic circuitry for the display on an IC wafer and then by overlaying a thin film, light emitting EL structure on top of the IC to produce a fully integrated emissive display. The AMEL device structure overcomes size limitations of traditional TFEL technology by integrating the driver electronics onto the wafer, which forms the substrate for the AMEL device. Using this approach, Planar has demonstrated AMEL displays with a resolution of 1000 lines per inch (lpi) in display formats of both 640x480 and 1280x1024. Additional AMEL displays have been built with resolutions as high as 2000 lpi.

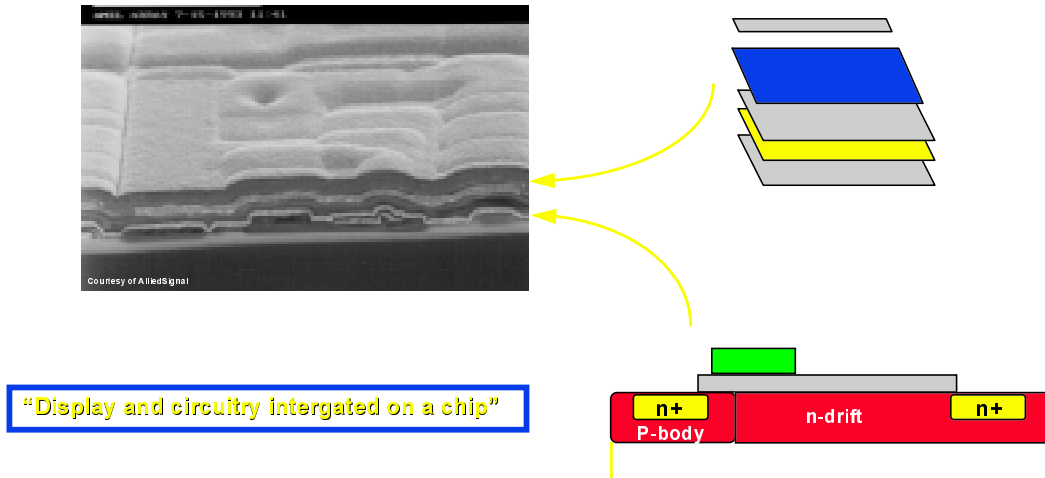


The first AMEL devices were monochrome displays but recent work has resulted in the development of color AMEL displays. The single color (usually amber) phosphor in the monochrome device is replaced with a broad band "white phosphor" which allows the primary red, green and blue colors to be obtained by filtering.

AMEL IC REQUIREMENTS

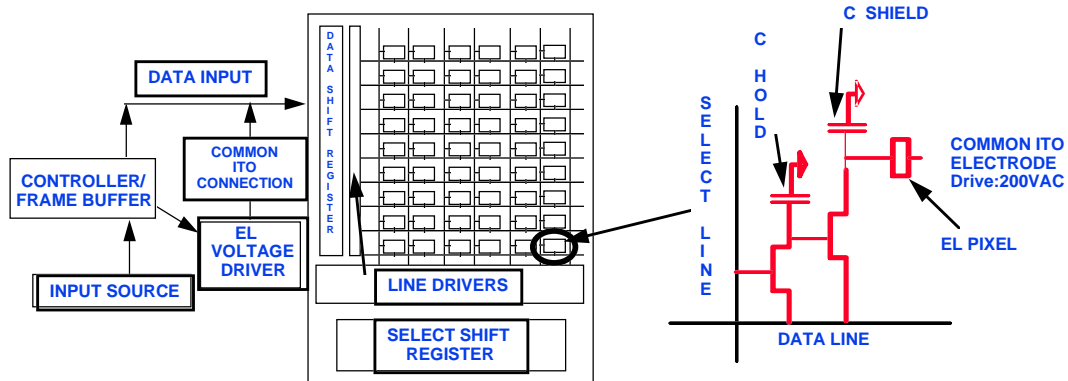
The creation of a miniature, high resolution electroluminescent display on a silicon chip requires that the pixel transistors withstand up to 80 volts AC. Therefore, careful attention must be given to the design of the structure of the pixel transistors in order to segregate the 80 volts from the low voltage circuitry. In addition, care must be given in the design to avoid undesirable parasitic capacitances that could make the pixel inoperable. These considerations necessitate the use of Silicon on Insulator (SOI) wafer substrates. Due to the superior isolation capabilities, SOI wafers make it possible to isolate high voltage structures in each pixel from each other and to isolate the high voltage illumination lines from the low voltage logic lines. The isolation achievable with SOI wafers, together with 1.0 micron design rules for the IC circuitry has enabled the fabrication of active matrix pixel elements in a 12 micron by 12 micron area (i.e >2000 lpi)³.

The 12 micron by 12 micron pixel size requires that the high voltage DMOS device is very compact, yet still capable of blocking enough voltage to modulate the EL device. Transistors designed with drift region lengths less than 10 microns have shown excellent characteristics with DMOS reverse breakdown voltages of over 80 volts. Typically, 80V is sufficient to modulate standard thickness TFEL devices.



The peripheral circuitry on the die consists of the shift registers and line drivers to eliminate the external driver ICs required for passively addressed flat panel displays. The AMEL array has a common top ITO electrode which is driven by a single external high voltage AC circuit to generate the light from the display. The data inputs and control signals operate at standard 5V logic levels. The 640x480 VGA device has 8 parallel data input lines to the AMEL die; thus, the number of inputs to the AMEL display is greatly reduced compared to those of a passively addressed VGA display, which would have over 1000 inputs.

AMEL SYSTEM ORGANIZATION



AMEL EL REQUIREMENTS

A major EL processing issue for the integration of TFEL and IC technology onto a single substrate is the need for the TFEL films to conformally coat the topography of the IC structures. Another requirement of the AMEL structure is the need to build the inverted structure. Planar utilizes its proprietary atomic layer epitaxy (ALE) process for the overcoating of the TFEL films on the processed IC wafers. The ALE process can be used to fabricate reliable EL devices on the varied topography of the AMEL wafer substrates.

Miniature AMEL displays offer a very wide dynamic brightness range by driving the EL at high frequencies (1 to 10 kHz). However, one of the potential issues that arises with this approach is the

aging characteristics of EL phosphors when driven at high frequencies. Typically, the aging rate of the brightness-voltage (BV) curve of the EL phosphor is accelerated in proportion to the driving frequency for the device. Experimentally, it is possible to build TFEL devices whose BV characteristics either tend toward an asymptotic value with time or continue to drift with longer aging times. In the case of AMEL devices, Planar has been able to develop a process for the yellow phosphor that produces a BV curve that quickly reaches a steady state condition. In this case, the high frequency drive actually helps to "burn-in" the device in a reasonably short time period.

Many of the applications for miniature displays require video capability. Specific examples range from the view finder in a camcorder to HMDs for very sophisticated simulators used by the military. EL technology has the basic high speed response required for video, but most commercial EL products do not offer sufficient gray scale capability for video applications. The gray scale drivers for passive EL have been a large part of the issue. The lower cost pulse width modulation drivers only achieve 16 gray levels and the higher performance analog drivers have been too expensive. The small capacitance and high illumination rate for AMEL devices enable a digital gray scale in which the intensity of the gray levels is changed by varying the number of excitation pulses to the pixel. This sub-frame gray level scheme is similar to that used to achieve gray scale for plasma displays. It has the added attraction that the EL devices and IC devices of the AMEL are always operated in either a fully "on" or "off" state. This relaxes the processing precision required for both the IC and the EL portion of the device.

Finally, it is clear in today's advanced state of display technology that color capability will be required if AMEL miniature displays are to meet the needs of advanced display applications. The approach used to achieve color AMEL is to use the broad band "white" phosphor, SrS:Ce/ZnS:Mn, developed by Planar International^{5,6} for passive matrix color TFEL displays. The chromaticity of the SrS:Ce/ZnS:Mn broad band phosphor is dominated by the yellow ZnS:Mn emission when driven using a 60 Hz bipolar pulsed waveform typical for passive matrix TFEL displays. Active matrix addressing enables the EL phosphor to be illuminated using a high frequency (5kHz) ac excitation which substantially increases the relative emission in the blue part of the spectrum as seen in Figure 4.

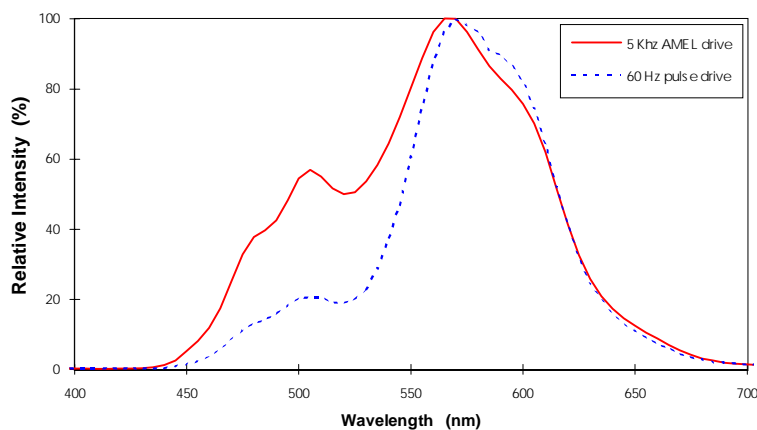


Figure 4 EL Emission Spectra of "white" AMEL Phosphor at 60 Hz and 5 kHz Drive Frequency

As shown in Figure 5, these two device structures have been investigated to produce color images from the broad band phosphor. In one approach a color filter with a quad pattern has been used in conjunction with an 1280x1024 AMEL IC array to build a color display with a color pixel resolution of 640x512⁴. In the second approach a fast LCD color shutter has been coupled to a 640x480 AMEL display to produce a frame sequential color VGA. As seen in Table I the performance in terms of brightness and

chromaticity was pretty similar. The liquid crystal color filter approach has the advantage of achieving a higher resolution color image with a less expensive IC die. This is gained at the expense of an increase in the thickness and weight of the device caused by the addition of the color shutter.

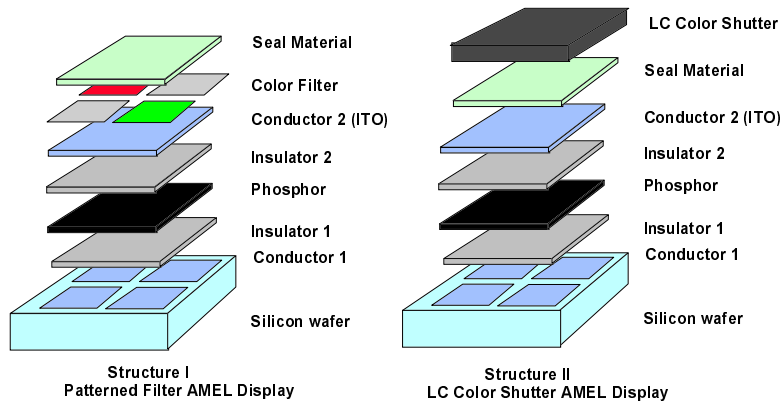


Figure 5 Color AMEL Display Structures

Table I Color AMEL Characteristics

Color	Quad Color Filter			Color Shutter		
	L ₄₀ (fL)	CIE coord.		L ₄₀ (fL)	CIE coord.	
		x	y		x	y
Red	8.5	0.62	0.37	9	0.63	0.35
Green	23	0.35	0.60	19.5	0.34	0.61
Blue	8.5	0.11	0.35	1.5	0.10	0.25
White	40	0.41	0.48	30	0.46	0.48

AMEL DEVICES FOR HMDs

Table II presents the specifications for a monochrome AMEL VGA device with 1000 lpi resolution.

Table II AMEL Display Specifications

Characteristic	Parameter	Value
Dimensions	Active Area	0.61"x0.45"
	Including Peripheral Circuits	0.71"x0.53"
	External Package	0.82"x0.95"
	Total Thickness	68 mils (1.7 mm)
Resolution	Matrix	640.480
	Density	1000 lines / inch
Color	Monochrome	Yellow (585 nm)
Brightness	Areal	100 fL (yellow)
Contrast	Ratio	100:1
Display Power		0.4 W
Interface Power		< 2.0 W
Gray Scale	6 bits	64 levels
Operating Temperature		-40C to +75C
Weight	Display	2.1 grams

The data in the table show that the characteristics of the AMEL device are ideally suited for HMD and hand held viewer applications which require small size, light weight, and low power consumption. These features are the result of the self emissive nature of the display which eliminates the need for an external light source, which in turn leads to the smaller size and lighter weight. Also, the elimination of the separate light source, which would be required for an LCD display, leads to a lower power consumption in two ways. First, the power needs only to be supplied to the lit pixels in an AMEL device, whereas, the light source is always fully illuminated in an LCD regardless of the image. Second, since the EL display is not a transmissive display, the active matrix does not occlude the aperture for the light transmission as in an LCD. The second factor becomes even more important as the resolution increases, as is the case with Planar's new 2000 lpi displays.

HMD APPLICATIONS

The first significant use of HMDs was by the Air Force as a cockpit target sighting aide and by Army helicopter pilots for night vision. The military is also developing HMDs for programs to provide enhanced night vision capability to the foot soldier, combat vehicle commanders and simulator training for pilots. Industrial applications for HMDs are now beginning to appear in products designed for applications like maintenance, inventory control, manufacturing assembly, surgical procedures, and public safety operations. In many of these applications, an HMD is combined with a belt worn computer system so that the operator can remotely access the required data base for the function that is being performed.

The next step in this evolutionary path will be the use of HMDs in information technology for the consumer. Already, there are low resolution HMD and hand held products available in the market for entertainment applications like games and virtual reality. With the availability of high resolution miniature displays, like those based on AMEL technology, HMDs are projected to be integrated into products for portable computers and communications devices which will have extended remote communications capabilities.

CONCLUSION

The availability of a new, small, light weight, low power and high resolution AMEL miniature display technology for HMDs has the potential to revolutionize our ability to build very small and portable information technology products with very powerful processing and communications capabilities. As the miniature displays are accepted in the market place, the technology will, for the first time, enable display manufacturers to get on a cost reduction path similar to the one that IC manufacturers have enjoyed where the performance can be increased and the price of display can be reduced by obtaining a higher functionality in a smaller size and thus less expensive device.

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