

MEMS-Based Display Technology Drives Next-Generation FPDs for Mobile Applications

Today, manufacturers of mobile electronic devices are faced with a number of competitive challenges. To remain viable, they must offer richer device functionality and higher performance, but they are being forced to do so in the face of demands for decreasing power, size, and cost.

by Jeffrey B. Sampsell

THE challenges facing today's mobile electronics devices also apply to mobile-device displays. Consider, for example, applications that enable the consumer to view video clips on a mobile phone. Such functionality requires a display that features low power consumption, excellent readability in direct sunlight, the ability to operate over a wide environmental range, and enough performance to handle multimedia content. While liquid-crystal-display (LCD) technology has long dominated the mobile marketplace, a new breakthrough in display technology – Interferometric Modulator (iMoD™) display technology – promises to address today's competitive challenges while providing substantial performance and power-savings benefits over current technologies. Thus, iMoD display technology is emerging as a candidate to drive a new generation of flat-panel displays (FPDs) for mobile applications.

Understanding iMoD Architecture

iMoD displays are reflective displays based

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on microelectromechanical systems (MEMS) technology that works by exploiting the fundamental concept of optical interference. It traces its origins back to 1989 to work done on a resonant membrane spatial light modulator (RMSLM).

The iMoD display is an electrostatically actuated, bistable MEMS device built on a glass substrate. Color is generated by the well-known principle of optical interference. iMoD elements can be described as two conductive reflectors separated by an air gap and dielectrics that are part of a thin-film stack

(Fig. 1). Since one of the reflectors, a metallic membrane mirror, can be displaced relative to the other by means of electrostatic force, the gap between the reflectors can be varied. The display's color is governed by the optical path length between the mirror and the reflector in the thin-film stack. If the gap is large, a long wavelength resonates in the gap, allowing the viewer to see the color (*e.g.*, green) associated with that wavelength. To generate a low reflectivity state (*e.g.*, black), a very small gap is produced to move the resonant wavelength into the UV portion of the spectrum. The

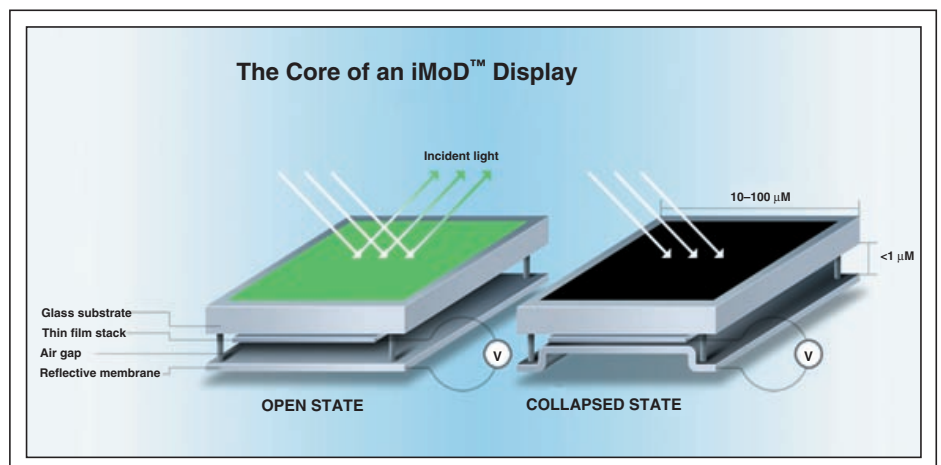


Fig. 1: This graphic depicts the typical iMoD architecture.

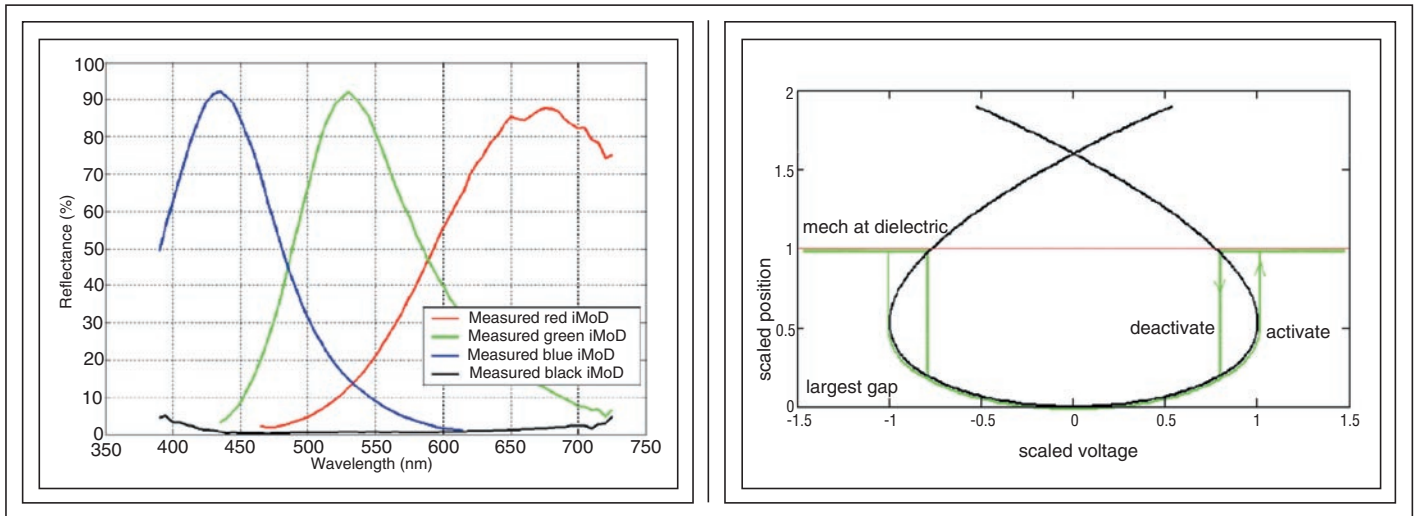


Fig. 2: Shown here are the results of using different gaps. Optical spectra from iMoD elements are designed to reflect in red, green, black, and blue. The black-state spectrum is at the bottom of the graph.

Fig. 3: This plot shows the solution balancing electrostatic force with restoration force for the movable membrane/mirror. The resulting hysteresis loop is plotted on top of the solution.

viewer sees the absence of visible light as black. The results of using different gaps are shown in Fig. 2.

The inherent mechanical hysteresis of the iMoD element’s moving membrane is crucial to producing a high-quality display. The hysteresis provides electromechanical memory, which makes it possible to eliminate the thin-film-transistor (TFT) array; the TFT array is a significant component in many matrix-addressed LCDs. The hysteresis effect allows an iMoD reflective membrane that has been pulled down into the black state to be stable at the same time that quiescent mirrors in the bright state are stable. This bistability, a result of the electromechanics of the iMoD elements, allows data to be written and held with a modest bias voltage – requiring significantly less energy to hold the mirror in place than was needed in pulling it down. Figure 3 plots the system results of a simple model in which the loops of the characteristic hysteresis curve are shown. The two stable states are two different membrane positions, each with a characteristic color.

The display architecture derived from an iMoD solution exhibits a higher degree of functional integration than an LCD-based solution, and therefore boasts advantages on a system-wide level. Consider, for example, that every display has three operating functionalities: color selection, modulation of the

color intensity (e.g., more blue, less red, etc.), and memory (each pixel is addressed for only a small amount of the frame time but must “remember” its setting for the entire frame time). LCDs utilize color filters, polarizers, alignment layers, liquid-crystal materials, TFTs, and optical films to accomplish these functionalities. In contrast, the mirror in the iMoD is able to perform the color selection, modulation, and memory (with its inherent hysteresis) all in one element.

Some of the important benefits realized by this iMoD architecture include the following.

Brightness. As a modulator, the iMoD display element is very efficient. Consider that reflective media, such as a magazine or a newspaper, must be exceptionally bright to be readable in a variety of ambient conditions. The former generally have a brightness of about 80%, while the latter has on average brightness of 55%. iMoD pixels routinely achieve reflective peaks in excess of 85%. The result is an average brightness of 30%; a figure that makes iMoD displays viewable even in exceptionally dim environments. Additionally, this attribute minimizes, and in some cases eliminates, the need for supplemental lighting.

Exceptional Readability. The iMoD display appearance and usage is similar to that of a printed page. It can be easily used in any lighting condition, including direct sunlight.

Interference enables the iMoD display to be 2–3 times as bright as competitive technologies, which typically use polarization effects. It even has twice the reflectivity across the visible spectrum as state-of-the-art color reflective TFT-LCDs; thereby minimizing the need for power-hungry supplemental lighting. The fact that the iMoD display’s bright reflective quality draws from ambient-light sources results in minimal power usage in most conditions. Only in dark environments is additional lighting required. The iMoD display also possesses a wide viewing cone free of contrast inversion effects associated with polarization-based displays. Color shift throughout the viewing cone is managed with diffusing films. Minimal diffusion, suitable for monochrome displays, provides a “metallic” appearance with moderate color shift. Increased diffusion, as applied to color displays, provides a paper-like “matte” appearance and minimal color shift.

Excellent Power Consumption. The bistable nature of the iMoD display means that it requires very little power to function. While conventional LCD technologies require constant refreshing to maintain or change any image, the iMoD display only consumes power when a pixel is changed. Even then, power usage is minimal because less than 10 V is required to move the minute iMoD elements. Furthermore, power consumed

MEMS displays

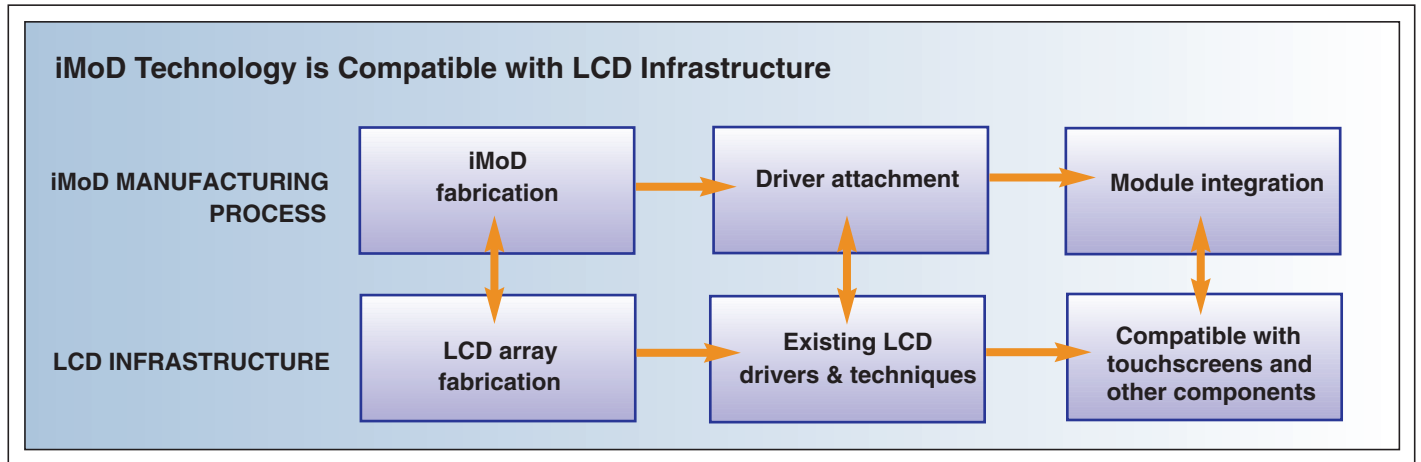


Fig. 4: Although iMoD technology is a fundamentally new approach to mobile information display, the tools, processes, materials, and components used in its production are a subset of those used in current LCD manufacturing.

relates directly to the type of information being displayed. Only the segments of the display that change need to be updated. Typical mobile information usage, such as e-mail and personal-information management (PIM) functions, draws very little power. Displaying a still image requires none at all.

Robust Design. Because iMoD displays are made of inorganic materials, the end product is not affected by environmental factors such as extreme temperatures, humidity, or UV radiation. Without the use of dyes or pigments for color creation, there is no risk that the iMoD display quality will fade or degrade over time. In contrast, the performance of competitive technologies that use liquid crystal or other liquid materials changes radically in extreme temperatures. Additionally, the design of the iMoD MEMS element and careful material choices assure that structural fatigue is not a factor in iMoD display reliability. The potential customers we have been working with have provided specifications for accelerated lifetime tests (elevated temperatures and humidity) for lifetimes beyond 10 years. iMoD displays have passed these tests and met the required specifications.

iMoD Fabrication. From its very inception, iMoD technology was architected so that it could be fabricated on large-area substrates typical of the LCD industry (Fig. 4). It makes use of a catalog 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. In turn, the risk and the effort required to adopt iMoD technology is substantially lowered for the customer.

It is important to note that while iMoD displays utilize materials that are already in use and well characterized, production tools rarely deliver the same performance as tools in a development environment. As a result, the technology transfer process somewhat resembles a re-development effort. The development team must accept this fact early on and prepare accordingly. One approach includes advance sampling and characterization of production materials in parallel with fundamental technology development.

From the standpoint of establishing a foundry in an existing factory, the issue of line balancing also emerges. For iMoD displays, upwards of 90% of the equipment set already exists within a TFT active-matrix-LCD (AMLCD) fab. However, the sequence

of process steps for which the factory layout was designed is such that the toolset is not optimized for efficient production of iMoD elements (Fig. 5). TFT processes tend to be “heavy” in dielectrics and “light” on the metals side. The resolution of this circumstance is not trivial because it involves trade-offs between early incremental equipment changes with potentially large future expenses versus initial large expenditures with growing savings in the future.

A Closer Look at Manufacturing

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 XeF₂

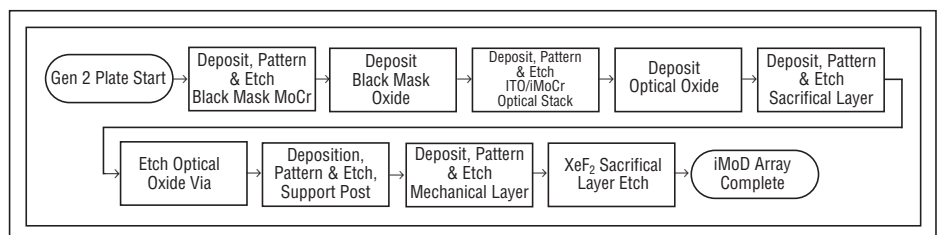


Fig. 5: This diagram illustrates the process sequence required for iMoD-array manufacturing.



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Fig. 6: Photograph of the “Release and Encapsulation Bay” in one of the laboratories at QUALCOMM’s MEMS Research and Innovation Center (MRIC) in San Jose, California.

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 bi-plane 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 backplate with a recess to hold a desiccant. The backplate is sealed to the iMoD array using an adhesive (Fig. 6).

The iMoD architecture allows for development at wafer scale. QUALCOMM MEMS Technologies, Inc. (QMT), for example, fabri-

cates the technology using 6-in. (150-mm) glass wafers (Fig. 7). A “Copy Exact” process transfer is not possible, since QMT does not develop iMoD technology on FPD production tools. However, QMT performs what it refers to as a “Copy Smart” process transfer. Here, the company mimics the standard semiconductor tools, processes, and process integration used to develop on 6-in. wafers, with FPD tool sets. As the majority of unit processes used to build iMoD arrays utilize physical principles that are similar to FPD processes, the iMoD architecture can easily scale up to fabrication on FPD lines, enabling customers to put drivers on the glass and make selections such as the resolution, number of pixels, aspect ratio, and diagonal ratio that are specific to their application.

Because the controller interfaces, integrated into drivers used with the iMoD display modules, conform to industry standards, the modules can be easily integrated into standard mobile systems. These interfaces include standard RGB STN-TFT, serial (SPI, I²C), and parallel (8080-type) interfaces. Standard



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Fig. 7: A researcher is holding a 6-in. round glass wafer, which is the standard glass processed in QUALCOMM’s MRIC in San Jose, CA.

power supplies are also supported with no special voltage levels required.

Conclusion

Currently, LCDs are the technology of choice for mobile applications. However, with the emergence of iMoD technology, a new alternative will soon be available. Not only does this promising technology offer the brightness and power consumption required to meet the demands of manufacturers and consumers alike, 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. These capabilities may one day enable it to empower a uniquely new generation of FPDs for mobile applications.

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