Digital Light Processing™ and MEMS: An Overview

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Introduction

Sights and sounds in our world are analog, yet when we electronically acquire, store, and communicate these analog phenomena, there are significant advantages in using digital technology. This was first evident with audio as it was transformed from a technology of analog tape and vinyl records to digital audio CDs.

Video is now making the same conversion to digital technology for acquisition, storage, and communication. Witness the development of digital CCD cameras for image acquisition, digital transmission of TV signals (DBS), and video compression techniques for more efficient transmission, higher density storage on a video CD, or for video conference calls. The natural interface to digital video would be a digital display. But until recently, this possibility seemed as remote as developing a digital loudspeaker to interface with digital audio.

Now there is a new projection display technology called Digital Light Processing™ (DLP™) that accepts digital video and transmits to the eye a burst of digital light pulses that the eye interprets as a color analog image **(Figure 1)**.

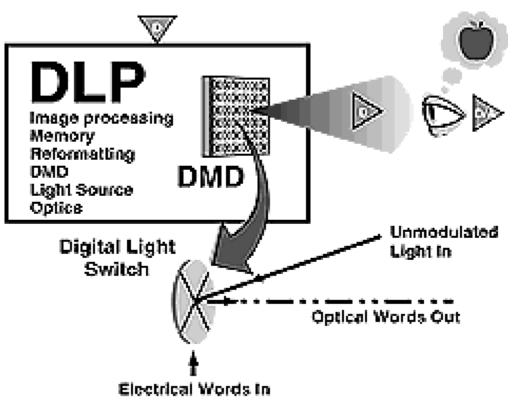

Figure 1

DLP is based on a microelectromechanical systems (MEMS) device known as the Digital Micromirror Device™ (DMD™). Invented in 1987 at Texas Instruments, the DMD is a fast, reflective digital light switch. It can be combined with image processing, memory, a light source, and optics to form a DLP system capable of projecting large, bright, seamless, high-contrast color images with better color fidelity and consistency than current displays.

The DMD Light Switch

The DMD light switch **(Figure 2)** is a MEMS structure that is fabricated by CMOS-like processes over a CMOS memory.

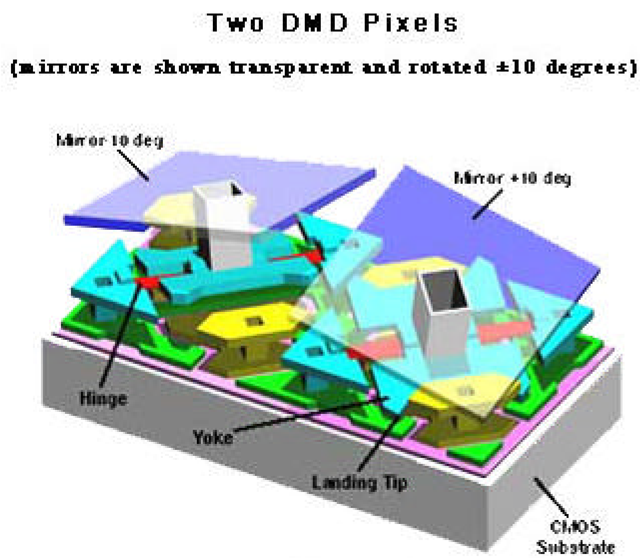

Figure 2

Each light switch has an aluminum mirror that can reflect light in one of two directions depending on the state of the underlying memory cell. With the memory cell in the (1) state, the mirror rotates to +10 degrees. With the memory cell in the (0) state, the mirror rotates to -10 degrees. By combining the DMD with a suitable light source and projection optics, the mirror reflects incident light either into or out of the pupil of the projection lens. Thus, the (1) state of the mirror appears bright and the (0) state of the mirror appears dark. Gray scale is achieved by binary pulsewidth modulation of the incident light. Color is achieved by using color filters, either stationary or rotating, in combination with one, two, or three DMD chips.

DMD Architecture and Fabrication

The DMD light switch is a MEMS structure consisting of a mirror that is rigidly connected to an underlying yoke. The yoke in turn is connected by two thin, mechanically compliant torsion hinges to support posts that are attached to the underlying substrate. Electrostatic fields developed between the underlying memory cell and the yoke and mirror cause rotation in the positive or negative rotation direction. The rotation is limited by mechanical stops to +10 or -10 degrees.

The fabrication of the DMD superstructure begins with a completed CMOS memory circuit. Through the use of six photomask layers, the superstructure is formed with alternating layers of aluminum for the address electrode, hinge, yoke, and mirror layers and hardened photoresist for the sacrificial layers that form the two air gaps. The aluminum is sputter-deposited and plasma-etched. The sacrificial layers are plasma-ashedto form the air gaps. **Table 1** lists distinguishing features of this MEMS technology compared with conventional MEMS.

Table 1

Distinguishing features of DMD MEMS technology

	Process
Number of moving parts	0.5 to 1.2 million
Mechanical motion	Makes discrete contacts or landings
Lifetime requirement	450 billion contacts per moving part
Address voltage	Limited by 5 volt CMOS technology
Mechanical elements	Aluminum
Process	Low temp., sputter deposition, plasma etch
Sacrificial layer	Organic, dry-etched, wafer-level removal
Die separation	After removal of sacrificial spacer
Package	Optical, hermetic, thermal vias
Testing	High-speed electro-optical before die separation

DLP Business Opportunities

Texas Instruments is actively pursuing two broad business opportunities for DLP: projection displays and continuous-tone color printing. The color printing application will be presented in a companion invited paper at this meeting. The projection display opportunity falls in three market segments: professional (large audiences), business (portable), and consumer/home (small audiences). Texas Instruments is currently teamed with market makers in each of these segments. TI is providing to the market makers DLP subsystems or digital display engines (DDEs). The DDE is the DLP subsystem ready for integration with a video interface, power supply, sound, controls, and a cabinet.

Currently, TI is manufacturing DDEs for the business projector segment with VGA resolution (640 x 480). Soon, DLP-based business projectors will be on the market. DLP systems with SXGA resolution (1280 x 1024) have recently been demonstrated.

References

1. L.J. Hornbeck, "Digital Light Processing and MEMS: Timely Convergence for a Bright Future", Plenary Session, *SPIE Micromachining and Microfabrication '95*, Austin, Texas (October 24, 1995). Color reprint available from Texas Instruments Digital Imaging Group, 214-995-2426.
2. J. M. Younse, "Projection Display Systems Based on the Digital Micromirror Device (DMD)," *SPIE Conference on Microelectronic Structures and Microelectromechanical Devices for Optical Processing and Multimedia Applications*, Austin, Texas, SPIE Proceedings Vol. 2641, pp. 64-75 (October 24, 1995).