IMOD DISPLAY: AN OVERVIEW

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Abstract— In today's world where displays are such an integral part of any computing system and with the growth of the internet usage on computing devices, the demand for an increasingly efficient display system has resulted in extensive researches in this field. The end point to one of those research routes has led to the development of a MEMS based technology known as Interferometric modulator display (trademarked Mirasol). IMOD uses the process of light interference within thin films, the same technique that gives colour to butterfly wings and peacock, to display technology. In essence, IMOD is a bio mimetic display that uses thin-film optics and MEMS structures to create an always-on bistable reflective display that consumes far less power and has paper-like readability (even in direct sunlight) compared to organic-light-emitting-diode (OLED) or liquid-crystal displays (LCDs). In this paper, we review the display technology from the architectural to the production point of view. We further move onto reviewing the advantages and the challenges in this set up and where this technology stands in the market.

Keywords— Abrasion, active-matrices, amplified, bio-mimetic, bistable, CCFL, colour-filters, constructively-interfere, counterbalance, desiccant, destructively-interfere, e-readers, electrostatic, encapsulation, entrenched , EPD, etching, FPD, glass-substrate, GPS, hysteresis, IMOD, interference, LCD, light-modulation, MEMS, micro-embossed, mimics, Mirasol, Morpho butterfly, NRE, OLED, optical-cavity, PDAs, pixels, polarizer, Qualcomm, reflectivity, replicate, retooling, robustness, sandwich-pillars, singulate, spray-coated, stiction, substrate, TFT, Toq, transmissisive, ubiquitous, ultraviolet, viscosity, wavelength-gaps, XeF2.

I. INTRODUCTION

Interferometric Modulator (IMOD) technology is the revolutionary technology mainly found in Qualcomm's mirasol® displays. Based upon micro-electro-mechanical systems (MEMS), IMOD technology displays enable reflective, direct view, flat panel displays. An IMOD-based reflective flat panel display includes hundreds of thousands of individual IMOD elements each a MEMS-based device. The structure exploits interference, providing a highly efficient reflective display which enables superior viewability across a wide range of ambient viewing conditions. The electro-mechanical behavior of the MEMS device provides bistability, in turn providing low power consumption. IMOD pixels are capable of switching speeds in the order of microseconds, enabling video-rate-capable displays. Displays fabricated using IMOD technology have demonstrated reflectivity of greater than 60 percent, contrast ratios greater than 15:1 and drive voltages below 5 volts. Though simple in structure, displays using IMOD elements provide the functions of light modulation, colour selection and memory while replacing the functionality provided by polarizer's, liquid crystal, colour filters, and active matrices found in Liquid Crystal Displays (LCD).

II. BASIC STRUCTURE

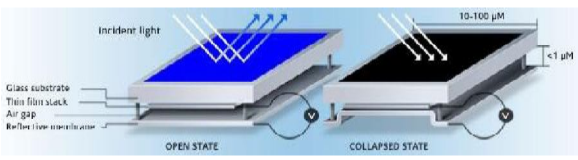


Figure 1: Core of an IMOD Display

The basic elements of an IMOD-based display are microscopic devices that act essentially as mirrors that can be switched on or off individually. The IMOD element is a simple MEMS device that is composed of two conductive plates. One is a thin film stack on a glass substrate, the other is a reflective membrane suspended over the substrate. There is a gap between the two that is filled with air. The IMOD element has two stable states. When no voltage is applied, the plates are separated, and light hitting the substrate is reflected as shown above. When a small voltage is applied, the plates are pulled together by electrostatic attraction and the light is absorbed, turning the element black. Each of these elements reflects only one exact wavelength of light (such as a specific hue of red, green or blue) when turned on, and absorb light (appear black) when off. Elements are organized into a rectangular array in order to produce a display screen.

III. WORKING PRINCIPLE

IMOD displays use interfering light waves to create bright colours on demand. Each basic unit cell produces either a single colour or black. At the most basic level, an IMOD based display is an optically resonant cavity. The device consists of a self-supporting deformable reflective membrane and a thin-film stack (each of which acts as one mirror of an optically resonant cavity), both residing on a transparent substrate. When ambient light hits the structure, it is reflected both off the top of the thin-film stack and off the reflective membrane. Depending on the height of the optical cavity, light of certain wavelengths reflecting off the membrane will be slightly out of phase with the light reflecting off the thin-film structure. Based on the phase difference, some wavelengths will constructively interfere, while others will destructively interfere. The human eye will perceive a colour as certain wavelengths will be amplified with respect to others. The image on an IMOD-based display can switch between colour and black by changing the membrane state which is accomplished by applying a voltage to the thin-film stack, which is electrically conducting and is protected by an insulating layer.

When a voltage is applied, electrostatic forces cause the membrane to collapse. The change in the optical cavity now results in constructive interference at ultraviolet wavelengths, which are not visible to the human eye. Hence, the image on the screen appears black. A full-colour display is assembled by spatially ordering IMOD elements reflecting in the red, green and blue wavelengths. Multiple colour displays are created by using sub pixels, each designed to reflect a specific different colour. Multiple elements of each colour are generally used to both give more combinations of displayable colour (by mixing the reflected colours) and to balance the overall brightness of the pixel.

IV. KEY FEATURES OF IMOD

1. Bistability

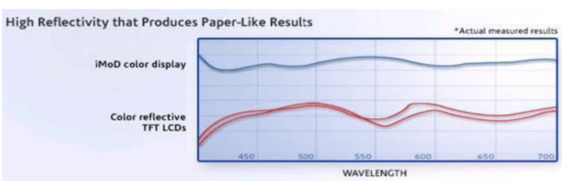
This allows near-zero power usage in situations where the display image is unchanged. This bistability derived from the inherent hysteresis of the material causes considerable power savings, especially compared to displays that continually refresh, such as LCDs.

2. Speed

Since visible light wavelengths lie in the nanometer scale (i.e., 380nm to 780nm), the deformable IMOD membrane only has to move a short distance (~100nm) in order to switch between two colours. This switching happens extremely fast, in the order of tens of microseconds. [2] This is 1000 times faster than that of traditional displays. Higher switching speed directly translates to a video rate-capable display with no motion-blur effects.

3. Robustness

In addition to microsecond switching, IMOD-based displays maintain their switching speed across a wide temperature range. In contrast, the switching speeds of organic liquid- crystal-based displays decrease as temperatures go into low environmental ranges.



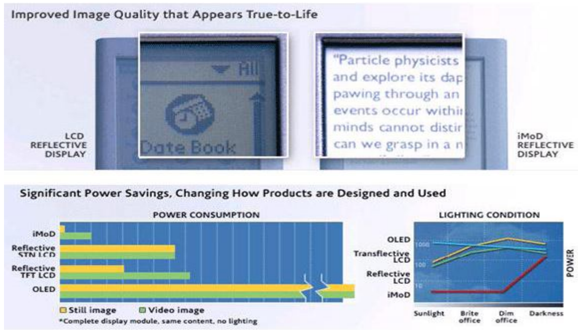


Figure 2: IMOD features

4. Readability

An IMOD-based display offers a superior contrast ratio in brightly lit environments. Qualcomm's IMOD-based displays offer reflectivity of 60 percent and contrast ratios greater than 10:1. By comparison, the Wall Street Journal newspaper offers a reflectivity of 60 percent and a contrast ratio of around 4:1. Reflective technology based on bio-mimetic models hold much promise for commercial use. Reflective displays need to be viewed in both daylight and in the dark. The commercialization of this technology is thus dependent on combining the benefits of backlit transmissive displays with the outdoor readability of reflective technologies.

5. Fabrication

From its very inception, IMOD technology was architected so that it could be fabricated on large area substrates typical of the LCD industry. It makes use of a catalogue of materials common to LCDs, as well as mature LCD tools. In addition, its display components are compatible with existing LCD module integration techniques. Because of this compatibility, IMOD displays can be procured directly from existing LCD-module vendors and those vendors can now offer a high-quality feature-differentiated lower-cost technology to their existing customer base.

6. Low Power Consumption

IMOD displays use just a fraction of the power needed by conventional technologies. The displays need little or no power-draining illumination in most viewing environments. And because the IMOD display does not demand continuous refreshing, once an image has been written to the display, very little power is required to sustain it.

7. Response Time

The fast response time of IMOD displays reduces blurring when viewing fast-moving video and gaming animation applications. IMOD display's response time is 10 to 1000 times faster than competitive LCD technologies.

8. Thinner, lighter and scalable

The absence of a backlight has the potential to significantly reduce the module size and weight, making it especially useful for mobile applications such as cameras, mobile phones, games, PDAs and GPS units. Once IMOD displays are perfected for smaller screens, they will be scalable to larger applications such as TVs and outdoor digital signs.

V. IMOD MANUFACTURING

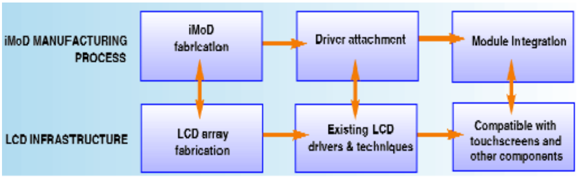


Figure 3: IMOD technology compatibility with LCD infrastructure

The IMOD display fabrication process starts from bare Gen 2.5 or larger glass. Two of the more critical steps in this IMOD fabrication process are the sacrificial layer etching and encapsulation. Because the IMOD element is a MEMS device, it requires removal of a sacrificial layer to free mechanical elements to move. Wet-etching techniques require the removal of the wet etchant with other fluids and eventually sublimation to avoid irreversible collapse of the MEMS structure during the release process. A gas-phase XeF_2 etch is used for release etching to reduce the complexity of the release process and to address many process integration issues.

After the sacrificial layer has been etched, encapsulation can take place. During encapsulation, array plates and large-area plates of recessed glass are joined together. The glass is processed and assembled to create a biplane assembly, which is subsequently singulated into encapsulated display panels. The encapsulation process is performed to protect the moveable membranes of IMOD arrays from particles, abrasion, and moisture. It is possible for MEMS devices to become non-functional due to stiction of moving parts. Such stiction is often driven by water absorption to surfaces of the MEMS devices, causing adjacent parts to stick together. It is important to note that the highly robust IMOD array does not fail due to short-term exposure to ambient oxygen or air. However, the IMOD array does require a managed environment in order to maximize functionality and lifetime. Encapsulation of the IMOD panel creates that environment via a glass back plate with a recess to hold a desiccant. The back plate is sealed to the IMOD array using an adhesive and it is sealed.

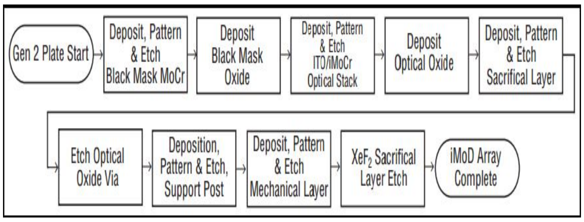


Figure 4: Process sequence required for iMoD-array manufacturing

VI. IMOD VERSUS LCD

A mirasol display's relative simplicity, low power usage and outdoor viewing characteristics make it a compelling replacement for LCDs. In the initial stages, the mirasol display will compete primarily with monochromatic (MSTN) and color super twisted nematic (CSTN) displays, used in portable devices. Below is a comparative outline of LCD and IMOD technologies on the basis of the parameters used to determine display electronics.

LCD	IMOD
The extensive use of optical films such as polarizers and colour filters and thin films transistor elements in LCDs makes fabrication difficult. Further, the necessity of using polarizers for LCDs limits the amount of light that is reflected or transmitted from the display by at least 50% as it is discarded by the polarizer.	An IMOD display operates as a reflective display powered illumination which is only needed when incident light falls below a level. It is a simple display which does not need an optical film.
Backlighting for LCDs is the single biggest power draw in portable displays. This is especially true in bright environments where the backlight has to be switched to the brightest mode.	IMOD displays do not require extra illumination in bright environments which gives them a big power-consumption advantage. If supplemental lighting is required, in a dark room for example, IMOD-based displays would still require only one-half to one-third the power needed by an LCD display.
In bright environments, the amount of light being transmitted by LCD is about the same as the ambient light around it. At the same time, the bright ambient light overpowers the dark pixels, making them appear brighter and reducing the contrast ratio to close to one, thereby making the display unreadable.	Its pixel is reflective and will reflect all the ambient light when driven to the bright state. In the dark state also, it is able to significantly reduce the reflected light.
Portable devices are subject to environmental extremes that can affect LCDs, which usually operate in the 10- to 30-degree Celsius range and which are limited by changes in viscosity of the liquid-crystal material.	IMOD based display's simplicity gives it an advantage because it can operate in extremes from minus 30 to plus 70 degrees Celsius.
Switching speed is low. Changes its state in probably 10 milliseconds.	Switching speed is high. Changes take about 10 microseconds which in turn results in a sharper looking image. Fast display response time also helps in optimum viewability.
Affected by UV radiation.	Impervious to UV radiation.

VII. COMPARISON OF DISPLAY TECHNOLOGIES

DISPLAY TECHNOLOGY	ADVANTAGES	DISADVANTAGES
LCD Optically active material modulates an artificial light source, such as a backlight.	Inexpensive, widely available, and technically simple.	High power consumption, poor legibility in sunlight, low resistance to temperature extremes, limited viewing angles, thick mechanism.
OLED Organic substances generate light when exposed to electric current.	Should be inexpensive after fabrication plants are built, and rapid electrical response.	High power consumption, poor legibility in sunlight, relatively short life span, susceptible to water and oxygen contamination, technically complex.
IMOD Reflective materials modulate ambient light and bounce it back off a mirror like surface.	Inexpensive, low power usage, always on, rapid electrical response, good readability in bright sunlight, wide viewing angle, technically simple.	New, unfamiliar technology, not yet available as full-colour displays. [8]

VIII. IMOD DISPLAY MANUFACTURING INDUSTRIES

1. Advantages

- Little or no retooling to manufacture – IMOD displays can be made on existing FPD (flat-panel display) assembly lines using existing materials. For IMOD displays, upwards of 90% of the equipment set already exists within a TFT active-matrix LCD.
- Low-risk adoption into standard mobile systems due to industry-standard interfaces.
- New market opportunities now that IMOD displays have brought instant access, low-power consumption, an intuitive interface and a smaller form factor to the user experience.

2. Challenges

- This technology is an alternative to LCD displays and works best under natural light but it is yet to prove its significance under non-natural lighting circumstances.
- Its power efficiency is "a significant tradeoff" for color resolution, which is notably poor in Mirasol screens.
- No yet great demand in the market. Apart from price and colour resolution, Mirasol isn't an industry standard as it is available only from Qualcomm.
- As the technology is registered with Qualcomm, unless it licenses its technology to other vendors, the manufacturing costs would never go down and neither would there be assurance for a secondary supply of Mirasol screens for the vendors.
- High NRE cost which apparently has required much more precise tolerances in the laying of the glass substrate, sandwich pillars and wavelength gaps, evidenced by the need to build a $700 million dedicated fabrication plant. Also the initial failure of Qualcomm’s product Mirasol to run on a technology which ran a 60 Hz video, in turn draining the battery which was supposed to be conserved has led to serious concerns regarding this innovative product which requires innovation at its best.

CONCLUSION

IMOD display technology is developing rapidly and is expected to soon become dominant in displays for low-power, portable applications like e-readers and remote equipment for military applications, though LCDs are the technology of choice at the moment for different computing applications. However, with the emergence of IMOD technology, a new alternative is now available. Not only does this promising technology offer the brightness and power consumption required to satiate the demands of manufacturers and consumers alike but it also takes advantage of existing LCD manufacturing processes and benefits from the unique functionalities of MEMS structures.

At the same time, IMOD technology provides system designers the flexibility they require to differentiate their products based on image quality, power consumption, and performance. Unlike other display entrants, it has the potential to play a role in a more diverse array of display market segments than its competitors as suggested by inventor Miles. With Qualcomm’s flagship product such as Toq coming out in the market, one can surely hope that these new displays will mean faster response times, better colour reproduction, and higher resolutions - a revolution in display technology.

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