The Grating Light Valve: revolutionizing display technology

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ABSTRACT

The Grating Light Valve™ (GLV™) technology is a micromechanical phase grating. By providing controlled diffraction of incident light, a GLV device will produce bright or dark pixels in a display system. With pulse width modulation, a GLV device will produce precise gray-scale or color variations. Built using micro electromechanical system (MEMS) technology, and designed to be manufactured using mainstream IC fabrication technology, the GLV device can be made both small and inexpensively. A variety of display systems can be built using GLV technology each benefiting from the high contrast ratio, fill ratio, and brightness of this technology. In addition, GLV technology can provide high resolution, low power consumption, and digital gray-scale and color reproduction.

Keywords: light valves, Grating Light Valve (GLV), micro electromechanical systems (MEMS), Silicon Light Machin**es,** Echelle, Inc.

1. Fundamental concepts

A Grating Light Valve (GLV) device consists of parallel rows of reflective ribbons. Alternate rows of ribbons can be pulled down approximately one-quarter wavelength to create diffraction effects on incident light (see figure 1). When all the ribbons are in the same plane, incident light is reflected from their surfaces. By blocking light that returns along the same path as the incident light, this state of the ribbons produces a dark spot in a viewing system. When the (alternate) movable ribbons are pulled down, however, diffraction produces light at an angle that is different from that of the incident light. Unblocked, this light produces a bright spot in a viewing system.

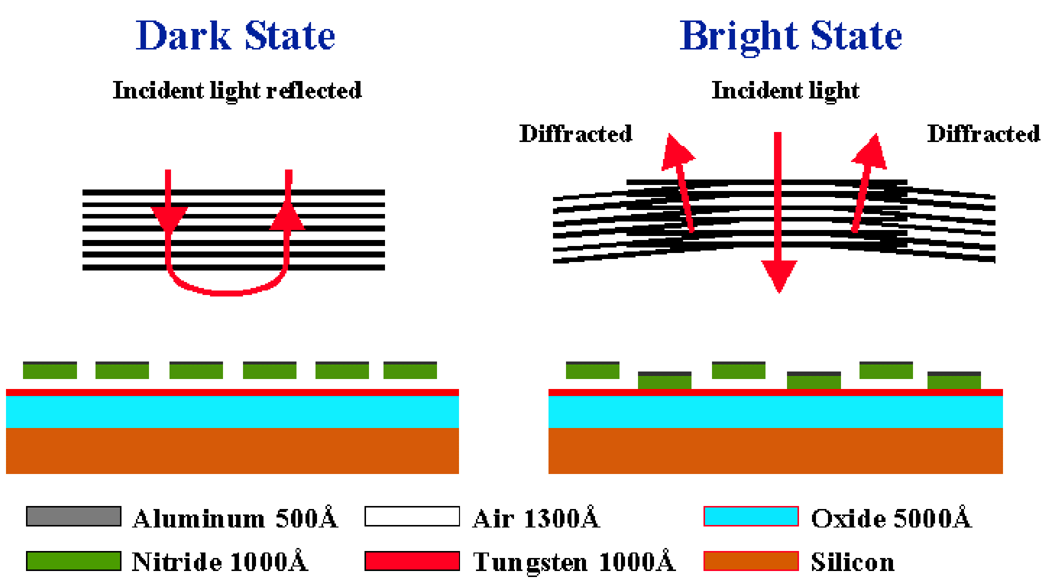

Figure 1: The Grating Light Valve uses reflection and diffraction to create dark and bright image areas.

If an array of such GLV elements is built, and subdivided into separately controllable picture elements, or pixels, then a white-light source can be selectively diffracted to produce an image of monochrome bright and dark pixels. By making the ribbons small enough, pixels can be built with multiple ribbons producing greater image brightness. If the up and down ribbon switching state can be made fast enough, then modulation of the diffraction can produce many gradations of gray and/or colors.

There are several means for displaying color images using GLV devices. These include color filters with multiple light valves, field sequential color, and sub-pixel color using "tuned" diffraction gratings.

These are the fundamental concepts involved in GLV design. Now let's examine a practical method for manufacturing GLV devices.

2. Building the GLV device

The following describes the materials, dimensions and packaging of a GLV device capable of implementing a high-resolution display. The entire GLV device is designed to be built using mainstream IC fabrication technology (e.g. photolithographic masking, deposition, etching, metalization, etc.) to create the micro electromechanical systems (MEMS) that make up the GLV device. The GLV ribbons are built using silicon nitride, then coated with a very thin layer of aluminum (see figure 2). By making the aluminum layer very thin, one avoids some of the surface roughness that otherwise scatters the light reducing the contrast ratio.

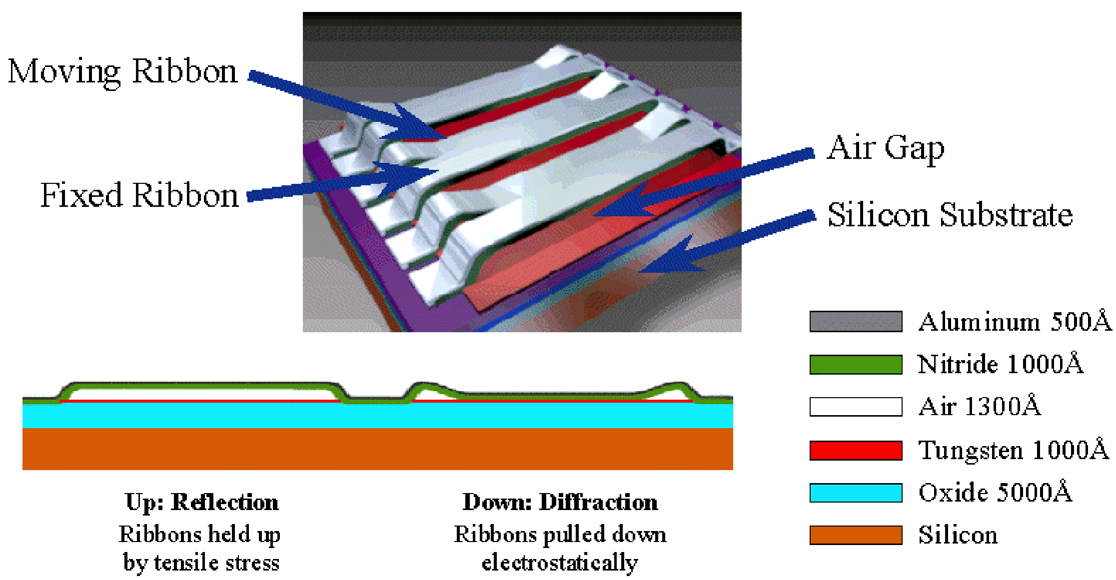

Figure 2: Build using IC fabrication technology, the Grating Light Valve consists of pairs of fixed and movable ribbons located approximately a quarter wavelength above a silicon dioxide layer.

In one implementation which Silicon Light Machines has built, the ribbon lengths are 20 µm, and the ribbon pitch is 5 µm. The pull-down distance is approximately 1300 Angstroms, or approximately one-quarter wavelength of green light. With these dimensions, a set of four ribbons (two fixed and two movable) produces a 20 µm square pixel (see figure 3).

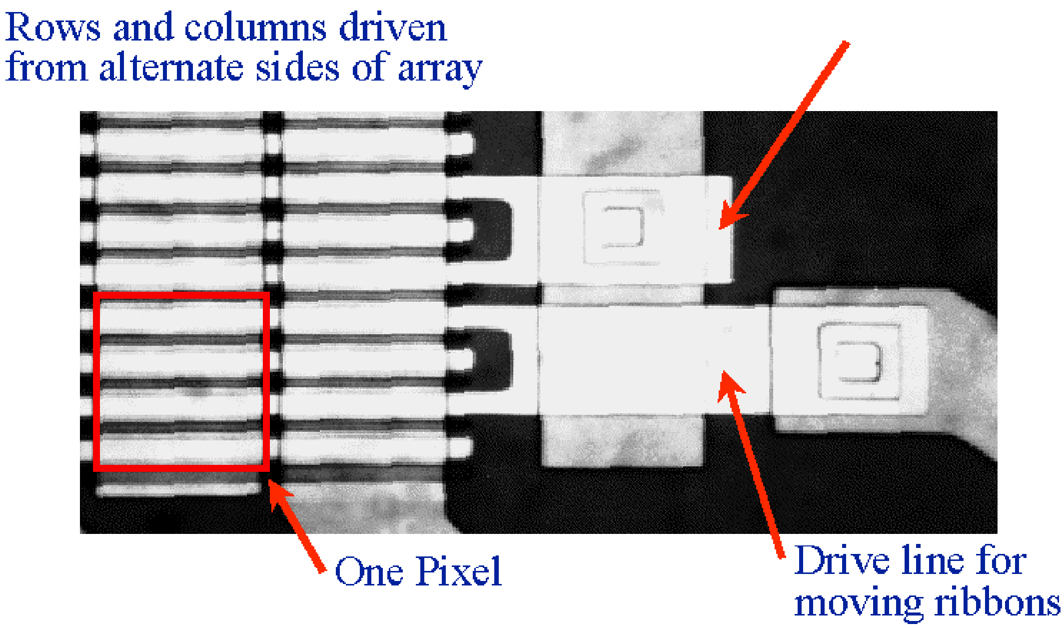

Figure 3: A single pixel consists of a pair of fixed and a pair of movable ribbons.

The "up" position of the ribbons is maintained by the tensile stress of the silicon nitride material. With no other forces applied, the ribbons will naturally "snap back" into an upward position. By integrating electrodes below the ribbons, and applying different voltages to the ribbons and the bottom electrodes, an electrostatic attraction force will pull the movable ribbons downward. The deflection distance is determined during manufacture.

The basic GLV pixel is defined using a simple, 2-mask IC process. Silicon Light Machines has built devices using only 7 masks. In general, the more masks needed to manufacture an IC, the higher the initial cost. And, each additional masking step has a negative impact on yield (i.e. the percentage of good versus faulty components). Thus, the simple GLV design should provide lower initial costs and higher yields compared with light-valve technologies that require more complex manufacturing. When the GLV device is finished and tested, a clear glass lid is fixed above the ribbons area sealing in a dry nitrogen environment for pressure equalization and to prevent oxidation. As shown in figure 4, additional electronic driver and control logic is built into a complete, lightvalve, multi-chip module.

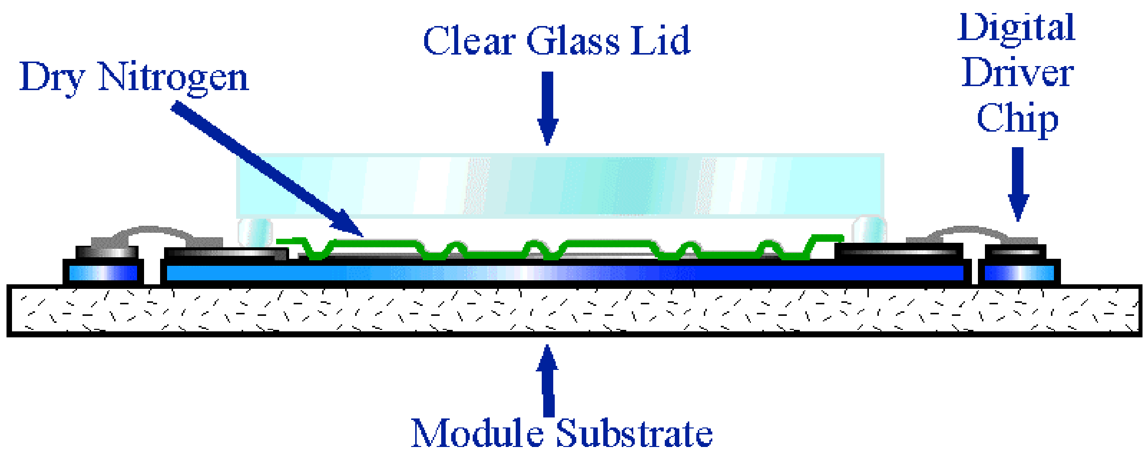

Figure 4: The packaged GLV subsystem can include additional electronic interface circuits for higher integration and lower cost.

Having examined this blending of MEMS and IC technologies, let's see how this GLV device is controlled, and how it performs.

3. Controlling the GLV device

To control a GLV-based device, one simply directs the up and down ribbon movement of this two-state technology. As mentioned previously, the ribbons will naturally assume the up state. To pull them down, one must apply a voltage difference (e.g. the switch-down voltage, V2) between the movable ribbons and bottom electrodes. Interestingly, the ribbons maintain their down state even as the voltage differential is reduced. Thus, one can pull the ribbon down with a switch-down voltage (V2), and maintain that state with bias voltage, Vb, such that $V1<Vb<V2$ volts (see figure 5), where V1 is the switch-up voltage at which the ribbon returns to its up state. We've built GLV devices such that V2/V1 is approximately 2. This ribbon hysteresis permits one to maintain present pixel states with a bias voltage, without drawing current. In other words, a static pixel configuration can be maintained with practically zero power consumption. Other display technologies require significantly more complex control circuits to maintain pixel states.

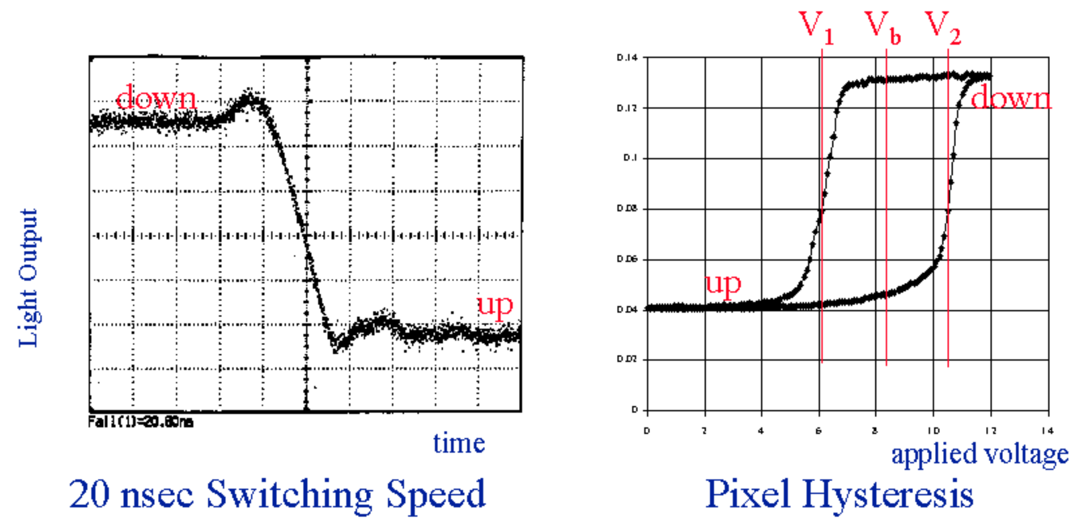

Figure 5: To switch a ribbon down requires a voltage differential of V2 volts or more between the ribbon and a bottom electrode. The ribbon will remain down until the voltage differential falls below V1 volts. This ribbon hysteresis offers mechanical memory and zero-power pixel-state retention. Switching time is approximately 20 nanoseconds.

The up and down ribbon switching occurs very quickly. The GLV device described here switches in 20 nanoseconds. That is roughly a million times faster than conventional LCD display devices, and about 1000 times faster than another light-valve technology (i.e. Texas Instruments DMD micro-mirror technology). The reasons for the high speed are the small size and mass, and small excursion, of the GLV ribbons. This high-speed switching offers several benefits. At these speeds, it is easier to streamline drive electronics and to simplify the memory requirements. There is no need to provide buffers or delay functions to complement the mismatch in speeds between electronic devices and this MEMS device.

Another speed advantage is the ability to modulate, over a wide range, the time ratio of up-to-down states (or dark and bright states) which produces the effect of shades of gray or color variations. GLV switching speeds make it easy to implement an 8-bit or greater gray scale, and are fast enough to support colors and grays over a 1000-to-1 dynamic range. This is much broader gray and color accuracy than is produced using LCD technology, for example.

The combination of speed and mechanical memory (e.g. ribbon hysteresis) make controlling the GLV device very simple. An elegantly simple row and column addressing scheme can be used, and passive matrix (rather than the more complex active matrix) pixel control is all that is required. This eliminates the need for any transistors in the GLV array itself, greatly simplifying the manufacturing process. The GLV device thus lends itself to an easy interface to other display system electronics.

Contrast ratios, fill ratios and optical efficiencies are important metrics for distinguishing among various display technologies. High contrast ratios provide crisper images. A GLV system we built using relatively inexpensive optics exhibits a contrast ratio of better than 200-to-1. Fill ratios — the ratio of optically active area to total pixel area — is already better than typical LCDs. In a prototype GLV array we built using mature 1.25 micron design rules, we achieved fill ratios of 67.5 percent compared with 60 percent for LCDs. Using more modern, smaller, design rules, fill ratios of 80 percent are expected.

Finally, optical efficiency for reflective devices is naturally higher than that for transmissive devices. In a typical GLV prototype, where the optical system collects +/- 1 order of diffraction, about 81 percent of the incident light can be collected in the bright state. This makes for brighter images compared with other technologies when operated at comparable power consumption levels.

4. Applying the GLV technology

In general, the GLV device can be used to build a relatively simple display system (see figure 6.) Video input is format converted and then input to a digital driver. The latter interfaces directly with the GLV device. Light is diffracted by the GLV device into an eyepiece for virtual display, or into an optical system for image projection onto a screen.

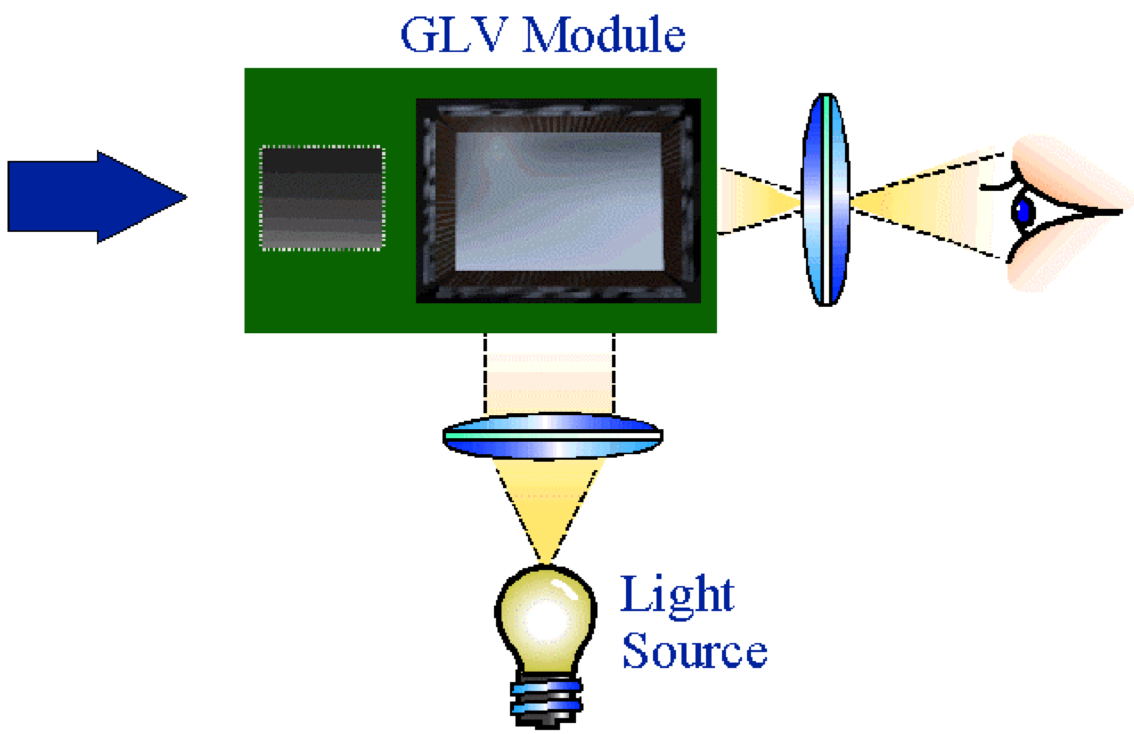

Figure 6: A GLV subsystem provides a simple interface to upstream electronics.

One way of reproducing color images is by using different ribbon pitch to create a red-green-blue pixel "triad" instead of the monochrome pixel described earlier (see figure 7). In such a system, white light is introduced at an angle slightly off-axis to the GLV device. In essence, the red area, having the widest pitch, refracts red light normal to the GLV plane while green and blue light is refracted at other angles. The green and blue areas, having narrower pitch, do the same for green and blue light, respectively. Color is produced by reducing the slit width to allow only a limited bandwidth about each of the primary colors to be selected.

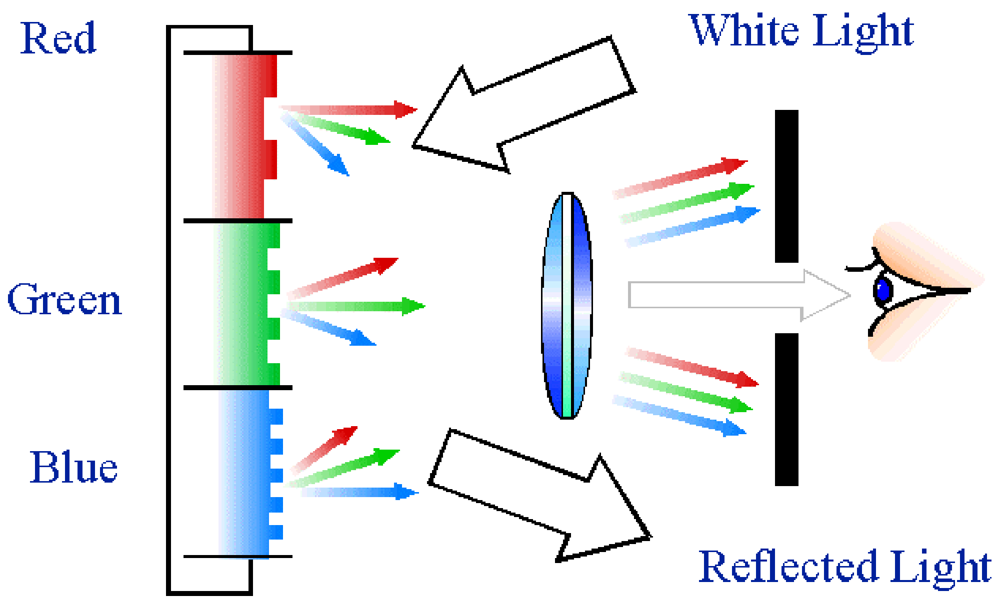

Figure 7: By using different spacing between ribbons, one can create color-oriented sub-pixels.

In a frame-sequential projection system (figure 8) a white light source is filtered sequentially (by a spinning red-green-blue filter disk, for instance). By synchronizing the image data stream's red, green and blue pixel data with the appropriate filtered source light, combinations of red, green and blue diffracted light is directed to the projector lens. In this system, as shown, a turning mirror is used both to direct light onto the GLV device, and as an optical stop blocking reflected light.

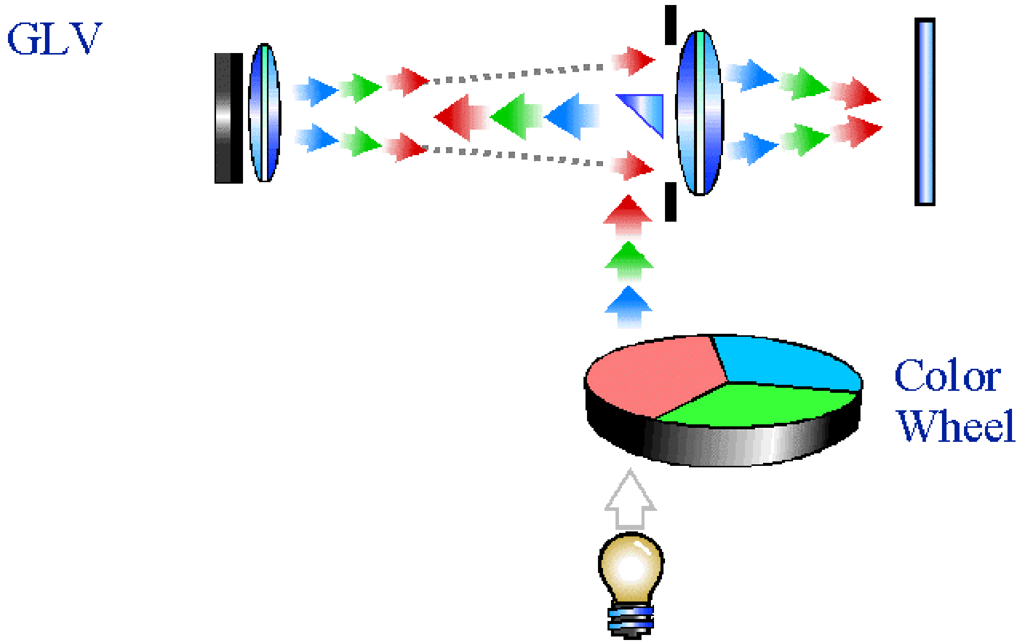

Figure 8: A simple color display can be built using a single light source, single GLV, and rotating RGB filter disk.

An even simpler, handheld, color display device (see figure 9) uses three LED sources (red, green and blue). A single GLV device diffracts the appropriate incident primary -color light to reproduce the color pixel information sent to the controller board.

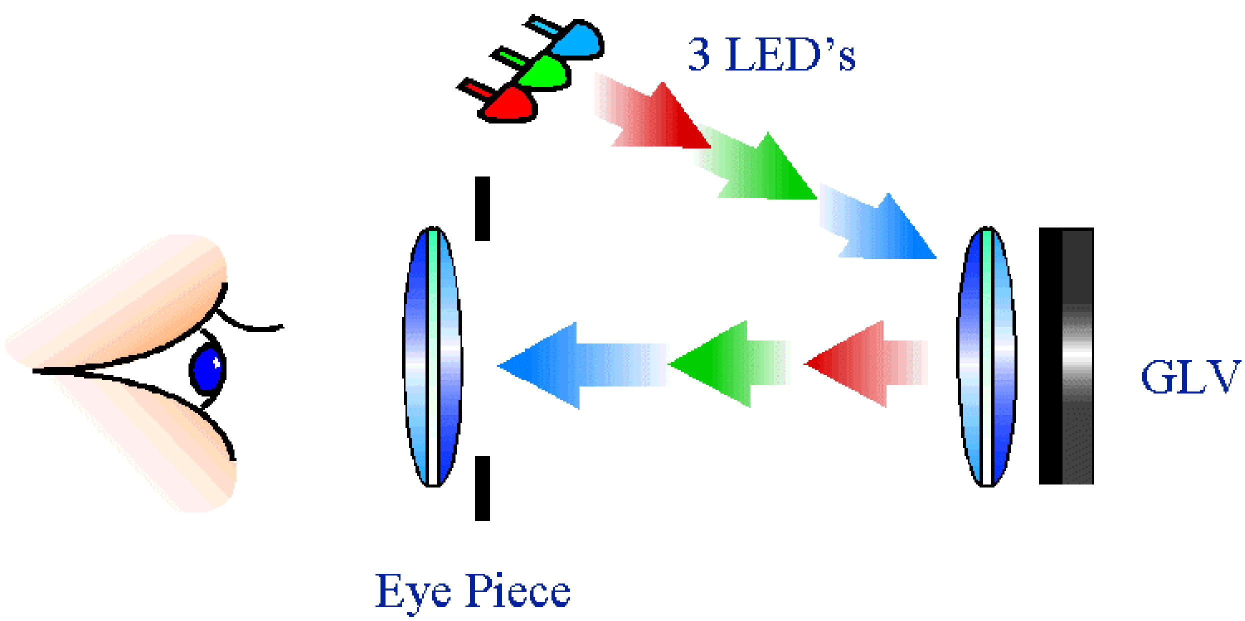

Figure 9: An even simpler color display can be built with 3 LEDs (RGB) and a single GLV

A more elaborate and accurate color projection system can be build using three GLV devices. By passing the source's white light through dichroic filters, red, blue and green light are incident on three separate GLV devices. Diffracted light is collected and directed through the optical system to a viewing screen. This represents a much smaller and lower-cost solution, say, to the three-tube projection systems now used for large-screen projection of PC images and videos. An implementation scheme (see figure 10), shows the light source, optical components, and three-GLV module.

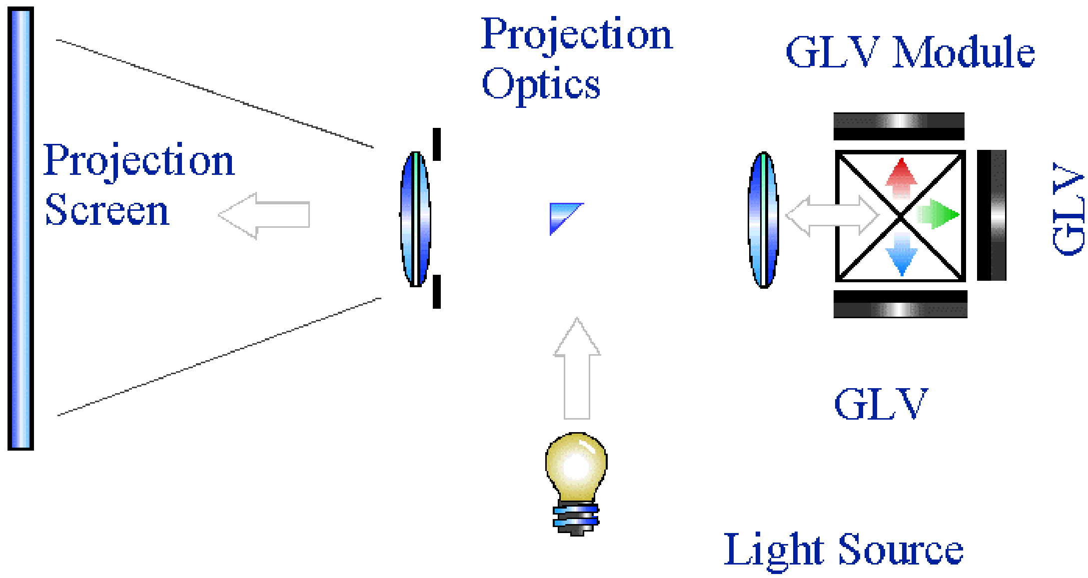

Figure 10: A three-GLV color display solution is shown for a large-screen projector.

5. Comparing the GLV

To succeed as an alternative to existing display technologies, GLV technology must demonstrate some compelling benefits, and it does. Compared to its closest alternative — micro-mirror light valve technology — the GLV device is much simpler to fabricate, requiring only 7 mask steps. GLV devices use smaller, lighter, mechanical structures that move through smaller excursions than alternative light-valve technologies. Hence, it is faster, requires less external memory and no transistors in the MEMS array.

Several orders of magnitude faster than conventional LCDs and other light-valve technologies, GLV technology matches much more closely the speeds of its electronic interface components. As a result, the interface is simpler. GLV speeds also provide for higher gray scale and color variation accuracy. For example, a GLV device can be used to build a 10-bit-per-pixel, high-resolution display, compared with 8-bit-per-pixel, LCD displays.

Because GLV devices are built using mainstream IC fabrication technology, ribbon dimensions are easily scaled allowing the production of smaller, lower-cost, devices with higher resolution and fill ratios.

The GLV technology's MEMS architecture is exhibiting very encouraging reliability. Early experiments have shown no ribbon fatigue after 210 billion ribbon switching cycles. This is equivalent to a television display system running non-stop, without failure, for 15 years.

With their higher optical efficiencies, GLV systems can deliver higher levels of brightness per watt of power consumed. Their small size makes it practical to build over a million pixels in a 1.3 inch diagonal. Coupled with their mass producibility, this makes the GLV a candidate for building high-resolution, low-cost displays. And their inherent zero-power pixel-state retention make them ideal for use in small, battery-powered devices.

In essence, the GLV technology promises to revolutionize display system design by making them smaller, cheaper, brighter, less power consuming, and with higher resolution.

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