

OLED DISPLAY

FUNDAMENTALS AND APPLICATIONS



TAKATOSHI
TSUJIMURA

 **WILEY**

SID

Series in Display Technology

Wiley-SID Series in Display Technology

Series Editor:
Anthony C. Lowe

A complete list of the titles in this series appears at the end of this volume.

OLED Displays

Fundamentals and Applications

Takatoshi Tsujimura



A John Wiley & Sons, Inc., Publication

Copyright © 2012 by John Wiley & Sons, Inc. All rights reserved.

Published by John Wiley & Sons, Inc., Hoboken, New Jersey.

Published simultaneously in Canada.

No part of this publication may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, photocopying, recording, scanning, or otherwise, except as permitted under Section 107 or 108 of the 1976 United States Copyright Act, without either the prior written permission of the Publisher, or authorization through payment of the appropriate per-copy fee to the Copyright Clearance Center, Inc., 222 Rosewood Drive, Danvers, MA 01923, (978) 750-8400, fax (978) 750-4470, or on the web at www.copyright.com. Requests to the Publisher for permission should be addressed to the Permissions Department, John Wiley & Sons, Inc., 111 River Street, Hoboken, NJ 07030, (201) 748-6011, fax (201) 748-6008, or online at <http://www.wiley.com/go/permissions>.

Limit of Liability/Disclaimer of Warranty: While the publisher and author have used their best efforts in preparing this book, they make no representations or warranties with respect to the accuracy or completeness of the contents of this book and specifically disclaim any implied warranties of merchantability or fitness for a particular purpose. No warranty may be created or extended by sales representatives or written sales materials. The advice and strategies contained herein may not be suitable for your situation. You should consult with a professional where appropriate. Neither the publisher nor author shall be liable for any loss of profit or any other commercial damages, including but not limited to special, incidental, consequential, or other damages.

For general information on our other products and services or for technical support, please contact our Customer Care Department within the United States at (800) 762-2974, outside the United States at (317) 572-3993 or fax (317) 572-4002.

Wiley also publishes its books in a variety of electronic formats. Some content that appears in print may not be available in electronic formats. For more information about Wiley products, visit our web site at www.wiley.com.

Library of Congress Cataloging-in-Publication Data

Tsujimura, Takatoshi.

OLED displays: fundamentals and applications / Takatoshi Tsujimura.

p. cm.

Includes bibliographical references and index.

ISBN 978-1-118-14051-2

1. Flat panel displays. 2. Electroluminescent devices. 3. Organic semiconductors.

I. Title.

TK7882.I6T83 2011

621.3815'422-dc23

2011027371

Printed in Singapore.

10 9 8 7 6 5 4 3 2 1



Figure 4.26 A white monochrome passive-matrix OLED display product (EDIROL R09 digital audiorecorder).

4.4 ACTIVE-MATRIX OLED DISPLAY

As discussed above, active-matrix driving is necessary when larger or higher-resolution displays are needed. Active-matrix OLED display design techniques are discussed in this section.

4.4.1 OLED Module Components

Figure 4.27 shows an example of an active-matrix OLED (AMOLED) product. Active-matrix OLED display includes the following components.

- TFT (thin-film transistor) substrates (also called *backplane substrates*; discussed in Chapter 5)
- Encapsulation glass (discussed in Section 3.4)
- Driver integrated circuits (IC) (discussed in Sections 5.4.4 and 5.4.5)
- Circular polarizers (may be unnecessary in certain applications).



Figure 4.27 An active-matrix OLED display (a “media skin” cellular phone by KDDI).

As TFT is manufactured in large scale due to LCD needs, so its cost is reduced enough compared with other components. For the reduction, the main focus for active-matrix should be encapsulation, driver ICs, and material utilization.

4.4.2 Two-Transistor One-Capacitor (2T1C) Driving Circuit

Figure 4.28 shows an example of the OLED pixel emission of an actual product, and Fig. 4.29 shows how current is supplied to the OLED device by the driver TFT. By changing the gate node voltage of the driver TFT, the driver TFT current can be modified to control OLED emission intensity.

Figure 4.30 shows the most fundamental OLED display pixel circuit, the 2T1C circuit. As mentioned above, this acronym is derived from the fact that the circuit contains two transistors and one capacitor. Other pixel circuits are equipped with two TFTs and one capacitor; however, the designation 2T1C normally indicates a circuit configuration as shown in Fig. 4.30.

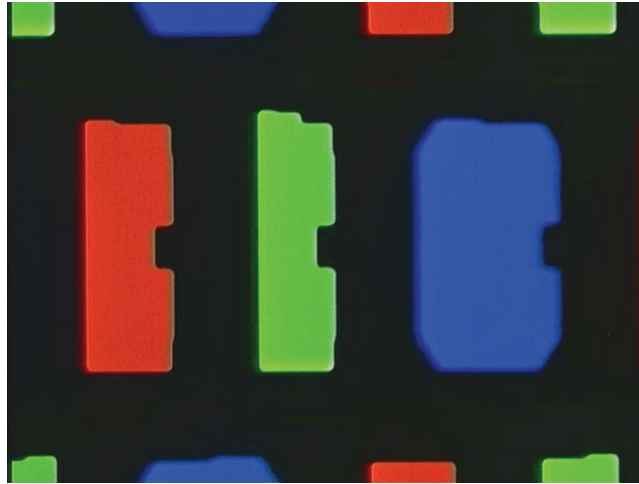


Figure 4.28 An example of an OLED pixel used in an actual product.

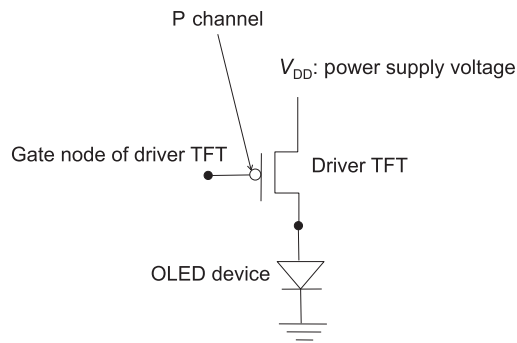


Figure 4.29 Circuit diagram showing current supply to an OLED device by driver TFT.

This circuit programs the gate node voltage of the driver TFT, which determines the OLED device luminance, by introducing a data line voltage signal through the switching TFT when the pixel is selected by the scan line. The method of programming the data line voltage signal through the switching TFT to the pixel capacitor is the same as that of the LCD pixel circuit.

For actual implementation, more complicated circuits are often used to compensate for the current distribution of the driver TFT and OLED device or for their instabilities. These techniques are discussed in Section 5.4.4.

Figure 4.31 shows the matrix arrangement of pixels. Color can be expressed by the combination of red, green, and blue subpixels. Most data drivers can

4.4 Active-Matrix OLED Display

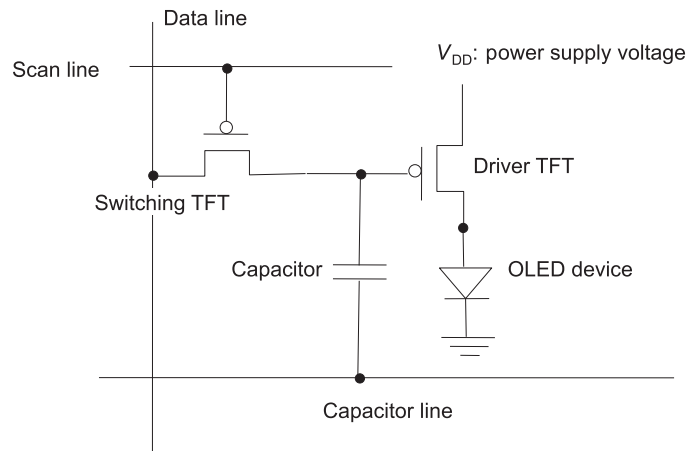


Figure 4.30 Circuit diagram of the two-transistor one-capacitor (2T1C) pixel driving circuit.

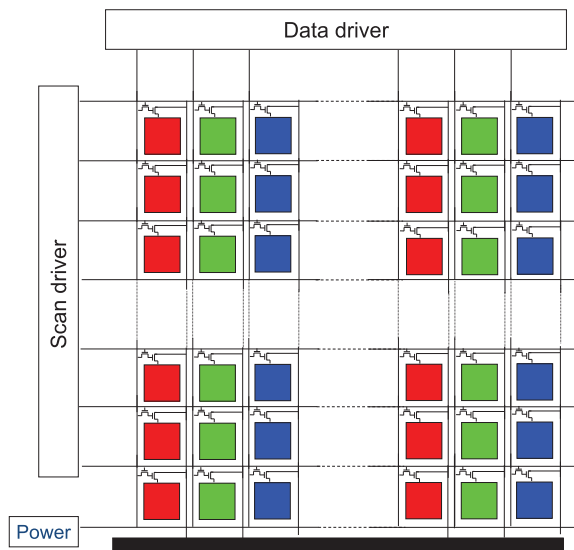


Figure 4.31 An active-matrix OLED display.

display has a simple structure, so a wall-mounted display with not much wall reinforcement may be possible even with a large display size.

5.4.4 LTPS-TFT Pixel Compensation Circuit

The liquid crystal in LCD displays is driven by voltage. (In fact, in the very early stages of LCD development, liquid crystal, e.g. that used in dynamic scattering-mode LCD, was driven by electric current rather than voltage.) On the other hand, OLED displays are driven by electric current, so small current variations can be distinguished as nonuniformity (*mura*). Thus, a simple driving method using a 2T1C circuit, for example, tends to cause yield loss due to mura.

Figure 5.30 shows an extreme-case example of luminance mura. The human eye is very sensitive to changes in luminance, so if there is driver TFT current non-uniformity in the display area, it is perceived as mura. In particular, LTPS-TFT treated by excimer laser annealing has a serious mura issue, so various compensation circuits have been proposed and applied in practice.

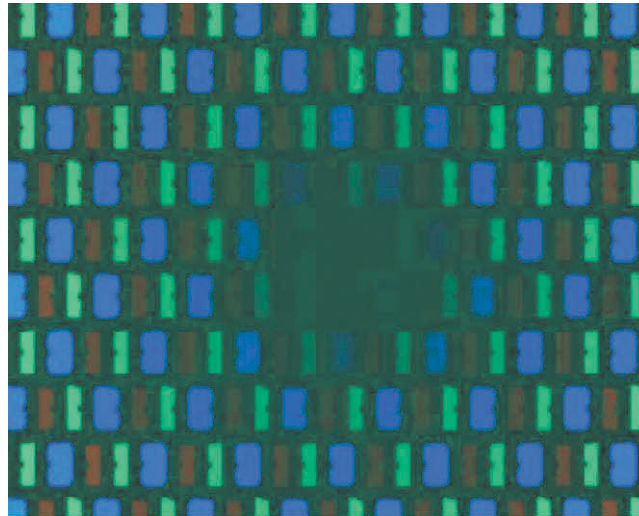


Figure 5.30 Image of luminance mura (nonuniformity) due to variation in threshold voltage.

Figure 5.31 Schematic representation of threshold voltage detection via gate–drain node connection.

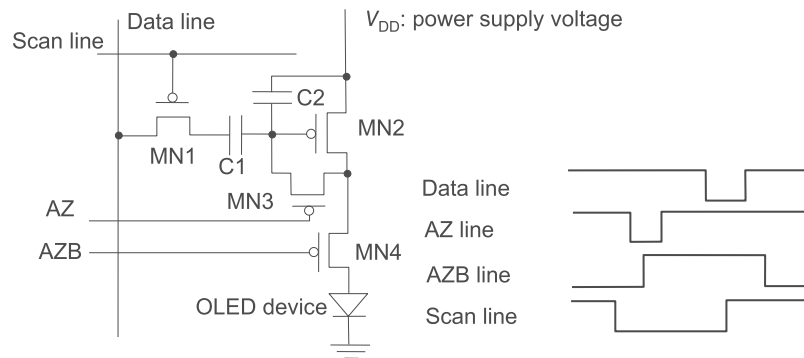
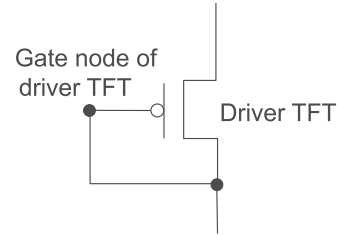


Figure 5.32 Voltage programming circuit drawn by Dawson et al. [7].

5.4.4.1 Voltage Programming

The basic principle of V_{th} compensation is to store the driver TFT V_{th} in the gate node as $V_G = V_D + V_{th}$, by connecting gate and drain nodes as shown in Fig. 5.31. This principle has been used in various compensation circuits, not only for voltage programming.

Figure 5.32 shows a V_{th} compensation circuit by voltage programming presented by Dawson et al. in 1999 [8]. This circuit is thought to be the prototype of most subsequent voltage programming compensation circuits [9–14].

Here, we discuss the working principle of the circuit, step by step:

1. The AZ line is set to negative voltage, and MN3 TFT turns on. (Note that the TFT is P-channel.)
2. The gate node and drain node of MN2 are connected and create the same scenario as shown in Fig. 5.31, so the gate node of driver TFT (MN2) stores V_{th} information.

3. The data line signal voltage is added to the driver TFT gate node using capacitance coupling of C1.
4. As the gate node of the driver TFT stores the data line signal plus V_{th} , the source–drain current of the driver TFT does not contain V_{th} information. Therefore mura (nonuniformity) related to V_{th} variation does not take place, due to the cancellation mechanism.

Voltage programming is the method most frequently used for actual OLED display products. The major reason is that an OLED driver IC is similar to an LCD display driver IC. As many circuit design techniques for LCD drivers can be applied for voltage programming drivers, IC drivers can be designed very easily and are also relatively inexpensive.

On the other hand, IC driver voltage programming has some disadvantages such as

- Inability to compensate for either mobility variation or OLED variation.
- Aperture ratio loss due to the occupied space by the programming circuit in the case of bottom emission structure. (Top emission can circumvent this issue.)

Note that the lifetime is proportional to $1/J^n$, as discussed in Section 2.2.4 (J = current density, $n = 1.2$ – 1.9). As current density is inversely proportional to the aperture ratio, therefore,

$$\text{Lifetime} \propto \frac{1}{J^n} \propto AR^n.$$

If $n = 1.5$, the lifetime becomes only 35% for $AR = 50\%$, 25% for $AR = 40\%$, and 16% for $AR = 30\%$; this is a significant reduction, so a top emission structure is useful to avoid such problems.

5.4.4.2 Current Programming

Figure 5.33 shows one of the most widely known current programming compensations, current mirror pixel circuit designs. [15]. The circuit uses four TFTs and one capacitor.

Here we assume that the TFT dimension T1 is equal to T2. (In actual implementations, T1 is intentionally designed with a dimension different from that of T2 to reduce the charging time.) Turning on T3 and T4, and also applying current I_{data} to T1, ensures that the gate nodes of T1 and T2 are charged to the target voltage so that the driver TFT can flow current equivalent to I_{data} . This method uses current, not voltage, as a reference, so it can

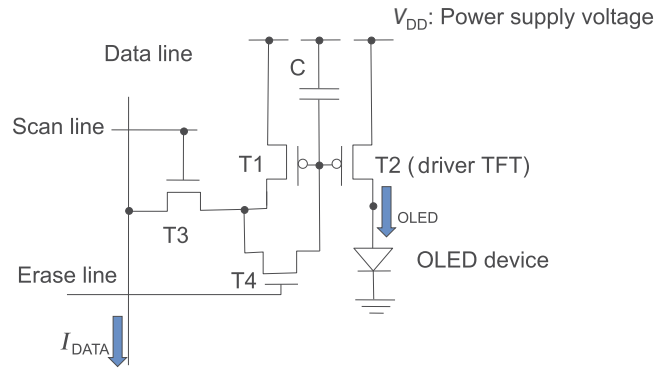


Figure 5.33 Current mirror-type compensation circuit proposed by Sasaoka et al. [14].

compensate for V_{th} and mobility of the driver TFT and also for any variation in OLED device characteristics.

Although current programming has various advantages, it has drawbacks such as driver IC cost (discussed above), and also its long charging period for low grayscale levels. Several methods have been proposed to address this issue.

5.4.4.3 External Compensation Method

There is minimal change in LTPS-TFT performance during the driving operation. Therefore, mura (nonuniformity) can be corrected by applying an offset to the pixel by the driver IC using a factory-set value. (This is called the *external compensation method* [16, 17].) This method is promising because the cost of memory is steadily decreasing. Figure 5.34 presents an example of a product using the external compensation method, referred to as global mura compensation (GMC). Actual uniformity data before and after implementation of the GMC method are shown in Fig. 5.35.

Figure 5.36 shows the process flow of the GMC external compensation method.

The manufactured panels are inspected pixel by pixel (actual inspection equipment is shown in Fig. 5.37), and the offset data are recorded in the memory mounted on each panel. Luminance error (mura) caused by LTPS-TFT current variation can be canceled by calculating the correct driver TFT gate node value (R' , G' , and B') using an offset measured in the factory when displaying R, G, and B signals on a display.