Introduction to Microdisplays

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Abstract

This chapter defines the term "microdisplay" and then overviews the origins, history, and applications of microdisplays. It briefly describes and compares various microdisplay technologies that are, and have been, prevalent. Subsequent chapters go into greater detail on selected technologies.

List of Abbreviations

α-Si	Amorphous silicon
AM	Active matrix
CMOS	Complementary metal-oxide semiconductor
CRT	Cathode ray tube
DLP	Digital light processing
DMD	Digital micromirror device
EASLM	Electrically addressed SLM
EVF	Electronic viewfinder
FLCOS	Ferroelectric LCOS

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J. Chen et al. (eds.), *Handbook of Visual Display Technology*,
DOI 10.1007/978-3-319-14346-0_125

HMD	Helmet (or "Head")-mounted display
HWD	Head-worn display
LCD	Liquid crystal display
LCOS	Liquid crystal on silicon
LED	Light-emitting diode
μLED	Micro-LED
MOS	Metal-oxide semiconductor
MOSFET	MOS field-effect transistor
MOST	MOS transistor (or MOSFET)
N-LCOS	Nematic LCOS
NTE	Near-to-eye
OASLM	Optically addressed SLM
OLED	Organic light-emitting diode
P-OLED	Polymer OLED
p-Si	Polycrystalline silicon
PHOLED	Phosphorescent OLED
PM	Passive matrix
SLM	Spatial light modulator
SMOLED	Small-molecule OLED
TFT	Thin film transistor
VGA	Video graphics array
XLCOS	Transmissive LCOS
x-Si	Semiconducting crystalline silicon

Introduction

The term "microdisplay" is generally accepted as referring to that class of miniature, high-information-content, electronic information display panels that are intended to be viewed indirectly by means of an optical system that provides a (typically highly) magnified image of the panel. This is in contrast to most other, even miniature, display panels that are intended to be viewed directly and without optical magnification although often with significant levels of optical enhancement. To be specific, then, the term "microdisplay" refers to the panel or display component alone. Additional electronic, mechanical, and optical components are usually required in order to complete the microdisplay module or system. Figure 1 is a photograph of a microelectromechanical system (MEMS)-based microdisplay, while Fig. 2 is a photograph of a polymer organic light-emitting diode (P-OLED) on a CMOS microdisplay that gives a good impression of the small size of these components.

In this section, we deal with only those microdisplay devices that contain a 2-D Cartesian array of pixels arranged in rows and columns. 2-D microdisplay-based systems are sometimes in competition with systems that contain (a) an image engine with a 1-D pixel array, such as the grating light valve, that produces one

Fig. 1 Photograph of a DLP microdisplay unit

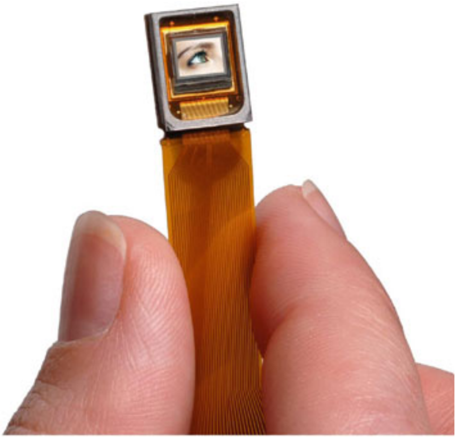


Fig. 2 Photograph of a P-OLED microdisplay unit

line of an image at a time and is quickly scanned in 1-D in the direction orthogonal to the 1-D array in order to produce all of the lines required for a 2-D image or (b) a single spot producing engine (such as a laser) that is scanned in 2-D and modulated synchronously to produce a 2-D image. These 1-D and 2-D scanning systems and their component devices will not be described here.

History

The earliest microdisplays were miniature CRTs that enabled the development of CRT-based HMDs for military purposes as described much later in Rash (1999). Most other early modulating microdisplay technologies were developed alongside or were derivatives of a class of devices called spatial light modulators (Casasent

1977; Efron 1994; Fisher and Lee 1987) (SLMs) also known as light valves. By way of example, one of the first reports on the DMD (Pape and Hornbeck 1983) (at the time called the deformable mirror device and only later to become the digital micromirror device) classed it as a SLM – not a microdisplay.

A spatial light modulator is a device that can impress a 2-D pattern on to an optical wave front. This would include a 35 mm transparency placed in a slide projector. SLMs are generally considered to be programmable or addressable and split into two subclasses – optically addressable SLMs (OASLMs) and electrically (or electronically) addressable SLMs (EASLMs). Light-modulating microdisplays comprise a subset of EASLMs.

SLMs were developed primarily to exploit the parallelism of optics in a field called optical information processing or optical computing at a time before the longevity of Moore's Law and microelectronics was fully appreciated. SLMs were very expensive in the mid-1980s, and, amusingly, commercially available handheld TVs were sometimes cannibalized and their LCD screens (typically 1 or 2 in. in size) used as low-cost medium-quality SLMs (see, e.g., Casasent and Xia 1986).

Classification of Microdisplays

One method of classification of microdisplays relates to the means of light output within each pixel, namely, *emissive* or *modulating*. An emissive microdisplay is a process in which an electrical signal applied to the optical layer of a pixel (typically a current passed through it) causes the emission of light by electroluminescence or some other means. A modulating microdisplay is a process in which an external illumination source causes light of equal intensity to fall on the optical layer of all pixels; then an electrical signal applied to the optical layer of each pixel (typically a voltage or electric field applied across it) causes either a direct change in the amplitude of the output light or a change in some other property (such as direction or polarization state) of the output light that is converted to amplitude modulation further downstream. Modulating microdisplays can be reflective or transmissive depending on whether a combination of reflective electrode and opaque substrate, or transparent electrode and substrate, is used. Examples of emissive, reflective, and transmissive microdisplay pixels are shown in schematic cross section in Figs. 3, 4, and 5, respectively.

Generic Microdisplay Architecture

Viewed notionally from above, a microdisplay is a miniature version of, but in other ways very similar to, most electronic information display panels, comprising a 2-D Cartesian array of pixels. A generic schematic is shown in Fig. 6. The pixels may be square or rectangular and may contain sub-pixels (e.g., a color pixel usually contains three sub-pixels, namely, red, green, and blue).

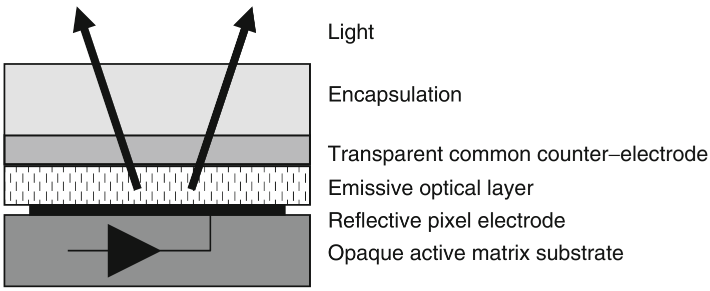


Fig. 3 Schematic cross section of a pixel of an emissive microdisplay panel

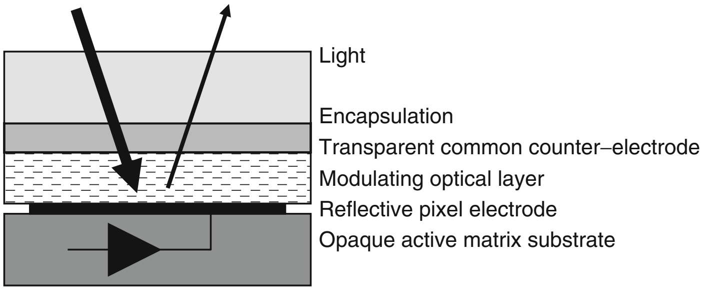


Fig. 4 Schematic cross section of a pixel of a reflective-modulating microdisplay panel

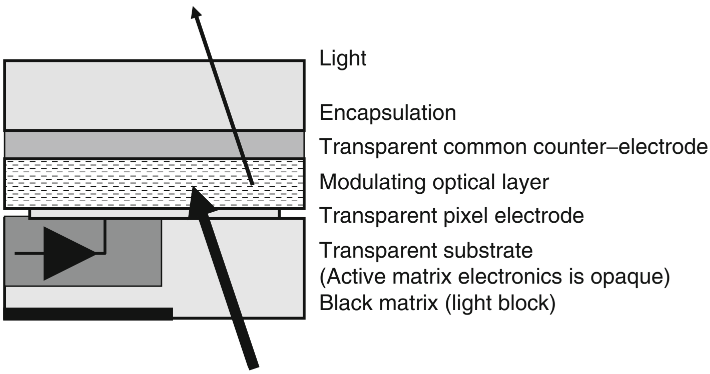
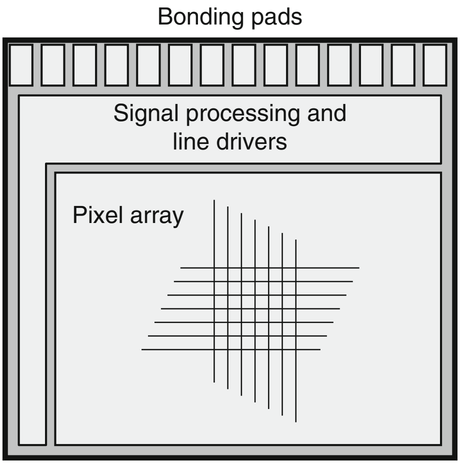


Fig. 5 Schematic cross section of a pixel of a transmissive-modulating microdisplay panel

Overview of Microdisplay Technologies

Viewed notionally in cross section, a microdisplay has two main functional layers. The substrate, or backplane, offers mechanical rigidity and support. It also contains the electronics and handles all of the necessary processing,

Fig. 6 Schematic plan view of a typical microdisplay



sorting, storing, and transmission of data. The vast majority of microdisplay technologies use almost standard mainstream-integrated circuit technology for the substrate, namely, complementary metal-oxide semiconductor (CMOS). The primary alteration is that of a custom finish to the top metal surface (mirror-quality metal layer on a highly polished planar dielectric) in order to create a high-quality reflective substrate. A few microdisplay technologies use a miniaturized version of the transmissive polycrystalline silicon TFT-on-glass active-matrix LCD technology that is common in high-performance small-to-medium-area active-matrix LCDs.

The overlying electrooptical layer, or front plane, carries out, on a pixel-by-pixel basis, conversion of the electrical stimulus to an optical format that achieves or enables, in conjunction with downstream components, the formation of the image. Widely used modulating front-plane technologies for microdisplays include many configurations of nematic LC, surface-stabilized ferroelectric LC, and MEMs including the digital micro-mirror device (DMD). Historically, magneto-optic and many other approaches have been used. Emissive front-plane technologies include various types of OLED and gallium nitride (GaN) micro-LED.

Qualitative Technology Comparison

The primary characteristics of the mainstream 2-D microdisplay backplane technologies already mentioned (along with, for comparison purposes, α-Si and organic TFT) are summarized qualitatively in Table 1, while those of the main front-plane technologies are summarized qualitatively in Table 2.

Table 1 Qualitative comparison of microdisplay and other backplane technologies

	Plastic TFT	α-Si TFT	p-Si TFT	x-Si MOST
Electron mobility	Very low	Very low	Med+	High+
Hole mobility	–	N/A	Med−	High−
n-Channel available	Yes	Yes	Yes	Yes
p-Channel available	Yes	(No)	Yes	Yes
OFF leakage current (pA)	–	1	1	0.1
Relative minimum feature (μm)	–	Large	Medium	Small
Example minimum pixel pitch (μm)	–	Large	Medium	Small
Minimum display size	Medium	Medium	Small	Very small
Maximum display size	Huge	Huge	Large	Very small
Typical mask count	N/A	4–6	6–10	20+
Integration capability	Low	Low	Medium	Very high
Stability (variation with time)	Poor	Poor	Good	Very good
Uniformity (spatial variation)	Poor	Good	Poor	Very good

Applications of Microdisplays

Microdisplays are used in a number of major display applications within two main classes of application. These are projection systems and near-to-eye (NTE) systems.

Projection systems create a highly magnified real image of the microdisplay on a flat surface where it can be seen by one or more viewers simultaneously, as illustrated schematically in Fig. 7. Types of projection systems include – in order from larger to smaller – digital cinema, lecture theater, home cinema, PC and laptop (data projector), portable projector, and pico-projector. The last category is a novel class of projector that emerged in the late 2000s. Pico-projectors are unique in that they are pocket sized and battery powered, thus setting tight constraints on size, weight, and power consumption. Pico-projectors may be stand-alone units designed to connect to a base unit such as an iPad or a mobile phone; alternatively a pico-projector function may be integrated into a digital camera, camcorder, or cell phone.

Near-to-eye systems create a highly magnified virtual image that can be seen by an individual viewer placing their eye close to (within the eye box of) the magnifying lens or lens group, as illustrated schematically in Fig. 8. NTE systems split into those, called electronic viewfinders, which are integrated into handheld devices such as cameras and camcorders and those which are integrated into hands-free consumer, professional, commercial, and military/security systems such as helmet-mounted displays (HMDs), head-worn displays (HWDs), and video glasses.

Table 2 Qualitative comparison of microdisplay electrooptical or front-plane technologies

	Nematic LCOS	FLCOS	XLCOS	TFT-LCD	DLP	OLED	Micro-LED
Mode	Reflection modulation	Reflection modulation	Transmission modulation	Transmission modulation	Reflection modulation	Emission	Emission
Contrast ratio	Very high	Very high	High	Very High	Very high	Very high	Very high
Switching time ON/OFF	Slow	Fast	Slow	Slow	Fast	Very fast	Very fast
Grayscale method	Analog	Binary pulsed	Analog	Analog	Binary pulsed	Either	Either
Active-matrix mode	Analog/digital	Digital	Analog	Analog	Digital	Analog/digital	–
Color	RGB/FSC	FSC	RGB/FSC	RGB	FSC	W + CF	–
Color range	Good/very good	Very good	Good/very good	Very good	Very good	Good	–
Aperture ratio	Very high	Very high	Medium	Medium	Very high	Very high	Low

Key: *RGB*, spatial sub-pixels; *FSC*, field-sequential color; *W* + CF, white emission with RGB color filters

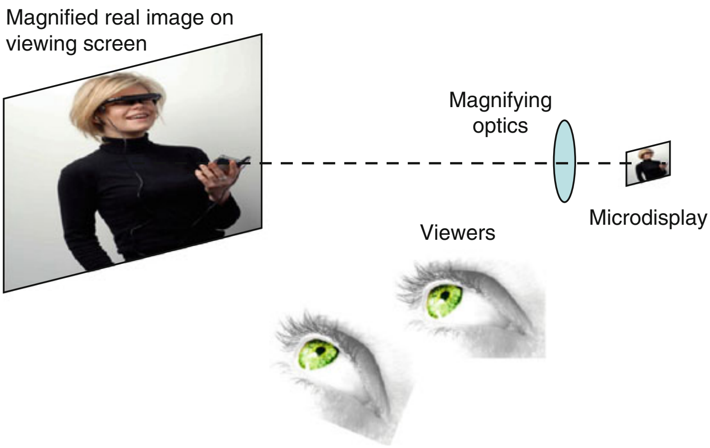


Fig. 7 Simplified schematic of a projection optical system

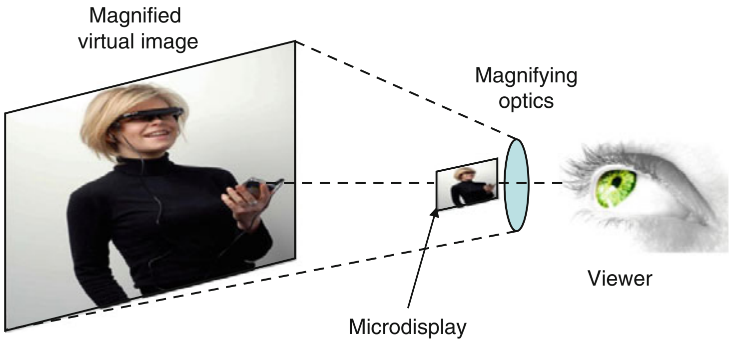


Fig. 8 Simplified schematic of a near-to-eye optical system

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