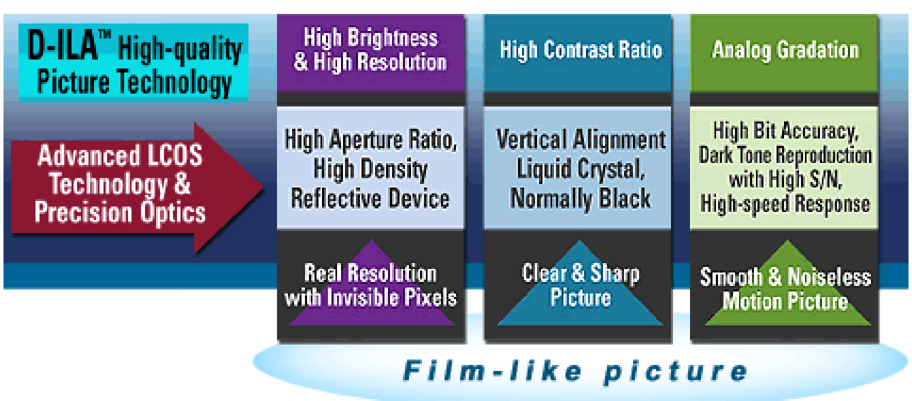
D-ILA™ Projector Technology: The Path to High Resolution Projection Displays

Introduction

In 1998, JVC produced the first projector using liquid crystal on silicon (LCOS) microdisplay technology for image projection. LCOS technology "sandwiches" liquid crystals between a cover glass and a silicon chip with an aluminum matrix of pixels. JVC has the most advanced version of LCOS technology with its Direct Drive Image Light Amplifier™ (D-ILA™), based on an innovation in microchip design that permits the viewer to enjoy the full range of benefits from any high quality source whether from a video deck or a computer device. For true HDTV performance, the D-ILA technology in the DLA-HD2K packs 1920x1080 pixels — a total of nearly 2.1 million pixels- on a single 0.8" chip. This makes possible display of HD images at full-spec resolution of 1920 x 1080.

The D-ILA's innovative placement of the CMOS electronics and high density pixel array is the key to reproducing all the details in a high-definition picture. By placing the matrix addressing switches and electronics right behind (not between) the light-modulating liquid crystal layer, JVC has created a D-ILA chip with a "three-dimensional" layout. The result is a 93% fill factor and virtual elimination of the annoying "grid" or "screen door effect," so evident in other fixed-matrix display technologies.

What is the end result? Images as smooth and natural as film with impeccable reproduction of all the details and information contained in the original source. What supports this high picture quality is accurate color temperature at the proper light level, high resolution, high contrast and analog gradation. Accurate color temperature is achieved with an advanced optical illumination system. High resolution is achieved using a reflective device with a high aperture ratio and high-density pixels, providing real resolution with invisible pixels. High contrast is achieved using vertical alignment liquid crystals of normally black operation and a high-precision optical system. Analog gradation makes it possible to reproduce dark areas with high S/N (signal-to-noise ratio) because the D-ILA device has a natural S-shape gamma response. In combination with the high-speed response of the vertical alignment liquid crystal, JVC's D-ILA technology makes it possible to reproduce smooth, noiseless motion pictures with clear, sharp high definition and film-like picture quality.



A Closer Look at D-ILA Technology

D-ILA is JVC's proprietary reflective-mode active matrix liquid crystal display, technology which offers many inherent advantages over competing technologies enabling the production of small size 3 chip projectors with high reliability:

- **Efficiency and Reliability** — The unique high performance and small dimensions of single crystal silicon backplane circuitry allows a high level of integration of driver and processing circuitry, enabling the development of affordable three-chip projectors. This is coupled with the high electro-optic efficiency and reliability of liquid crystal materials.
- **Adaptability and Scalability** — With LCOS technology, in contrast to digital light processing's (DLP's) micromirror technology, pixel size and format can be readily adjusted to meet optical system requirements.
- **Smooth Images** — Pixels are spaced close together so there is no screen door effect or visible pixel grid giving the image film-like quality. The liquid crystal structure in the D-ILA device produces pixels that appear to be smoothly blended together. This reduces the harshness of a digital image and makes the image easier for the eyes to watch.
- **Thermal Stability** — The silicon backplane can be thermally controlled across the entire aperture for stability, optical uniformity, and reliability in operation which is key to applications using multikilowatt Xenon arc lamps.

Table 1 charts the modulator characteristics of the D-ILA devices, from SXGA+ to QHDTV resolution.

<table>
<tr><th colspan="2">Device Name</th><th>Display size (inch)</th><th>Pixels (H x V)</th><th>Aspect Ratio</th><th>Major Applications</th></tr>
<tr><td rowspan="3">New</td><td>1. 1.7 inch 4K2K</td><td>1.7</td><td>3480x2048</td><td rowspan="3">16.9</td><td>Ultra high-definition video systems, simulation, etc.</td></tr>
<tr><td>2. 0.8 inch full HD</td><td>0.8</td><td>1920x1080</td><td>High-end home theaters DLA-HD2K, wide-screen rear projection TVs, etc.</td></tr>
<tr><td>3. 0.7 inch 720P</td><td>0.7</td><td>1280x720</td><td>Rear-projection TVs, home theaters, amusement, etc.</td></tr>
<tr><td rowspan="3">Existing</td><td>4. 1.3 inch QXGA</td><td>1.3</td><td>2048x1536</td><td rowspan="3">4.3</td><td>Digital cinema, simulation, exhibitions, etc.</td></tr>
<tr><td>5. 0.7 inch SXGA+</td><td>0.7</td><td>1400x1050</td><td>Presentations, AV theaters, etc.</td></tr>
<tr><td>6. 0.9 inch SXGA</td><td>0.9</td><td>1365x1024</td><td>Presentations, CG Monitors, etc.</td></tr>
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TABLE 1: D-ILA Image Modulators

Figure 1 graphically shows the range of resolutions that D-ILA can produce and the images of the D-ILA devices themselves. A key advantage of D-ILA and LCOS is that the device is easily scaleable to larger resolutions as the requirements for resolution increase in the future.

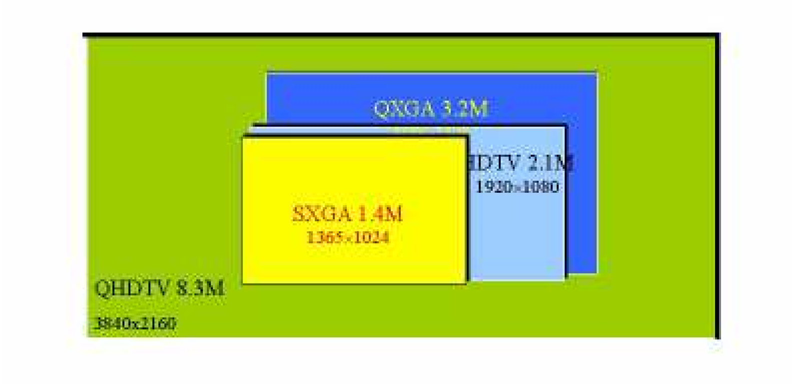

FIGURE 1: Comparison of Image Formats

D-ILA Device Structure

With the D-ILA design, electronic signals are directly addressed to the device. The light valves use active matrix addressing of the liquid crystal to achieve the spatial modulation. Each pixel is directly accessed through the x-y matrix circuitry that is printed directly behind the device. This means that light does not have to pass through the drive electronics since all circuitry is behind the light path.

Since the nematic liquid crystal responds to voltage level directly, the gray scale is determined by the value of voltage set on each pixel. Less processing power is required to produce accurate gray scales compared to digital micromirror devices (DMDs) or plasma panels. In addition, black-level detail and peak-white detail is increased without the need for added processing overhead.

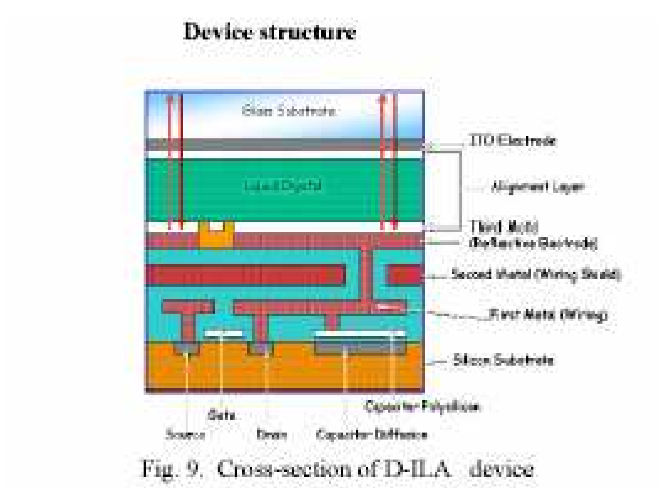

FIGURE 2: Cross-section of D-ILA Device

Figure 2 depicts how the D-ILA X-Y matrix of pixels is configured on a CMOS substrate via the commonly-used planar process, a standard in integrated circuit (IC) technology. Key elements of the device construction are:

- **Vertical pixel alignment** — improves black level capabilities

- **Thickness** — enables the response time to be fast enough for full motion video
- **Polarization** — controls what light will go through the lens to create an image when voltage is applied
- **Gamma characteristics** — ranges from 2.2 – 2.6 (similar to that of CRT due to the nature of the nematic liquid crystal), requiring less processing to produce the gray levels than with other display technologies.
- **Reflectivity and light blocking structure** — Separates the light from the drive electronics

The pixel electrodes of the D-ILA device have a 93% aperture ratio, and have high intrinsic reflectivity with a final pixel mirror approaching a reflectivity of 98%. The light blocking layer is formed under the mirror electrode in order to prevent light leakage to the transistor located on the first metal layer in the silicon chip. Light leakage would activate the transistor. Each metal layer also has anti-reflective layers on both sides. A light-induced voltage drop in the pixel electrode could cause decreased projection light output due to decreasing liquid crystal modulation. With anti-reflection layers, no voltage drop was observed with high light input from the illumination system. It will be possible to produce projection systems with greater than 20,000 lumens using D-ILA devices.

Liquid Crystal Alignment

Vertically aligned nematic (VAN) liquid crystals allow high device contrast ratio across the entire visible light spectrum range. The liquid crystal molecules are aligned almost perpendicular to the surface with a small pre-tilt angle at off state — an important factor in achieving high contrast ratios and good quality in the projected image.

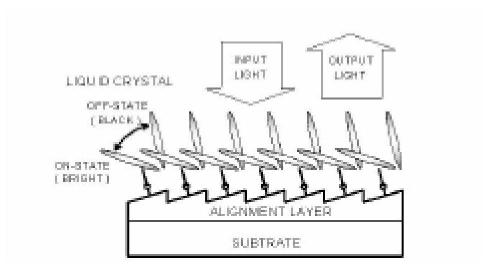

FIGURE 3: The D-ILA VAN Liquid Crystal Alignment

Figure 3 shows a schematic of the VAN liquid crystal alignment. There is a range of pre-tilt angles best suited for producing a high contrast ratio and a good uniform image without liquid crystal disclination. With optimized pre-tilt the intrinsic device contrast ratio for a $f/2.4$ optical system is greater than 5000:1. As shown in Figure 2, the molecules are rotated away from the perpendicular state by the electric field from the pixel corresponding to input image signal. This movement of the molecules changes the amount of rotation of the polarized projection light.

The JVC alignment method uses no organic alignment layers common in other liquid crystal devices, achieving high stability under conditions that degrade organic layers and cause short operating lifetimes. It is important to note that the device contrast can approach 5000:1. Studies have shown that liquid crystal devices that use an organic alignment layer such as in typical LCD projectors will deteriorate and cause the color of the projector to become very poor in as little as 2500 hours. JVC's non-organic alignment layer alleviates this problem.

The D-ILA device has a true video-rate response time (the rise time plus fall time equals less than 12 milliseconds). Generally, the response time of liquid crystal layers is strongly related to the layer thickness. Reflective mode permits a thinner liquid crystal cell gap compared to transmissive-mode LCDs because in this mode the light passes through the liquid crystal twice — effectively doubling the modulation. The liquid crystal's pre-tilt angle of liquid crystal is also determining factor for response time; set at a high enough value to avoid potential liquid crystal artifacts that can occur at very low tilt angles while maintaining video-rate response.

D-ILA Projector Technology

As previously discussed in the D-ILA device section, the driving IC controls the voltage across the liquid crystal layer between reflective pixel electrode and transparent electrode based on image signal level. This signal level determines the intermediate levels, or gray scale, of the image. Polarized light from the light source (Xenon lamp or other high intensity discharge lamp) passes through the activated liquid crystal and is reflected by reflective pixel electrode for each selected pixel. The liquid crystal molecules change birefringence according to the signal voltage, changing the polarization direction of the illumination light.

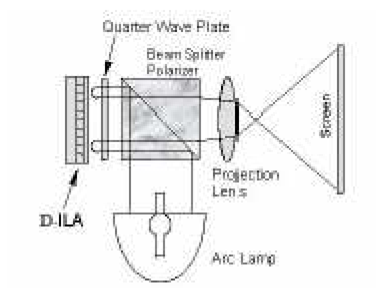

FIGURE 4: Optical Schematic of Basic D-ILA Projector

A schematic of the optical system to read the image on a single D-ILA device is shown in Figure 4. The individual operation for each of the RGB D-ILAs is the same. The light from the arc lamp is separated into two linear polarization states by the polarizing beam splitter (PBS) before it reaches the D-ILA. One state is reflected by the interface in the PBS and reaches the D-ILA device. To improve the contrast ratio of the PBS, a nominal quarter wave plate retarder is inserted between the PBS and the D-ILA, with the polarized light then reflected by pixel electrode and modulated by the liquid crystal again, thus receiving the gray scale image information.

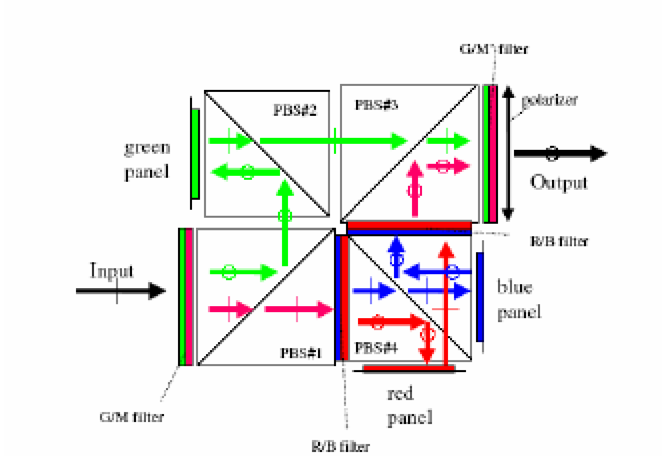

FIGURE 5: Schematic of Color Quad Color Management System Architecture

Figure 5 shows a schematic of the new compact D-ILA projector color management architecture using ColorQuad™ technology, representative of many possible ColorQuad system configurations. This type of optical engine is used in the DLA-HD2K and several other JVC projectors. Four PBS are used to split the polarized white light into three primary color beams. The Color Select™ filters separate the color beams into orthogonal polarizations before the PBS to efficiently channel the light through the system. The colors are determined by the angle insensitive Color Select filters. Thus no degradation in color results from the use of low f/number systems down to f/2.

A Bright Future

The path to the future of ultra-high resolution displays began in 1998 with the benchmark JVC G1000 D-ILA projector and continues through today with the availability of the DLA-HD2K HD projector. The JVC Research Division continues their efforts to deliver D-ILA technology that surpasses today's performance maxims in resolution and overall image quality to deliver the perfect viewing experience.