Optical Short Course International

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What's "In The Box"?

Optics of Digital Projectors Weekly Newsletter

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Spatial Light Modulators in Digital Projectors

By Michael Pate, President, OSCI

The spatial light modulator is they key component where an electronic digital image is transformed into and optical digital image. It is where raw illumination is transformed into a spatial masterpiece and captured by a projection lens assembly and imaged with great magnification onto the viewing screen. This key component that has so much transformational power in the optical system is also one of the highest cost components in digital projectors. It is for these reasons along with the tremendous growth of this industry that many companies are investing in spatial light modulator research and development efforts. Lets take a look at what is happening and why in this area of the digital projector technology.

The Business Case for Investing in Modulator Development

If one looks at the bill of materials for a front or rear digital projector the largest components are the spatial light modulator/driver board, and the lamp/ballast. If one looks at the number of patents in the technology areas you will find many patents in the modulator/driver, and bulb/ballast areas. Certainly there are patents in the other technology areas of digital projectors such as illumination system, imaging system, color filter wheels, etc but not nearly as much as in the two high cost areas.

If we look to the personal computer industry for guidance we can see where displays are headed like most other consumer electronics products. In a PC the two components which cost the most are the microprocessor and the software. The rest of the components are essentially commodities and are easily interchangeable and standardized. In digital projectors I conceptually think of the modulator as the microprocessor and the bulb/ballast as the software. If this is where the largest percentage of the revenue will come from and the market numbers for unit sales is large and growing then this becomes an attractive business opportunity. Now we know the financial opportunity looks like so many large consumer electronics companies want to play as well as many smart and aggressive entrepreneurs.

Great business reasons to investigate the market and now let's look at some technology reasons to play. Modulators by their nature take many of the same tools that are used in microelectronics industry for fabrication and development. Tools and processes such as microlithography, thin film deposition, etching, CMP, packaging, bonding, testing, failure analysis tools. Smart companies with smart people who like technology start thinking and playing with their tools because they have some utilization "free" and a new project is born internally.

A few more business facts that are often forgotten or are not considered are:

- Transmissive LCD took 7 years of development: year to profitability and investment unknown
- DMD took 15 years of development: years to profitability and investment unknown
- LCoS and D-ILA took 10 years of development: years to profitability and investment unknown

If you look at this market and do some patent searching you will find that virtually every large consumer electronics company has or is playing in this market and there are many smaller entrepreneurial firms playing too.

They are: Intel, Philips, Epson, JVC, Sony, HP, Kodak, TI, 3-5 Systems, Sharp, Microsoft, etc.

Modulation Methods

Over the last several issues of In The Box we have seen the three or four main methods of spatial light modulation in digital projectors. Specifically we have looked at transmissive LCD panels that work by transmission and polarization, DMD panels that work by reflection, and LCoS and D-ILA panels that work by polarization and reflection. These optical phenomena are only two of the several methods of modulation of light. If we look to the conservation of energy or light in an optical system or optical surface we can see that there are at least eight optical phenomena: diffraction, reflection, absorption, transmission, scatter, polarization, fluorescence, and interference. All of these optical phenomena are not efficient methods of modulation many are viable methods and have received some research attention by various companies.

Interference Based Modulators

The interference based modulator is based upon a moveable thin film interference filter technology. There is an air gap in the thin film stack. The air gap can be changed by the applied voltage across the gap. Conceptually the large air gap gives a red color upon reflection from the cell or pixel. The medium air gap gives green, and the small air gap blue and a very small air gap black. The company Iridigm www.iridigm.com has commercialized this type of modulator see Figure 1. The pixels are large in the 25 to 60 micron size range with 50 microsecond switching speeds. The pixels have a large viewing angle of +/- 60 degrees and a 95% fill factor.

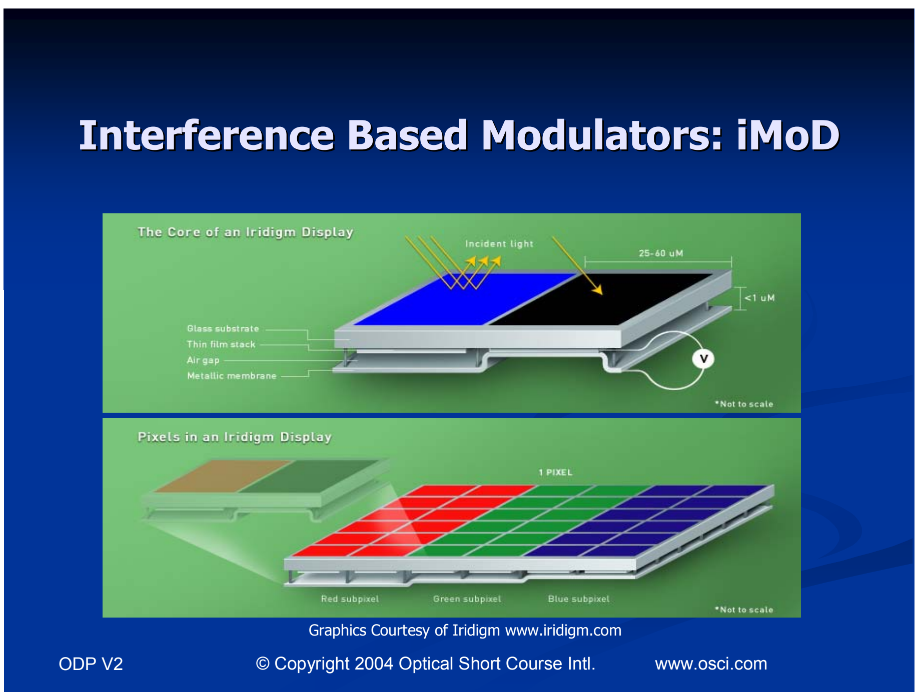

Figure 1. iMoD Interference Based Spatial Light Modulator
From OSCI's Optics of Digital Projectors DVD Course
http://www.oscintl.com/prod01.htm
Graphics Courtesy of Iridigm

If you don't understand why big pixels are good just wait a while until we get to étendue and you will understand why a large area is good for plumbing more light through an illumination system.

Resonant Microcavity Phosphor: CRT

Quantum Vision, Inc. of Sunnyvale, CA has developed a novel light source that is also a modulator and is based upon CRT technology and interference. I like this technology because it meets one of my digital projector technology breakthrough criteria: the light source is the modulator. I'll say it again the light source is the modulator.

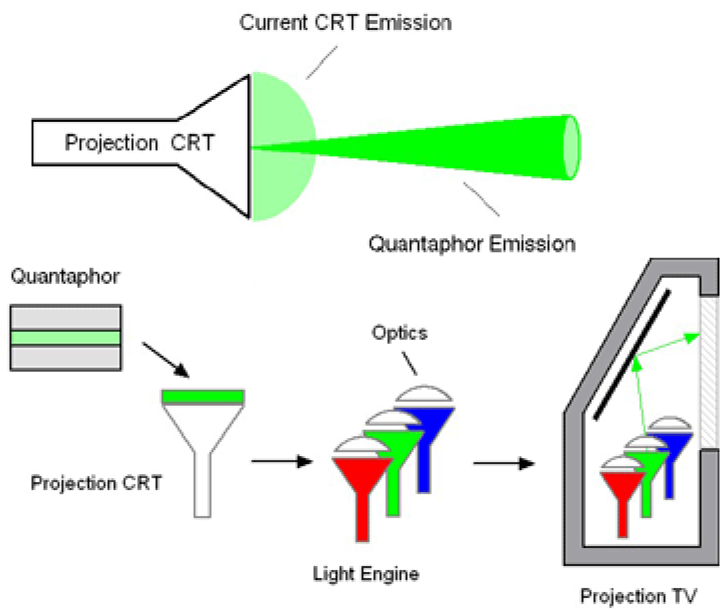

Figure 2. Quantum Vision Quantaphor Emission
Graphic Courtesy of Quantum Vision

The technology is based upon interference as they form a resonant microcavity or Fabry-Perot cavity on the front of the projection CRT tube. The phosphor is in the center of an interference stack or Fabry-Perot cavity and this narrows the spectral line width of the emission and it also controls the source divergence. This Quantaphor source emits light normal to the surface and into a small controlled angle of about 28 degrees. A typical CRT emits light into the full 180 degree hemisphere because of the nature of the scattered light from the phosphor.

There are many different phosphors with emission at a variety of different wavelengths. This is useful in designing the Fabry-Perot cavity to emit at a selected wavelength in order to provide the largest color gamut. The Quantaphor sources mix to give a color gamut that is much larger than the mercury or xenon sources in standard digital projectors. An example of the three wavelengths is 455, 544, and 624nm and because they are relatively wide spectral bandwidth compared to laser sources they do not have the speckle issues to contend with. These sources are also CRT based so their lifetimes are in excess of 10,000 hours.

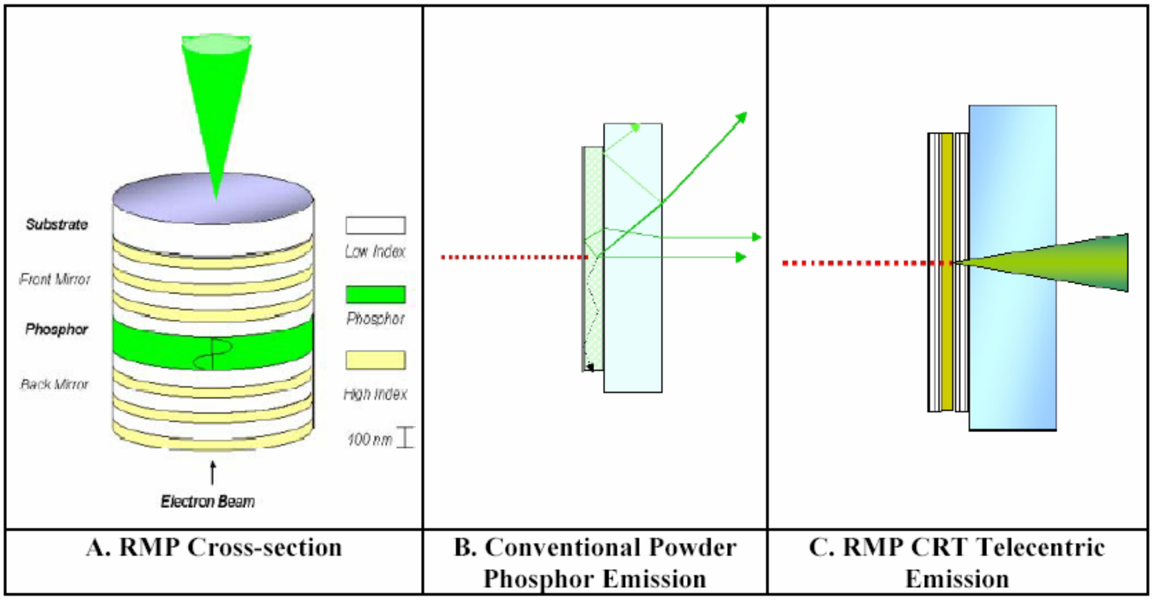

Figure 3. Quantum Vision Quantaphor Emission
Graphic Courtesy of Quantum Vision

Quantum Vision is the first to offer 1920 x 1080 format from their 7 inch CRT based modulators packaged into an RPTV. You may notice some other benefits of using a 7 inch modulator in that the required projection magnification is significantly reduced compared to the typical 1 inch modulator panels. Their displays come in 3:4:5 and 16:9 aspect ratios. Quantum Vision, www.quantumvision.com lists other applications for their RMP modulators as training and simulation, head up displays, medical, and direct write lithography.

This technology should have fundamental cost advantages in several areas over the typical MEMS based modulators for RPTV applications. CRT technology and manufacturing techniques are well established and up the learning curve. Thin film technology for the Fabry-Perot cavities should be well established and up the learning curve. This advanced state of this technology should give it inherent cost advantages for RPTV light engines.

Diffraction Based Modulator

Silicon Light Machines developed a modulator technology based upon diffraction that they call grating light valve. This technology works by forming a grating by modulating alternate mirror ribbons by a capacitive effect. If no mirror ribbons are deflected the device acts as a plane mirror and the pixel is dark or off. If it is necessary to provide light to the screen the mirror ribbons are modulated so that the light is diffracted into the correct diffraction order and exits the device at the correct angle to pass through the projection lens assembly and out onto the screen.

Silicon Light Machines was acquired by Cypress Semiconductor a few years ago and has been developing this technology. Cypress has an exclusive agreement with Sony that all digital cinema uses of the grating light valve will be for Sony. There are a few white papers about the technology on the Silicon Light Machines website and a few business articles by Cypress CEO about their acquisition on the Cypress website.

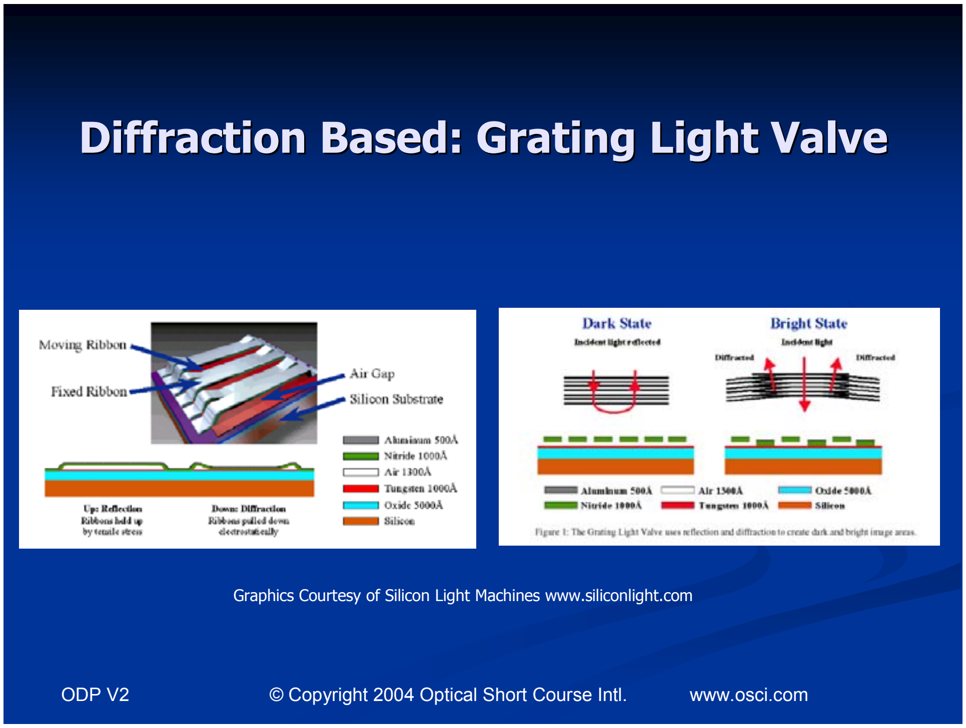

Figure 4. Grating Light Valve from Silicon Light Machines
From OSCI's Optics of Digital Projectors DVD Course
http://www.oscintl.com/prod01.htm
Graphics Courtesy of Silicon Light Machines

Kodak's Grating Electromechanical System or GEMS

Eastman Kodak has been working on developing a diffractive based grating modulator that they call Conformal Grating Electromechanical System or GEMS. The Kodak GEMS device has reflective ribbons that are suspended above a silicon substrate above a periodic series of speed bumps. When the GEMS ribbons are electrostatically actuated they are pulled down over the periodic speed bumps and the ribbon forms the shape of a sinusoidal grating. Most of the diffracted light goes into the first two diffracted orders (+/- 1 and 2).

In one implementation of the device the mirror ribbons are about 10 to 20 microns wide and the speed bump period is about 15 to 50 microns which puts about 40% of the light into the first orders which can be collected and imaged to the screen. The switching times are 50 nanoseconds. The GEMS modulator has been used with semiconductor lasers in a scanned 115 inch diagonal display. There are 4 ribbons per pixel and the current devices have 1080 pixels.

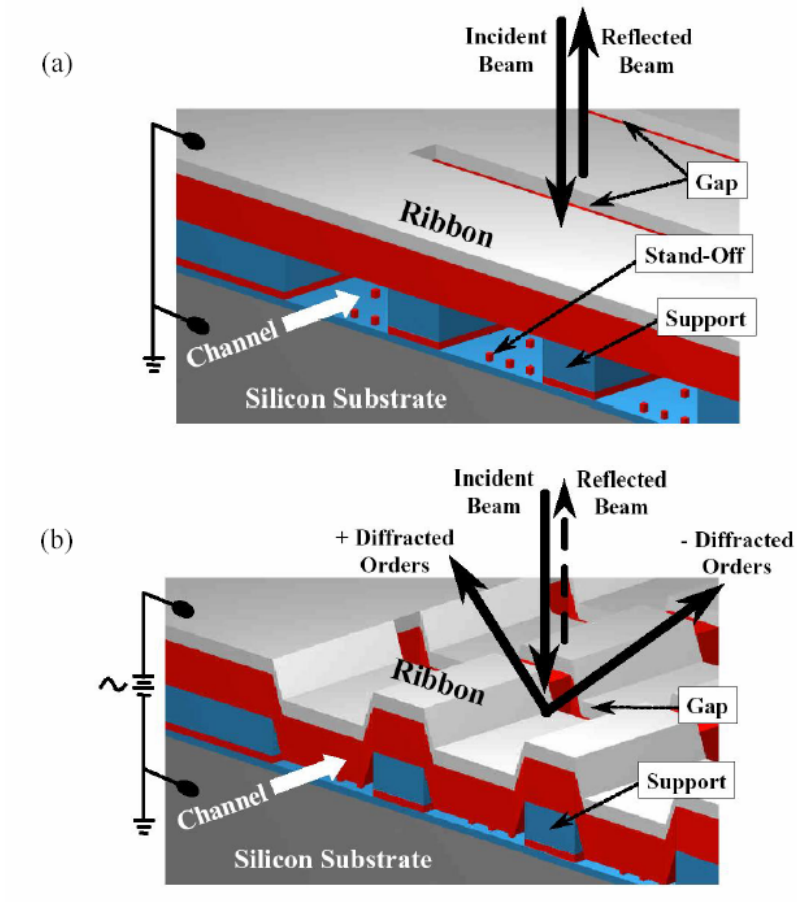

Figure 5. Kodak's GEMS Modulator
Graphics Courtesy of Eastman Kodak Company

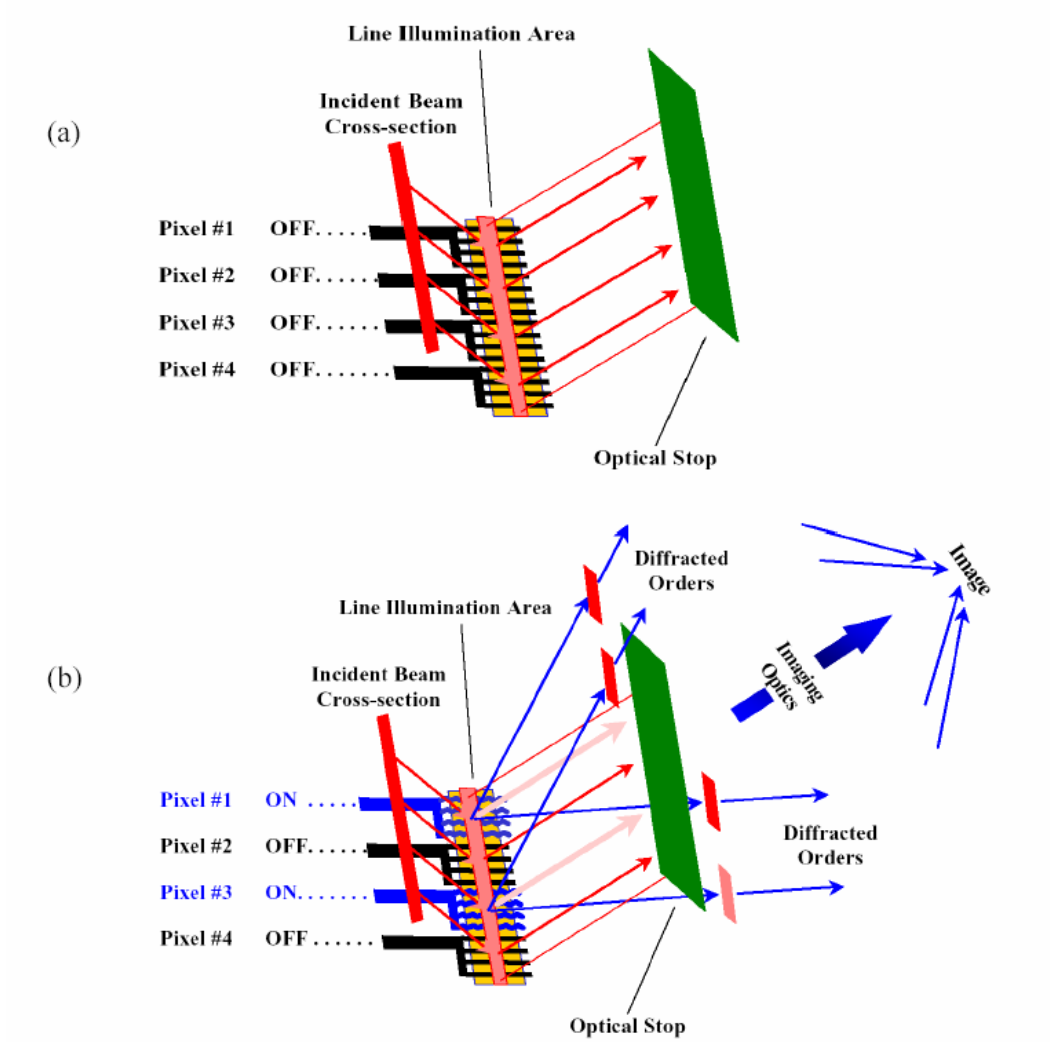

Figure 6. Kodak's GEMS Modulator
Graphics Courtesy of Eastman Kodak Company

The full length of the modulators 1080 pixels is illuminated with a strip of illumination from one of the three color lasers working at 440, 532, and 630nm. They have about a 90% fill factor for their modulator because this 1080 X 1 pixel array is scanned they can create some very large wide field displays. Attention training and simulator, command and control, and gaming phreaks: They have demonstrated the capability of a seamless image that is 7680 x 1080 pixels and 9 bits of color depth per pixel.

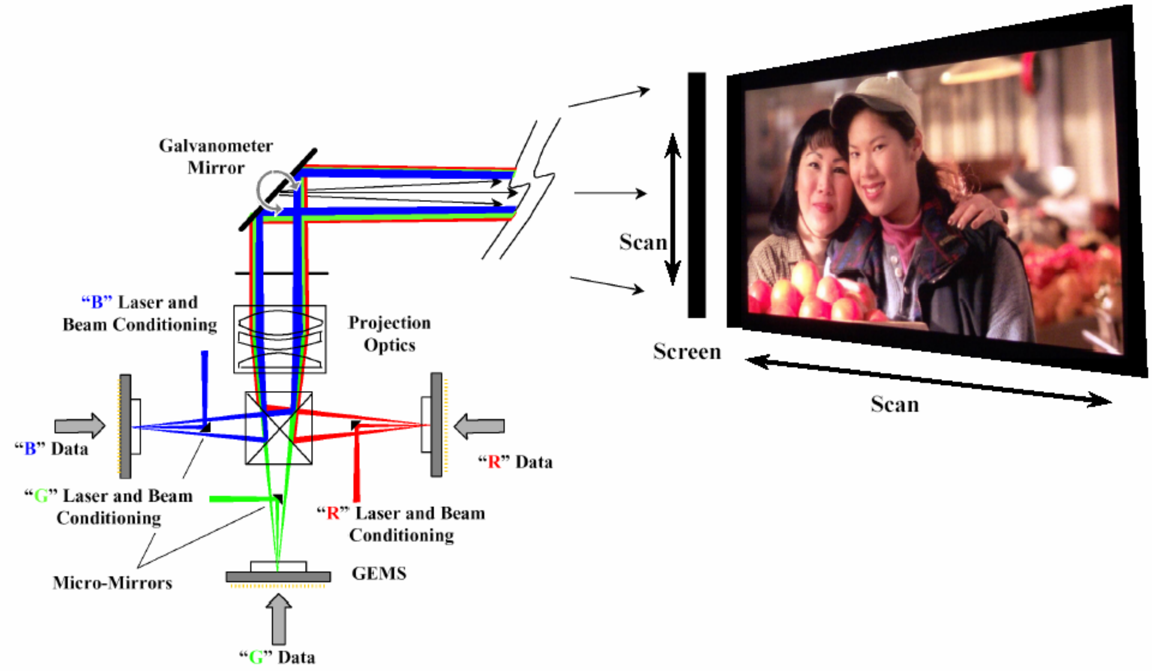

Figure 7. Kodak's GEMS Modulator Scanning Light Engine Configuration
Graphics Courtesy of Eastman Kodak Company

One implementation of the light engine is to have the laser and beam condition optics fold off of a strip mirror into the modulator array. The zero order or reflected beam comes back on itself and does not get projected to the screen to cause noise. The diffracted orders are propagated around each side of the strip mirror and collected by a projection lens assembly and combined using an X-Cube type beam combiner. One implementation is three projection lenses and one X-Cube, another is shown in Figure 7 above with one X-Cube and one projection lens assembly.

Laser Power (total RGB)	10 W
Vertical Resolution (device pixels)	1080
Horizontal Resolution (scan lines)	1920
Frame Rate	60 Hz
Display Bit Depth (per color)	11 bit
System Contrast (ANSI checkerboard)	>250:1
System Contrast (frame-sequential)	>1000:1
Data Stream	1080i
Size	115 in. diag

GEMS 115 Inch Laser Projection Display Specifications

The color gamut of this display like other laser projection system is very large compared to mercury or xenon light sources because of the ability to choose laser wavelengths that optimized the color gamut. Coherent light sources often have concerns of laser speckle reduction and while it is easy to spoil the coherence it is difficult to achieve without throwing away large amount of the energy. The GEMS R&D team has used line broadening techniques, moving diffuser, moving screen, volume scatting in the screen, and depolarization methods to control the laser coherence.

While Kodak is in the prototype and business investigation phase with this technology they are actively in business discussions with various companies to determine best how to bring this technology to market in a successful manner. In thinking about this technology compared to the other modulators that we have looked at over the past several weeks I am pretty excited by the GEMS technology for several reasons. It uses solid state light sources in laser diodes is a great start. The standard CMOS based MEMS structure is relatively simple compared to the other modulation technologies. This simple structure means that in high volume they should have a high yield and a fundamentally much lower cost than the other more complicated technologies.

Summary

We have looked at some interference and diffraction based modulators that are in prototype and business development stages of their growth curve. We did not look at any of the R&D programs or technologies that are in various stages of development. I believe that as long as there is a large growing market for displays we will continue to see entrepreneurial ventures in this area. I am looking forward to seeing what the innovative minds in the industry continue to develop. Please let me know what you are up to in this area if it is public knowledge.

Stay tuned and keep looking for your weekly dose of "In The Box" to understand the optics of digital projectors. If you enjoy increasing your knowledge about digital projector optics please tell a friend about this e-newletter, your referral is the kindest compliment we can get to show your appreciation.