Activity 2 – Optical MEMS
Instructor Guide

Notes to Instructor

This is the second of three activities for the film MEMS: Making Micro Machines, an overview of microelectromechanical systems, produced and directed by Ruth Carranza of Silicon Run Production. This activity should be completed after viewing the second part of the film titled: Optical MEMS.

This activity is a general knowledge crossword puzzle that challenges the participants on terminology and processes associated with optical MEMS applications and optical MEMS fabrication and packaging. There are several Post-Activity Questions that challenge the participants' comprehension, applications and analysis of the information.

You many choose to assign all or part of this activity before and/or after the participants have viewed the first part of the film. The film script is provided as a supplement to this learning module.

This activity is part of the MEMS: Making Micro Machines Learning Module. Below are the contents of this learning module:

- Knowledge Probe – Pre-assessment
- Activity 1 – Microfluidics
- **Activity 2 – Optical MEMS**
- Activity 3 – Sensors
- Supplement – Film Script
- Final Assessment

Description and Estimated Time to Complete

This is the second of three activities for the film MEMS: Making Micro Machines, an overview of microelectromechanical systems, produced and directed by Ruth Carranza of Silicon Run Production. A DVD can be ordered through the SCME website while supply lasts (http://scme-nm.org) or you can purchase it or access it online via Silicon Run (http://siliconrun.com/our-films/mems/). This activity should be completed after viewing the second part of the film: Optical MEMS.

This activity consists of two parts:

- A **crossword puzzle** that tests your knowledge of the terminology and acronyms associated with MEMS applications, optical MEMS, and the packaging and testing of optical MEMS.
- **Post-activity questions** that ask you to demonstrate your understanding of optical MEMS and optical MEMS fabrication and testing processes.

Estimated Time to Complete

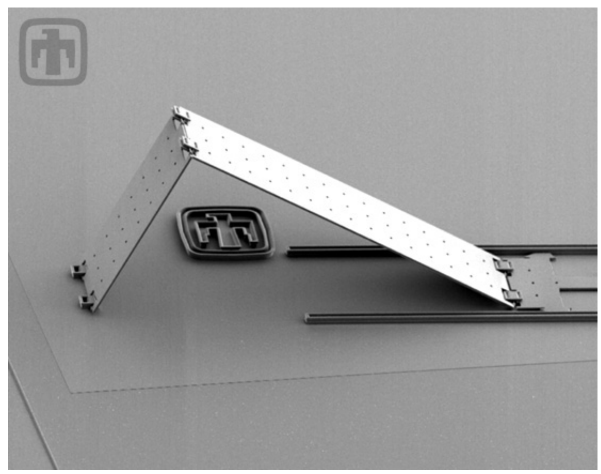
Allow at least 30 minutes to complete this activity.

Introduction

The objective for optical MEMS is to integrate optical, mechanical and electronic functions into one device. Optical MEMS usually consist of moveable micromirrors, lenses, diffraction elements for modulating light. Actuators for moving these elements, sensors and electronics for receiving, processing, and transmitting signals as well as providing the inputs for the actuators.

MEMS micromirror arrays are often the key components used in spatial light modulators or SLM's. These devices are used in high definition display systems as well as optical switching networks. Optical micromirror arrays transmit optical information without going through the timely and costly signal conversion process of optical to electronic and back to optical. The micromirrors can act as switches that direct light from a fiber optic to another fiber optic or to a specific output port by moving up and down, left to right or swiveling to a desired position. This requires the individual mirrors to be actuated, supported on a movable mount or stage, and integrated into a digital network.

The scanning electron microscope image to the right shows a popped-up micromirror. Notice the hinge allowing for the different angles needed to direct light in different directions. Also notice the track that assists in positioning the mirror at the correct angle.



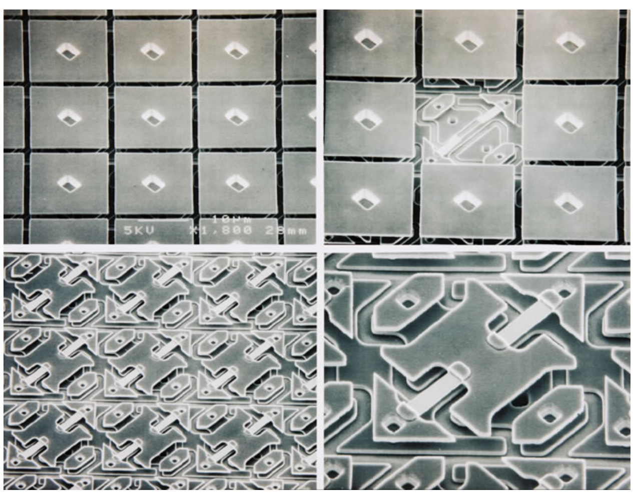
MEMS Pop-up mirror for optical applications
[Image Courtesy of Sandia National Laboratories SUMMIT™ Technologies, www.mems.sandia.gov]

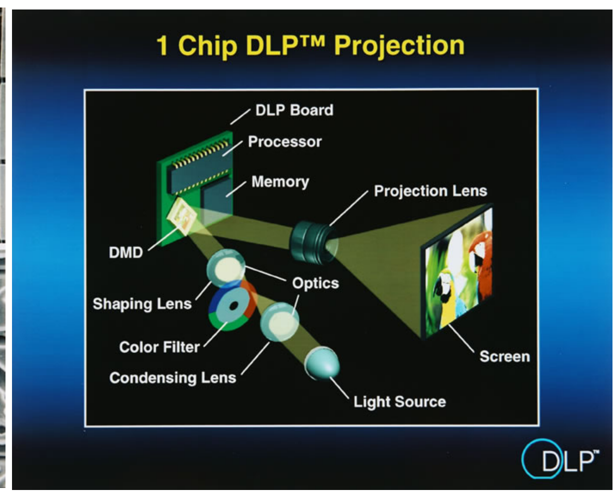
Applications of optical MEMS include the following:
- Projection displays (GLV's and DMD's)
- Tunable lasers and filters
- Spatial Light Modulators (SLMs)
- Variable optical attenuators
- Optical Spectrometers
- Bar code readers
- Mask-less lithography

Optical MEMS have already been quite successful in display technologies. This success is rapidly growing with the innovations of high definition (HD) displays.

Texas Instrument's Digital Mirror Devices (DMD) have been used for several years in a variety of projection systems including film projection and digital cinema. The technology is called digital light processing or DLP™, a trademark owned by Texas Instruments, Inc. A DMD is an array of micromirrors *(see figure of DMD array below and left)*. Each micromirror (between 5um and 20um per side) is designed to tilt into (ON) or away from (OFF) a light source. The mirror tilts when a digital signal energizes an electrode beneath the mirror. The applied actuator voltage causes the mirror corner to be attracted to the actuator pad resulting in the tilt of the mirror. When the digital signal is removed, the mirror returns to the "home" position. In the ON position, the mirror reflects light towards the output lens. In the OFF position, the light is reflected away from the output optics to a light absorber within the projection system housing. One mirror can be turned OFF and ON over 30,000 times per second.

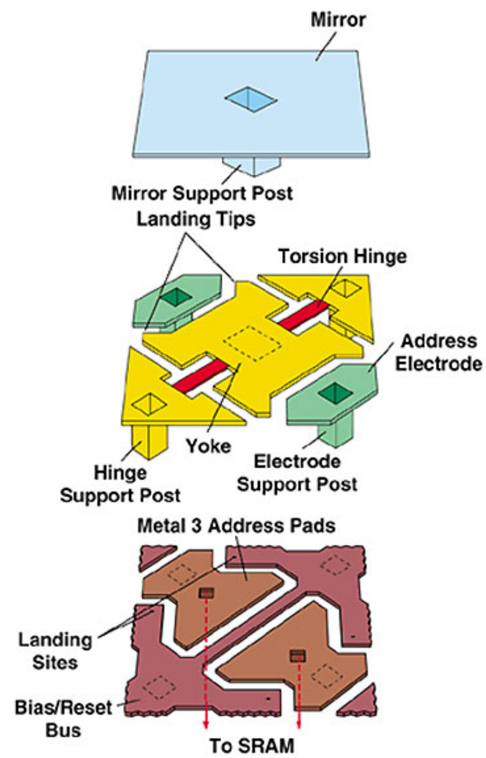
There can be over 2 million mirrors in an array with less than 1 μm spacing between each mirror. The DLP 1080p technology delivers more than 2 million pixels for true 1920x1080p resolution.[1,2] The diagram below (right) illustrates how the DLP projection system works. The left set of images are scanning electron microscope images of the DMD mirrors and underlying hinge system.





Levels of a DMD Array (left) and How a DLP system works (right).
[Images Courtesy of Texas Instruments]

The illustration below breaks down a digital mirror of a DMD into three levels. It shows the mirror, support post, hinge, yoke and electrodes discussed in the film. The film MEMS: Making Micro Machines discusses the fabrication, packaging and testing of this DMD. You should recognize some of the components mentioned in the film (e.g., mirror, torsion hinge, yoke). To learn more about the operation of a digital light projector (DLP), visit Texas Instruments webpage How DLP Technology Works. http://www.dlp.com/technology/how-dlp-works/default.aspx



[Images Courtesy of Texas Instruments]

Activity Objectives and Outcomes

Activity Objectives

- Identify terms or acronyms associated with definitions related to MEMS, optical MEMS, optical MEMS fabrication, packaging and testing.
- Demonstrate your understanding of digital MEMS and DLP fabrication, packaging and testing by correctly answering the Post-Activity questions.

Resources

- MEMS: Making Micro Machines, an overview of microelectromechanical systems, produced and directed by Ruth Carranza of Silicon Run Production.
- "MEMS Applications". Southwest Center for Microsystems Education (SCME). 2009.
- "Photolithography". Southwest Center for Microsystems Education (SCME). 2009.
- "Deposition". Southwest Center for Microsystems Education (SCME). 2009.

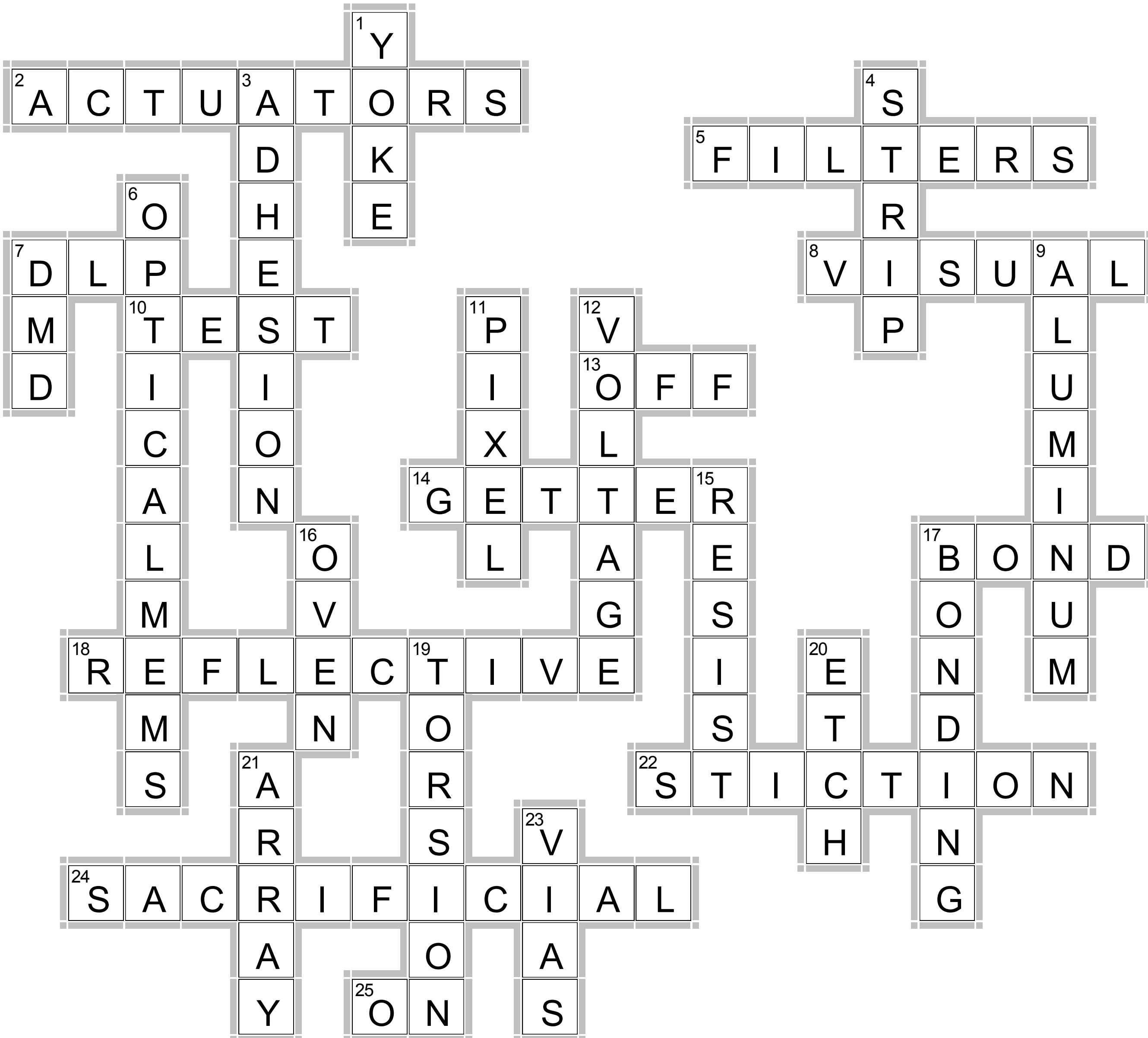
Documentation

1. Completed Crossword Puzzle
2. Questions and Answers to the Post-Activity Questions

Activity 2: Optical MEMS Crossword Puzzle

Complete the crossword puzzles using the clues on the following page.

Answer Key



EclipseCrossword.com

Answers / Hints

Across

2. **ACTUATORS**—MEMS components that move mirrors or other MEMS devices are called ________________.
5. **FILTERS**—Three or more colored _________ are contained in the color wheel of a DLP system to provide a colored output from the DMD array.
7. **DLP**—The acronym for digital light processing.
8. **VISUAL**—After fabrication, a DMD goes through a series of tests, most of which are electrical. The final test is a ___________ test.
10. **TEST**—To electrically _____ a DMD array, the mirrors are turned ON and OFF for 2 to 24 hours inside a burn-in furnace.
13. **OFF**—When a DMD mirror is not reflecting light it is said to be ______.
14. **GETTER**—A ____ strip is placed on DMD windows for the purpose of absorbing moisture.
17. **BOND**—To ______ is to join two or more components together.
18. **REFLECTIVE**—An anti- ________coating that enhances the transmission of light is applied to the protective windows in a DMD
22. **STICTION**—The tendency for surface forces to cause small structures to stick.
24. **SACRIFICIAL**—In MEMS fabrication, a _____ layer provides spacing between two or more components by first being deposited, then removed.
25. **ON**—When a micromirror is reflecting light it is said to be ____.

Down

1. **YOKE**—The component of a DMD micromirror that supports the mirror's support post.
3. **ADHESION**—Small spring tips are constructed on the yoke of a DMD mirror to overcome ________, the tendency of a micromirror to stay ON with voltage removed.
4. **STRIP**—The fabrication process used to remove the protective resist layer after the develop process step is called a plasma ______________.
6. **OPTICALMEMS**—A microsystems device that integrates optical, mechanical and electrical.
7. **DMD**—The acronym for digital mirror device.
9. **ALUMINUM**—The material used to construct the post, hinge and yoke of a DMD micromirror.
11. **PIXEL**—In a DMD, one micromirror is one _____.
12. **VOLTAGE**—A __________ is applied to the electrode of a micromirror to turn the mirror ON.
15. **RESIST**—The thin film used as a sacrificial layer that provides spacing and protection for the micromirrors.
16. **OVEN**—A(n) ______ is used to harden epoxy.
17. **BONDING**—A __________ process uses UV light, heat and pressure to connect the windows of the DMD to the CMOS wafer.
19. **TORSION**—In a DMD the hinge that is fabricated to overcome stiction is called the ____ hinge.
20. **ETCH**—The fabrication process that removes unwanted material from a layer.
21. **ARRAY**—Hundreds and even thousands of micromirrors on a chip is called a(n) _______.
23. **VIAS**—The fabricated channels that provide access to the CMOS circuitry.

Post-Activity Questions / Answers

1. What is the objective of optical MEMS?

   Answer: To integrate optical, mechanical and electrical functions.

2. For the transmission of data optical information, optical mirrors may be faster and cheaper because they eliminate the conversion process of ______________________________.

   Answer: converting light to an electrical digital signal, and then back to an optical (light) signal. Optical micromirrors receive and reflect digital light data.

3. Micromirrors need to move. What MEMS components are required to move micromirrors?

   Answer: Actuators (e.g., electrodes (as with DMDs), comb drives)

4. What company developed DMDs?

   Answer: Texas Instruments

5. In your own words, briefly explain how a DMD works.

   Answer: A DMD is an array of micromirrors. Each micromirror is designed to tilt into (ON) or away from (OFF) the light source. The mirror tilts when a digital signal energizes an electrode beneath the mirror. The applied actuator voltage causes the mirror corner to be attracted to the actuator pad resulting in the tilt of the mirror. When the digital signal is removed, the mirror returns to the "home" position. In the ON position, the mirror reflects light towards the output lens. In the OFF position, the light is reflected away from the output optics to a light absorber within the projection system housing. One mirror can be turned OFF and ON over 30,000 times per second.

6. How is the resolution of DLP projectors increased?

   Answer: by increasing the number of micromirrors in the DMD array.

7. Once the DMD array is fabricated, how is it protected during shipping to the packaging location?

   Answer: Photoresist is used as spacers between the mirrors and a coating to protect the surface.

8. In the fabrication of a micromirror, photoresist is used as a sacrificial layer. What is the purpose of this sacrificial layer?

   Answer: The photoresist layer initially creates a "space" between the floating mirror and the substrate. Release is the process of removing the sacrificial layer so that the micromechanical part can move, in this case, the mirror is free to tilt.

9. How is mirror movement tested?

   Answer: The first test turns the mirror ON and OFF for several hours. Another test checks mirror movement by applying various voltages and measuring the responses. [3]

10. The output of a 1-chip DLP™ projection is black and white. How is this black and white image converted to color?

    Answer: The reflected grayscale light from the mirrors pass through lenses and a color filter wheel as it spins. The wheel contains at least three filters, but newer wheels contain more filters for better images.

Summary

Optical MEMS integrate optical, mechanical and electronic functions into one device. Micromirror arrays are used for data transmission and for optical image production in DLP projection systems. There may be hundreds of thousands and even millions of mirrors in an array, fabricated on a single chip. Surface micromachining fabrication methods similar to those used in making computer chips are the primary fabrication technology used to make these devices. In the final tests, all of the mirrors must work in order for the chip to be used in a DLP device. This creates a special challenge in the fabrication and packaging of micromirror arrays.

References

[1] "How DLP sets work." Tracy V. Wilson and Ryan Johnson. HowStuffWorks. http://electronics.howstuffworks.com/dlp1.htm

[2] "How DLP Technology Works". DLP Texas Instruments. http://www.dlp.com/tech/what.aspx

[3] MEMS: Making Micro Machines, an overview of microelectromechanical systems, produced and directed by Ruth Carranza of Silicon Run Production.

Support for this work was provided by the National Science Foundation's Advanced Technological Education (ATE) Program through Grants. For more learning modules related to microtechnology, visit the SCME website (http://scme-nm.org).