William A. Barrow. "Electroluminescent Displays."

Electroluminescent Displays

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94.1 Introduction

Electroluminescence (EL) is the nonthermal generation of light resulting from the application of an electric field to a substance. The light-emitting substance is generally a luminescent crystal. Most commercially available monochrome EL displays utilize ZnS:Mn as the luminescent material. EL displays have become very important in certain display markets. These include medical instrumentation, industrial control equipment, portable instrumentation, and military vehicles. The attributes of EL displays that make them attractive in these types of applications are mechanical ruggedness, relative insensitivity to ambient temperature, rapid display response, essentially unlimited viewing angle, compactness, and light weight.

There are four types of EL devices: ac thin film, ac powder, dc thin film, and dc powder. The ac thin-film display is by far the dominant device type. Some liquid crystal displays use ac powder EL for backlights. There is currently little or no commercial application of dc EL devices, either thin film or powder [1]. The focus here is on ac thin-film EL (ACTFEL) devices. While there are no widely established standard measurement techniques for the other EL device types, measurements similar to those described herein for ACTFEL devices could be applied with appropriate modifications to the other methods of device excitation.

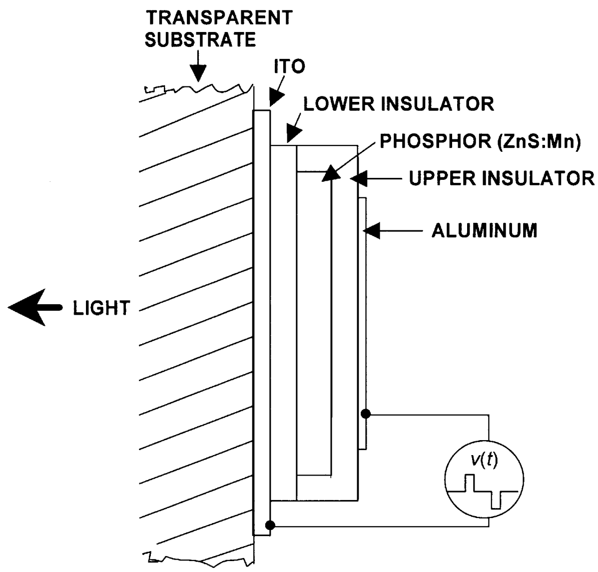

FIGURE 94.1 Schematic, cross-sectional diagram of the basic ACTFEL device structure.

94.2 Device Structure and Operation

A schematic, cross-sectional representation of the basic ACTFEL device structure [2] is shown in Fig. 94.1. The supporting substrate is usually made of very low sodium glass. If a suitable ion barrier layer is deposited between the substrate and lower electrode of the EL device, soda-lime glass can be used. The lower electrode, usually a transparent conductor such as indium tin oxide (ITO) is deposited next. The ITO is usually between 350 and 120 nm in thickness, providing sheet resistance in the range of 5 to 15 Ω/square. On top of the ITO electrode a lower insulator is deposited. This layer is typically SiON or aluminum titanium oxide (ATO). The thickness is normally around 200 nm. The phosphor layer, typically ZnS:Mn, is deposited between the lower insulator and a similar upper insulator. The phosphor thickness is typically in the range 200 to 1000 nm thickness, depending on the application. The upper electrode, typically aluminum, is deposited on top of the upper insulator. The aluminum is generally 100 to 200 nm thick.

A matrix-addressed monochrome display is created by dividing the upper and lower electrodes into orthogonal arrays of electrode stripes. The EL device is then excited locally by applying a voltage between a pair of crossing electrodes, causing an electric field to exist between them, which excites the phosphor. A color display can be created by dividing the phosphor into stripes of red-, green- and blue-emitting phosphors which are aligned with one of the sets of electrode stripes [3,4]. This is shown schematically in Fig. 94.2. Color displays can also be created by using an unpatterned phosphor which emits a broad spectrum including red, green, and blue and filtering the emission using either a patterned color filter which is aligned with the electrode stripes or a frame sequential color filter.

94.3 Device Fabrication

Thin-Film Deposition Methods

A wide variety of deposition techniques are used by various manufacturers and researchers in the fabrication of ACTFEL devices. The electrode materials ITO and aluminum are usually deposited by physical vapor deposition (PVD) techniques. ITO is almost universally deposited by dc magnetron

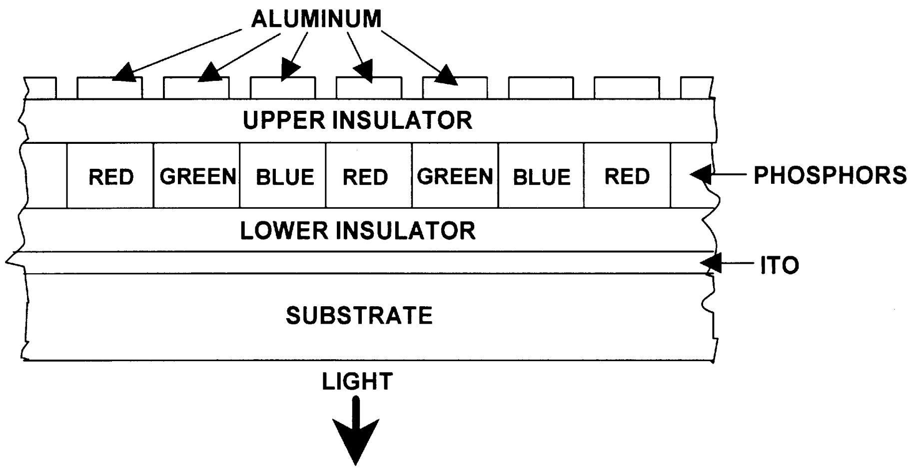

FIGURE 94.2 Schematic, cross-sectional diagram of a color ACTFEL device with the red, green, and blue primary colors produced by patterned color phosphor stripes. The color phosphor stripes are end on in this view.

sputtering from either a conductive ITO target or from a metal alloy target [5]. Optimum ITO conductivity is obtained by postdeposition annealing in a very low oxygen environment. Al is deposited either by dc magnetron sputtering from an Al metal target or by electron beam evaporation of Al metal. The insulator and phosphor layers are deposited by chemical vapor deposition (CVD) as well as PVD. Phosphor layers have been deposited by thermal as well as e-beam evaporation, sputtering, metal–organic CVD (MOCVD), and atomic layer epitaxy (ALE). Insulator layers have been deposited by e-beam evaporation, radio frequency (RF) sputtering, plasma-enhanced CVD (PECVD), and ALE.

Thin-Film Patterning Methods

Patterning of the electrodes is generally accomplished either through etching or liftoff, although some early workers patterned the upper aluminum electrodes by evaporating through a shadow mask. Aluminum is easily etched wet or dry. There are commercially available wet etches for Al. Dry etching of Al can be carried out using standard chlorine chemistries, e.g., Cl_2/BCl_3. Al can also be patterned by evaporating onto a reversed photoresist pattern and lifting off excess metal. ITO can be etched wet or dry. ITO wet etches generally consist of mixtures of HCl and HNO_3. ITO can be dry-etched in HI or HBr. Patterning of the phosphor layers is more problematic. Phosphor etches exist for most ACTFEL phosphor materials, but they are generally proprietary. Thin-film phosphors are difficult to etch because they are usually water sensitive, and some color phosphors contain heavy metals which are difficult to volatilize in a dry-etch process.

94.4 Device Operation

Luminescence Mechanisms

As the device structure shown in Fig. 94.1 indicates, ACTFEL devices are capacitively coupled. Since only displacement current can flow across the insulator layers, the drive signal must be an alternating polarity waveform. A typical alternating polarity, trapezoidal waveform is shown in Fig. 94.3. If the peak voltage, V_P, in Fig. 94.3 is larger than the **threshold voltage** of the device, V_{th}, then, when the positive pulse of the waveform is applied between the Al and ITO electrodes of the device structure shown in Fig. 94.1, the energy band diagram of the ACTFEL device will be as shown in Fig. 94.4. Electrons, which are the majority carriers in ACTFEL devices, tunnel out of the interface states on the left and into the conduction band. Once in the conduction band the electrons are accelerated by the large electric field, which is approximately 1 MV/cm = 100 kV/mm. The conduction electrons drift across the ZnS:Mn layer until they impact excite an Mn^{2+} center, transferring some energy to one of its electrons and causing it to undergo a transition to an excited state. The conduction electron may undergo additional collisions, eventually reaching the right interface and getting trapped in interface states there until the next voltage pulse, which is of the opposite polarity. This pulse causes the electrons to tunnel out and drift back across the ZnS:Mn layer, transferring energy to Mn^{2+} centers along the way, until eventually they are trapped again at the left interface. This transfer of charge back and forth between the interface states continues as long as the alternating polarity drive signal with a peak amplitude above the threshold voltage of the device continues to be applied. Light emission occurs when the Mn^{2+} centers, which have been impact excited by the hot electrons, relax [6-8]. The light emission thus results from transitions of the electrons within the Mn^{2+} centers, rather than electron–hole pair recombination near a *pn* junction as occurs in a light-emitting diode (LED).

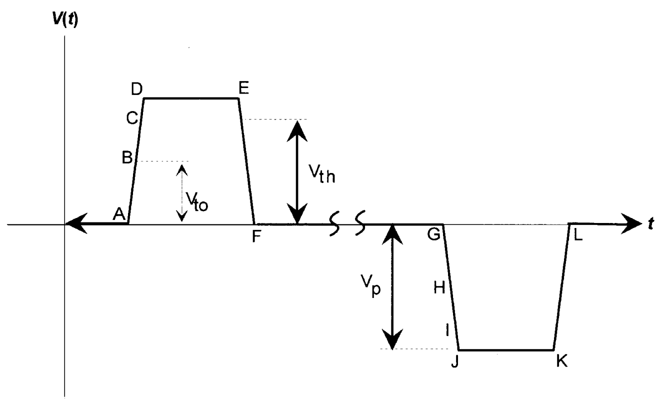

FIGURE 94.3 Typical alternating polarity, pulse drive waveform. Letters A–L mark points on the drive waveform which are referenced later in Figs. 94.5 and Fig. 94.6. The pulse width would generally be about 30 μs and the frequency would be between 60 and 500 Hz for a passive matrix-addressed display.

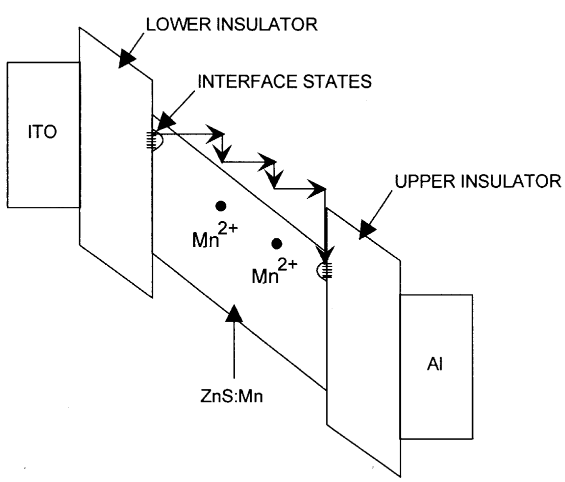

FIGURE 94.4 Energy band diagram of an ACTFEL device during the peak of the applied voltage pulse. Electrons tunnel out of insulator/phosphor interface states into the conduction band, are swept across the phosphor layer, and impact exciting emission centers as they go until they are finally thermalized and trapped at the opposite interface.

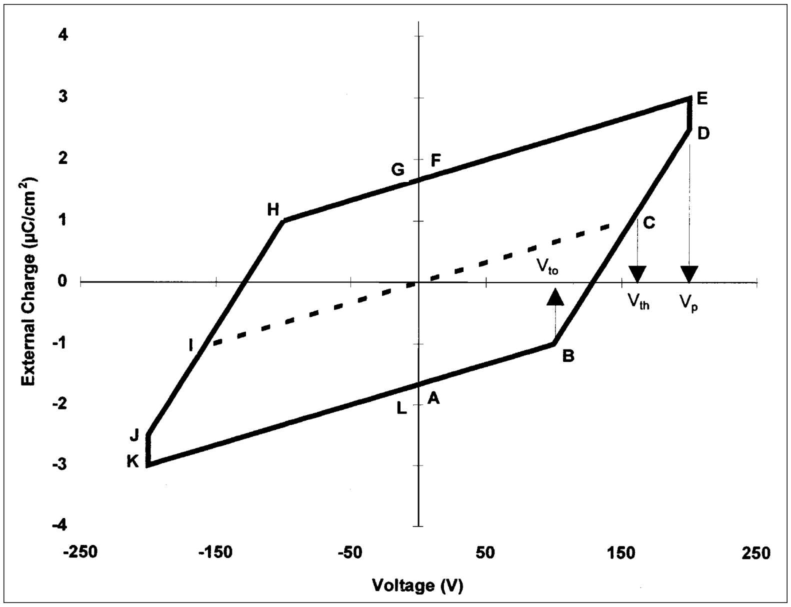

FIGURE 94.5 Idealized *QV* loop with no charge leakage from interface states between drive pulses. Letters A–L mark points on the *QV* loop which are coincident in time with the points labeled A–L on the drive waveform in Fig. 94.3. The dashed line is the *QV* loop for the case just below threshold. The solid line is the open loop above threshold. The area of the *QV* loop represents the energy dissipated by the device per cycle of the drive waveform.

Description of Charge Flow

If the external charge, *Q*, flowing into the ACTFEL device is plotted vs. the externally applied voltage, *V*, the resulting curve is called a ***QV* loop** [9,10]. If the amplitude of the applied voltage pulses is less than the threshold voltage of the device, the *QV* loop is simply a straight line with slope equal to the total capacitance of the insulator/phosphor/insulator stack. If the amplitude of the applied voltage pulses is greater than the threshold voltage of the device, the *QV* loop opens up. *QV* loops below and above threshold are shown in Fig. 94.5. Above threshold, power is dissipated in the ACTFEL device. The area encompassed by the *QV* loop is equal to the energy delivered to the device per period of the drive waveform.

The *QV* loop is measured directly. A theoretical extension of the *QV* loop that is sometimes used by researchers studying the physics of ACTFEL devices is a plot of the actual charge flow across the phosphor layer, Q_p, vs. the electric field across the phosphor layer, F_p. The quantities required for a plot of Q_pF_p can be calculated from the *QV* data if the thicknesses and dielectric constants of the insulator layers and phosphor layer are known. The actual charge flow across the phosphor is calculated by subtracting the reactive charge from the total charge. The field in the phosphor layer is calculated by adding the externally applied field to the internal **polarization field** due to the actual flow of charges across the phosphor layer. A Q_pF_p loop corresponding to the above threshold *QV* loop of Fig. 94.5 is shown in Fig. 94.6. The Q_pF_p loop is useful because it expresses the internal electrical characteristics of the phosphor layer during device operation.

Device Excitation

Whether the device under test is a test dot or a matrix display, the drive waveform must be ac coupled. Passively addressed matrix displays are scanned one row at a time. Data are loaded into the column drivers for a single row of pixels and the selected pixels in the row are all turned on simultaneously. The row pulse brings the voltage across each pixel in the row to a level just below threshold. The columns of selected pixels are then pulsed to bring the voltage across selected pixels to a level above threshold and the pixels are turned on. During the following frame the voltage polarities across the pixels are reversed.

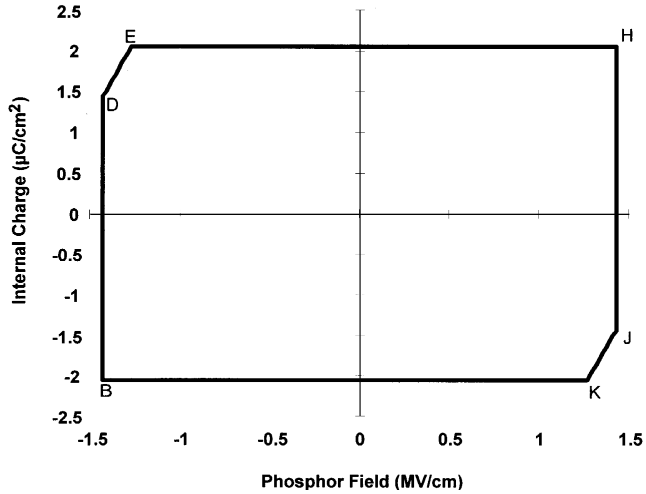

FIGURE 94.6 Q_pF_p loop corresponding to the above threshold *QV* loop in Fig. 94.5. This loop represents the charge flow across the phosphor layer as a function of the electric field across the phosphor layer.

Each individual pixel is subjected to a drive signal similar to that shown in Fig. 94.3. To activate a pixel fully requires the voltage to be held above V_{th} for 10 to 20 μs. Since each row must be scanned in sequence, a typical display with approximately 500 rows requires at least 5 ms to scan one frame. The maximum frame rate is thus approximately 200 Hz. Displays that are addressed by an active matrix of transistors are not scanned a line at a time as passively addressed displays are, but instead are bulk driven. They have one unpatterned common electrode, usually an upper layer of ITO, to which an ac drive signal is applied. Each pixel is connected to ground through a transistor which drops a portion of the applied drive voltage when the pixel is not selected. In this type of display the drive waveform can be any ac signal of the appropriate voltage. Sine, trapezoid, and triangle waveforms have been used. An active matrix display can be driven with a frame rate higher than a passive matrix-addressed display by a factor equal to the number of rows in the display, since row-at-a-time scanning is not required. Since a light pulse is emitted for each voltage pulse, the average luminance is proportional to the frame rate, resulting in much higher luminance capability for active matrix-addressed displays.

94.5 Standard Measurements

Measurable quantities of interest include luminance, luminous efficiency, emission spectrum, latent image, and defects. The luminance of an ACTFEL display is a function of the peak voltage and frequency of the drive waveform, the intrinsic efficiency of the insulator/phosphor/insulator stack, and the operating history (aging). The efficiency is a function of the drive waveform shape and frequency as well as various device parameters. The emission spectrum is primarily determined by the phosphor host material and activators, although it is also affected by deposition and anneal conditions and in some cases by the drive voltage and frequency. **Latent image** is the burning in of a permanent image of a fixed pattern which is displayed for long periods. It can appear as a faint dark image superimposed on a bright background or as a faint bright image superimposed on a dark background. Formation of latent image is affected primarily by drive waveform symmetry and device processing parameters. Display defects include pixel, line, and mura defects.

94.6 Time-Resolved Measurements

Measurements of luminance, efficiency, and emission spectra as introduced so far involve time-averaged light emission. There are two fairly common time-resolved measurements of ACTFEL light emission:

light emission decay time and time-resolved light emission spectroscopy. The **light emission decay time**, τ, is the time it takes for the light emission from one excitation pulse to fall to $1/e$ times its initial value. The measurement of τ is started just after the trailing edge of the excitation pulse. This is necessary in order that the measured value of τ not be affected by the continuing excitation of additional emission centers, so that it represents the intrinsic relaxation time of the emission center. In devices with evaporated ZnS:Mn phosphor, τ is a strong function of the Mn concentration. It can thus be used as an analytical technique to determine the Mn concentration. Time-resolved spectroscopy is the measurement of the emission spectrum occurring during specific portions of the excitation and emission process. An example of the application of this technique is the study of the separate light pulses emitted during the leading and trailing edges of the excitation pulse with the blue-emitting phosphor SrS:Ce. Both of these techniques are frequently used to help elucidate the excitation and emission mechanisms in ACTFEL phosphors.

94.7 Test Dot Characterization

Luminance and Efficiency

A schematic representation of a measurement system for collecting luminance and efficiency vs. voltage data on a test dot is shown in Fig. 94.7. An arbitrary waveform generator provides a drive signal with the waveshape, frequency, and peak voltage determined by a control computer. The waveform generator output signal is amplified from a ±5 V range to a ±300 V range. A photometer, also under computer control, measures the luminance, L, of the test dot. An oscilloscope measures the voltage across the test dot and the voltage across the sense resistor. The current is calculated by dividing the voltage across the sense resistor by its resistance. The control computer can thus adjust the peak voltage up and down and collect the luminance data, as well as the waveforms representing the voltage across the test dot and the current through it. The energy dissipated, E_p, during each drive pulse is calculated as

$$E_P = \int_D I(t) \times V(t) dt \tag{94.1}$$

where $I(t)$ and $V(t)$ are the current and voltage waveforms, respectively, and D is the duration of either the positive or negative drive pulse. This integration can be carried out by most oscilloscopes or the $I(t)$ and $V(t)$ data can be transferred to the control computer for the calculation, although this approach is generally slower. The average energy dissipated per period of the drive waveform, E, is the average of E_P for a positive pulse and a negative pulse. The average power dissipated, P, can be calculated by multiplying E by the frequency of the drive waveform. The efficiency, η, is calculated as follows:

$$\eta = \frac{\pi L A}{P} \tag{94.2}$$

where L is the luminance in cd/m^2, A is the area of the test dot in m^2, and P is the average power in watts. Values of L and η are collected for peak voltages ranging from 10 V below threshold to 40 or 50 V above threshold. Plots of L and η vs. peak voltage for a typical device are shown in Fig. 94.8.

Charge Flow and Electric Field

The QV loop is measured using a circuit identical to that in Fig. 94.7, except that the sense resistor is replaced by a sense capacitor and the photometer is not used. The sense capacitor value is chosen to be much larger than the capacitance of the ACTFEL device so that the voltage dropped by the sense capacitor is small. Since the sense capacitor and the ACTFEL device are in series, the charges stored on them are equal. The charge, Q, on the ACTFEL device is thus

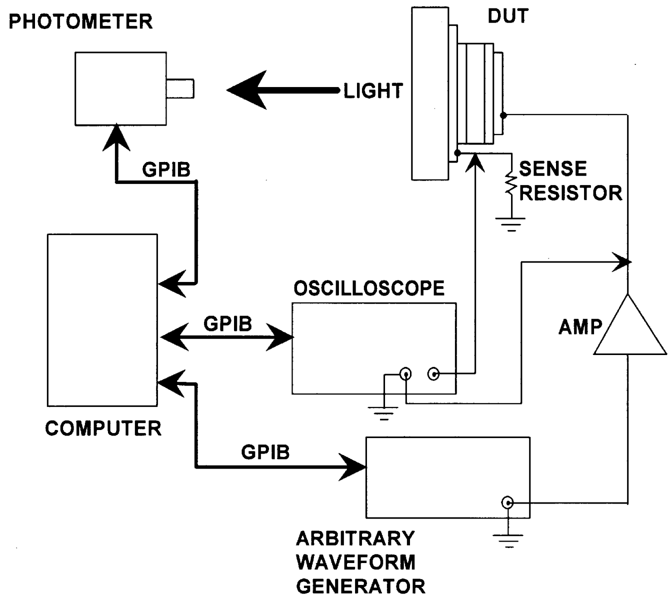

FIGURE 94.7 Schematic diagram of a system for measuring luminance and efficiency as functions of the peak drive voltage. The voltage waveform, $V(t)$, is measured by the oscilloscope at the Al electrode of the device under test. The current waveform, $I(t)$, is measured by the oscilloscope as the voltage across the sense resistor divided by its resistance. The luminance is measured by the photometer.

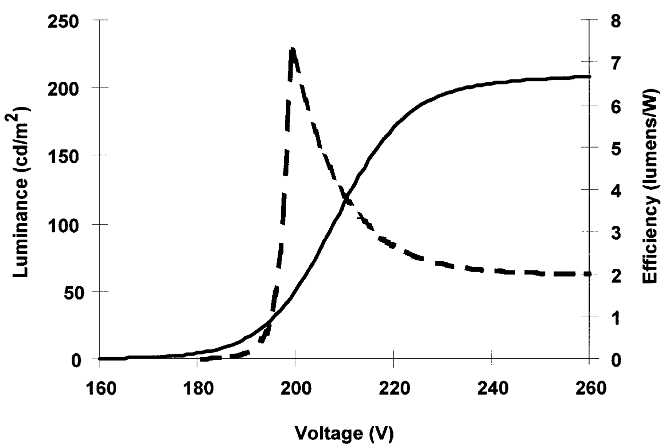

FIGURE 94.8 Plots of luminance and efficiency as functions of peak drive voltage. The solid line is the luminance and the dashed line is the efficiency.

$$Q = C_S V_S \tag{94.3}$$

where C_S is the capacitance of the sense capacitor and V_S is the voltage appearing across it. When $Q(t)$ is plotted vs. $v(t)$, the QV loop results. In the idealized QV loop shown in Fig. 94.5, V_{th} (C) is the threshold voltage, V_{to} (B) is the turn on voltage, and V_p (D,E) is the peak voltage of the drive waveform. Threshold voltage is the voltage at which the first knee in the LV curve occurs. If C_T is the total capacitance of the device below threshold, this is also the voltage at which the line $Q = C_T V$ intersects the open, above-threshold QV loop (C). In practice, it is sometimes defined as the voltage at which a certain luminance value occurs at a given frequency, e.g., the voltage at which the luminance is 1 cd/m^2 at 60 Hz. V_{to} is the voltage at which the slope of the *QV* loop changes from C_T to C_I, where C_I is the capacitance of the insulator layers.

Since a differential element of energy delivered to the ACTFEL device is $dE = V(t)dQ$, then

$$E = \int V(t)dQ \tag{94.4}$$

The energy delivered per period of the drive waveform is thus equal to the area encompassed by the *QV* loop. The power dissipated is just the energy per period multiplied by the frequency. In practice, the area of the *QV* loop is measured by numerical integration. The calculation can be carried out on the oscilloscope if it has analysis capabilities or the data can be transferred to the control computer for integration.

Generation of the $Q_P F_P$ loop does not require any electrical measurements other than those required for the *QV* loop. Q_P is the charge separation across the phosphor layer and F_P is the electric field across the phosphor layer. If the thicknesses and dielectric constants of the insulator and phosphor layers are known, Q_P and F_P can be calculated from the values of $Q(t)$ and $V(t)$ on the *QV* loop. This is accomplished by applying the following equations [11,12]:

$$Q_P(t) = \frac{C_i + C_P}{C_i} Q(t) - C_P V(t) \tag{94.5}$$

and

$$F_P(t) = \frac{1}{d_P}\left(\frac{Q(t)}{C_i} - V(t)\right) \tag{94.6}$$

where C_i is the capacitance of the insulators, C_P is the capacitance of the phosphor layer, and d_P is the thickness of the phosphor layer.

Time-Resolved Measurements

The apparatus for measuring τ is shown in Fig. 94.9. A photomultiplier tube (PMT) is used to detect the light emission as a function of time. The drive system is set to provide relatively narrow drive pulses, typically 10 µs pulse width, at relatively low frequency, typically 60 Hz. This approach works well for phosphors with relatively long decay times, on the order of 100 µs to a few milliseconds. This is the case for many common ACTFEL phosphors such as ZnS:Mn and ZnS:Tb. Phosphors such as SrS:Ce, however, have very fast decay times and cannot be measured in this manner. In such cases the photoluminescent decay time must be measured using a pulsed laser to excite the phosphor and appropriately low *RC* response time of the light detection system.

The general setup for measuring time-resolved emission spectra from ACTFEL devices is shown schematically in Fig. 94.10. The oscilloscope is triggered on the drive waveform and the signal integration period is set to the region of interest. A boxcar integrator can also be used to integrate the light signal during the desired time window. The monochrometer wavelength is scanned and the emission spectrum is collected for the selected portion of the emission process.

Aging

ACTFEL devices tend to stabilize after a few tens of hours of burn-in, but can exhibit complex aging behavior during the burn-in process. The luminance vs. voltage curves for ZnS:Mn devices in which the phosphor layer is deposited by evaporation, for example, tend to shift to slightly higher voltage during burn-in [2]. Luminance vs. voltage curves for devices in which the ZnS:Mn is deposited by ALE tend to shift to slightly lower voltage [13]. Aging data is collected by measuring luminance vs. voltage at selected

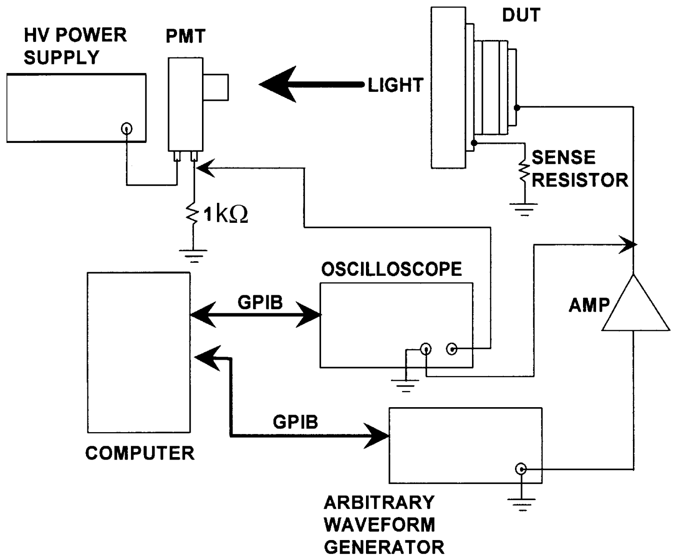

FIGURE 94.9 Apparatus for measuring the luminescent decay time of the ACTFEL phosphor. The light signal is measured by the oscilloscope across the sense resistor on the output of the PMT. The oscilloscope is triggered on the drive pulse.

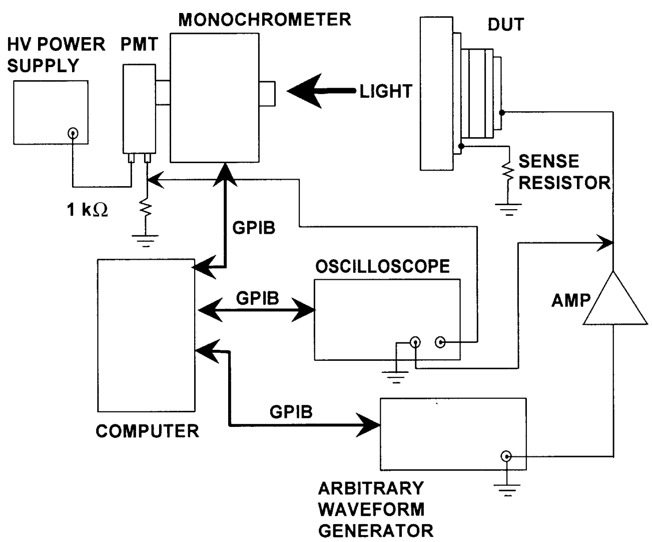

FIGURE 94.10 System for measuring the time-resolved emission spectrum of an ACTFEL device. The oscilloscope is set to integrate the light signal from the PMT during a selected time window. The monochrometer wavelength is scanned over the entire spectral range and the emission intensity data is collected from the oscilloscope.

time intervals during aging. The measurement is carried out as described earlier for luminance vs. voltage measurements. The aging is done by continuously operating the device at a fixed voltage or at a fixed voltage above threshold. The aging process can be accelerated by operating the device at higher frequency.

94.8 Characterization of Matrix-Addressed Displays

The characterization of matrix-addressed displays differs from characterization of test dots because less control of the drive waveform is readily available. The row and column drivers do not provide great flexibility, although some control can be exercised by varying the composite drive waveform and the control signals to the driver chips. These types of modifications, however, require detailed knowledge of the addressing and control electronics involved and are best left to the original display manufacturer. Measurements that are more accessible and of more general interest involve characterization of the luminance, chromaticity, uniformity, display life, latent image, and defects. For these measurements the display under test is controlled by a computer through a standard video output or a custom video display interface provided with the display. The display operating voltage and frequency are fixed. The display is placed in a dark room or enclosure. Luminance is measured with a photometer. Chromaticity is measured with a spectrophotometer or a photometer equipped with tristimulus filters. Uniformity can be measured by mounting either the display or the photometer/spectrophotometer on a translation system and collecting data at points in a regular array of locations throughout the display surface. Display life is characterized by operating the display in a full-on pattern, cycling through checkerboard patterns, etc., and making luminance measurements at exponentially increasing time intervals. Latent image is formed by displaying small blocks in various fixed locations and various fixed gray levels (if available) continuously for long periods. It is characterized by setting the entire screen to each gray level available and measuring the luminance in the locations which had blocks displayed during aging as well as unaged areas nearby. Latent image is the percent luminance difference between aged blocks and nearby unaged areas. Latent image is typically measured after aging the block pattern for 1000 h. Defects are classified into pixel, line, and mura defects. They are characterized by visual inspection with the aid of an eye loupe or by an automated flat panel inspection system.

94.9 Excitation and Measurement Equipment

Excitation of Test Dots

Test dots can be excited by any signal source that provides bipolar pulses up to a peak voltage of 300 V and sufficient current sourcing and sinking capability to charge and discharge the device capacitance. Bipolar pulse drivers with sufficient voltage and current output can be built with commercially available components. A hybrid circuit op amp, produced by Apex Microtechnology, provides sufficient voltage output and frequency response. A current boosting stage can be added to the output if the DUT capacitance is too large to drive directly. This amplifier approach is very flexible since any waveform that can be generated by the arbitrary waveform generator can be used. There are also some commercial amplifiers available that are effective for driving test dots for some measurements. They tend to have limited bandwidth and must be used with caution in situations in which the measurement is sensitive to the exact shape of the drive pulse. This would be the case, for example, in *QV* measurements and often in efficiency measurements.

Excitation of Matrix-Addressed Displays

Excitation of matrix-addressed displays is straightforward since the drive electronics are integrated with the display. Generally, only a standard ac power outlet and a computer with an appropriate video card are required. Test patterns for measurement can be created using simple computer programs.

94.10 Measurement Instruments

Measurement of Drive Voltage and Current

Digital oscilloscopes are used for all of the electrical measurements described in this chapter. Suitable instruments are available from several manufacturers, including Tektronix and Hewlett-Packard. A bandwidth of 100 MHz is more than sufficient. Waveform analysis capabilities are very helpful but not absolutely necessary. RS 232 or IEEE 488 interfaces are required for computer control and data transfer.

TABLE 94.1 Light Measurement Instruments

Instrument Type	Model	Manufacturer
Photometer	PR880	Photo Research
Photometer/spectroradiometer	PR650	Photo Research
	Pritchard 1980B	Photo Research
	GS-1280 RadOMAcam	Gamma Scientific (EG&G)
Photomultiplier tubes	—	Oriel Corp.
	—	Hamamatsu
Photodiode	PIN 10AP	UDT Sensors, Inc.
Flat panel inspection system	FIS 250	Photon Dynamics, Inc.

TABLE 94.2 Manufacturers of Light Measurement Instruments

Photo Research 9330 DeSoto Avenue, P.O. Box 2192 Chatsworth, CA 91313-2192 (818) 341-5151	Hamamatsu Photonics Systems Corp. 360-T Foothill Road, P.O. Box 6910 Bridgewater, NJ 08807-0910
Gamma Scientific (EG&G) 8581 Aero Dr. San Diego, CA 92123-1876 (619) 279-8034	UDT Sensors, Inc. 12525 Chadron Ave. Hawthorne, CA 90250 (310) 978-0516
Oriel Corp. 252 Long Beach Blvd., P.O. Box 872 Stratford, CT 06497-0872 (203) 380-4200	Photon Dynamics, Inc. 6325 San Ignacio Ave. San Jose, CA 95119 (408) 226-9900

Measurement of Emitted Light

Several types of instruments are used for measuring light emission from ACTFEL displays. Photometers are used for luminance measurements. Spectrophotometers are used for measuring the emission spectrum and with suitable software can also provide luminance measurements. Time-resolved measurements are accomplished by using photomultiplier tubes or photodiode detectors. Table 94.1 lists some examples of photometers, spectroradiometers, photomultipliers, and photodiodes along with the names of the companies that manufacture them. A relatively new development for characterizing the light emission characteristics of flat panel displays, including ACTFEL displays, is the flat panel inspection system. This is a large measurement system comprising a CCD camera detector, light-tight enclosure, control computer, image processor, and specialized software. This type of system images an entire flat panel display on the CCD camera and measures luminance, chromaticity, and various defects by analyzing the image. These systems are intended for high throughput manufacturing environments and cost several hundred thousand dollars. An example of this type of system is also included in Table 94.1. Contact information for the companies listed in Table 94.1 is provided in Table 94.2.

Defining of Terms

Electroluminescence: The nonthermal generation of light resulting from the application of an electric field to a substance, usually a luminescent crystal.

Latent image: The ghost image of a previously displayed pattern which can sometimes be seen in a full field on an electronic display screen.

Light emission decay time: The time it takes for the light emission from one excitation pulse to fall to $1/e$ times its initial value.

Polarization charge: The charge trapped at the phosphor/insulator interface following the application of a drive pulse.

Polarization field: The field across the phosphor layer resulting from the polarization charge.

***Q_pF_p* loop:** The closed curve which results from plotting the internal charge flow across the phosphor layer (Q_p) vs. the electric field across the phosphor layer (F_p).

***QV* loop:** The closed curve which results from plotting the external charge (Q) flowing into a TFEL device vs. the externally applied voltage (V).

Threshold voltage: The voltage amplitude of the drive waveform above which current flows across the phosphor layer and light is emitted from a TFEL device.

Turn-on voltage: The voltage corresponding to the first knee in the *QV* loop of a TFEL device. This is the voltage at which charge begins to flow across the phosphor layer. This voltage is generally less than the threshold voltage because the internal field across the phosphor layer is enhanced by the polarization field once the polarization charge has built up in the steady state.

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