ILA®/D-ILA™ Super Projectors for the Present and the Future

Mitsuru Hayakawa
Victor Company of Japan, Limited (JVC)

Introduction

Projectors are now an essential component in display systems for applications requiring a large screen image that provides an image so real, the viewer feels as if he is watching a live performance, while conveying vital information with sales appeal. On the one hand, the projection device, a key enabling component of the projector, requires resistance to light and heat since high intensity light rays are concentrated on the small device area, while at the same time high precision processing is required to achieve high resolution. Currently, many technological developments are advancing worldwide in an effort to create even higher performance projectors.

This paper describes the configuration and performance of unique spatial light modulators (SLM), the Image Light Amplifier (ILA®) and the Direct-drive Image Light Amplifier (D-ILA™) devices, and projectors incorporating them. It also discusses the future outlook for D-ILA™ devices.

Market Introduction of ILA® Projectors

In the early 1970s, Hughes Aircraft Company performed research in the U.S. on light addressed spatial modulators, and by the end of the 1980s it had established its projector technology for moving pictures.[1]

Meanwhile, Victor Company of Japan, Limited (JVC) conducted its own research and development of light addressed spatial light modulators viewing them as the optimal projection system for the coming age of large screen displays. These two companies that were developing common projection technologies established Hughes-JVC Technology Corporation, and began selling ILA® Super Projectors[2,3,4] in 1993. By the late 1990s the marketplace recognized these projectors as the principal projection method for large screen projection.

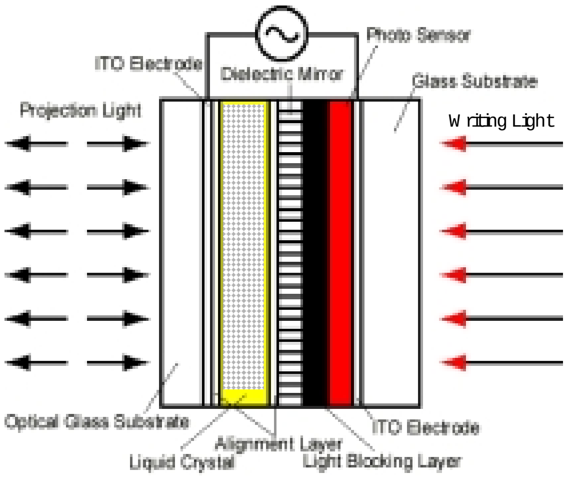

Figure 1. Cross sectional Schematic of ILA® device.

Configuration and Operation of the ILA® Device[1]

As shown in Figure 1, the ILA® device is configured by several layers of thin film sandwiched between two glass substrates. There are four principal thin film layers: a photosensor layer, a light-blocking layer, a dielectric mirror, and a liquid crystal layer. A characteristic of this configuration is that it creates an image without pixel artifacts. Figure 2 shows the basic design concept of the ILA® projector. The input image is provided by a CRT. The two-dimensional CRT writing light image is focused on the amorphous silicon (a-Si) photosensor. Since the impedance of the photosensor changes depending on the writing light intensity, the voltage pattern on the liquid crystal layer also changes. In the output projection, the light beam from the lamp passes through the polarizing beam splitter (PBS) and light in the S-polarization state enters the liquid crystal layer. Consequently, light modulation of the projection beam takes place and the returning P-polarization state output light travels through the PBS, and the projection lens focuses and magnifies the image onto a screen.

Features and Issues of the ILA® Projector

The ILA® Projector incorporates a system that enabled for the first time simultaneous achievement of the seemingly conflicting requirements of high brightness and high resolution. The features of this projector are listed below:

① The projection light that determines light output is reflected from the dielectric mirror that has 100% aperture ratio, thereby enabling the projection of high bright images without any light loss.
② The writing light that determines resolution is a low-intensity beam, therefore the CRT beam current is low, easily allowing for the achievement of high resolution images.
③ High contrast was achieved by successfully mass-producing for the first time, devices with homeotropic liquid crystal alignment which was said to be difficult to do.
④ Image reproduction without distortion is possible since there are no pixel artifacts, and no false signals are generated in response to the various input signals.

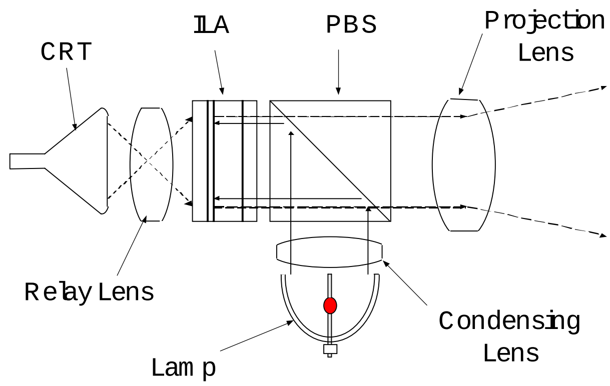

Figure 2. Basic Design Concept of ILA™ Projector.

While the ILA® Projector has proven its high performance capabilities by achieving a light output of 12,000 lumens, a limiting resolution of 1600 TV lines and a contrast ratio greater than 1000:1, some of its issues are listed below:

① As long as the ILA® is used for projection, and the CRT is used for device addressing, there is a need to have two key components in the projector. Consequently, size and weight inevitably grow, which in turn makes cost an issue.

② Since the writing light image is generated by the CRT's finite electron beam, the modulation transfer function (MTF) is that of a Gaussian shaped beam intensity profile. Consequently, the limiting resolution is extremely high which is perfect for image display, however legibility of small text becomes an issue.

Development of the D-ILA™ Projector

In recent years, the availability of high-speed, high capacity computers at a low cost has made the use of graphics and text in presentations commonplace. As a result of this trend, there has been a strong demand for improvements in text legibility.

In order to solve the issues of the ILA® Projector described above while maintaining its features, JVC independently developed the new D-ILA™ device that allows for direct projection of picture signals onto pixels. Believing it important to develop this new projection method to meet future market demands making it the mainstream technology in the 21st century, JVC launched the D-ILA™ Multi-Projector with SXGA resolution at the beginning of 1998.

Configuration and Operation of the D-ILA™ Device [5,6]

The liquid crystal on silicon (LCOS) configuration of the D-ILA™ device is shown in Figure 3. Using the CMOS process, the X-Y matrix for pixel address selection and the aluminum reflective electrode corresponding to each pixel are formed on the silicon substrate, and after the surface flattening process, the alignment layer is applied. The glass substrate has a transparent electrode and an alignment layer on it. The liquid crystal with homeotropic alignment is sandwiched between the silicon substrate and the glass substrate.

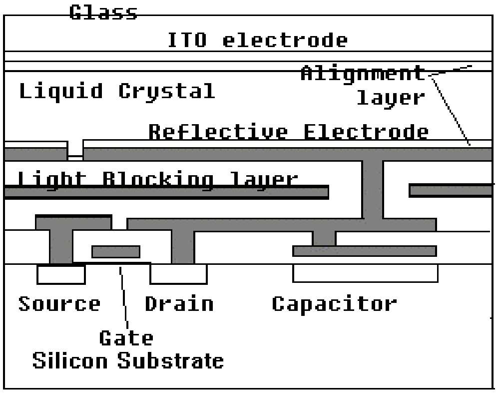

Figure 3. Cross-section view of D-ILA™ device.

The basic operation of the D-ILA™ projector is shown in Figure 4. As with the ILA® Projector, the light from the lamp travels through the PBS with the S-polarization state entering the D-ILA™ device. The incident light goes through the liquid crystal layer and is reflected back to the PBS by the pixel electrodes. At this time, in the activated pixels, the polarization direction of light in the S-polarization state is rotated in response to image modulation of the liquid crystal layer converting it to the P-polarization state, and this light goes through the PBS and projection lens, and is projected on the screen. The non-activated pixels produce no modulation of the liquid crystal layer, so the light in the S-polarization state is reflected by the PBS and returned to the lamp, thus becoming the black level.

Features of the D-ILA™ Device

① The LCOS structure of the D-ILA™ device induces a high aperture ratio of 93% because of the three-dimensional configuration of pixel address selection behind the light modulating liquid crystal layer. Thus, the entire device area can be used for reflection, excluding the insulation between the pixel electrodes.

② The high aperture ratio means that there are few instances of device thermal instability resulting from light to heat conversion, and error of the driving device due to light to signal conversion, making it simple to achieve high light output that can withstand high intensity light input.

③ The CMOS process enables a small pixel pitch so that 13.5 μm pitch on a 0.9" panel achieves SXGA (1365 x 1024) resolution. Further reduction in pixel pitch will enable higher resolutions, and of all current projection devices, the D-ILA™ has the greatest potential for higher density pixel structures.

④ This device is based on the proven performance of the homeotropically aligned liquid crystal of the ILA® device, and it can easily provide high contrast images. The device alone is capable of a contrast ratio greater than 1000:1.

⑤ A characteristic of reflective type devices is that modulation takes place while the light is passing in and out of the liquid crystal layer, allowing for half the cell gap of a transmissive type device, enabling this device to have a fast response time of less than 16 milliseconds.

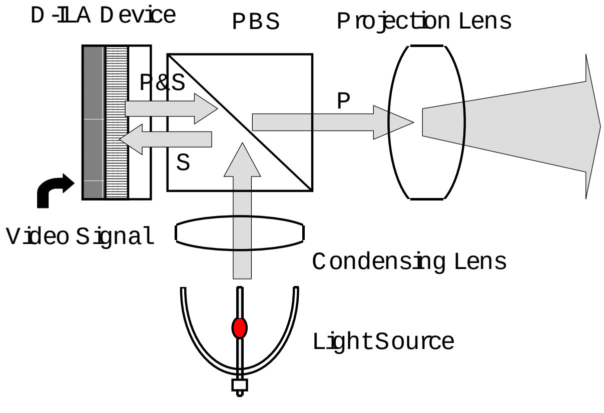

Figure 4. Basic Design Concept of D-ILA™ Projector.

Basic Configuration of the D-ILA™ Projector

Figure 5 shows the configuration for a three-panel D-ILA™ system. A large portion of the unpolarized light from the lamp is converted to the S-polarization state by passing through the PS Combiner (PSC), comprised of two fly-eye plates and a PBS plate, which simultaneously increases the light collection efficiency and improves light uniformity across the optical path plane. The light is then separated into red, green and blue components by the color separation optics and sent into the PBS corresponding to each color.

The S-polarization state that is reflected by the PBS is modulated by the D-ILA™ device for each color, as previously explained by Figure 4, and only light in the P-polarization state passes through the PBS, where the RGB color components are combined in the cross dichroic prism and a color image is projected through the projection lens onto the screen.

As just explained, the D-ILA™ Projector has successfully maintained the features of high brightness, high resolution and high contrast ratio of the existing ILA® Projector by changing the addressing system from an optical image to an electronic signal to directly drive the device. At the same time, this new technology has solved the ILA® Projector issues of size, weight, cost and text legibility.

Light output of the first D-ILA™ Projectors[7,8] was 1000 lumens, however, light output of the current product lineup ranges from 1500 lumens to 4000 lumens. Together with high brightness and high resolution, these projectors have been recognized for their outstanding color reproduction enabled by the use of a xenon lamp, thus establishing the D-ILA™ Projectors as a high quality image projector.

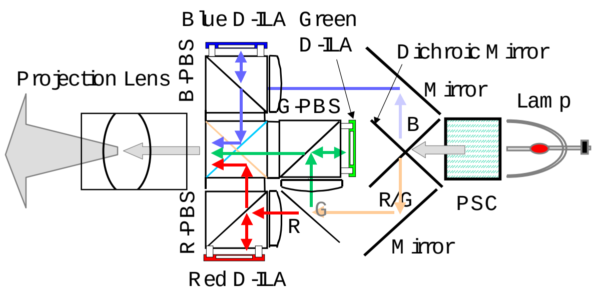

Figure 5. Optical system of D-ILA™ Projector.

D-ILA™ Application for Single Color Panel with Hologram

The three panel system, which is the basic configuration of the projector, is suitable for professional use because of the high light collection efficiency, and the device characteristics directly translates to projector performance. However, in the consumer market where business is dictated by low prices, there has been a strong call to make the projector more compact and affordable by having fewer panels or changing the optical system. Thus a single panel system is desirable.

There are two types of single panel systems: the field sequential system where color multiplexing is done temporally, and the simultaneous spatial multiplexing, where color multiplexing is done spatially.

The field sequential method, has the benefit of projecting the device's true resolution by sequentially switching between the RGB light components in synch with the field frequency. However, this requires three times more field drive frequency. In addition, other problems could arise more easily such as color break-up resulting from false signals due to a time differential, and color contamination and field flicker due to the driving conditions.

The spatial multiplexing method, on the other hand, separates the pixels on the single panel into red, green and blue, thereby avoiding the problems of color break-up, color contamination and flickering. While this method yields image quality similar to the three-panel system, a high pixel density single panel is essential since three times the number of pixels is required to produce the necessary resolution.

A common issue for both methods is the theoretical problem that simple color multiplexing causes a 1/3 reduction in the light collection efficiency.

In the D-ILA™ single color panel projector, the D-ILA™ device's high pixel density characteristics are utilized in combination with a hologram color filter (HCF), producing the new D-ILA™ Hologram Device that minimizes the reduction in light collection efficiency. A consumer projection television incorporating this new device has been in the market since the end of 1999.

Configuration and Theory of the D-ILA™ Hologram Device

Figure 6 shows the configuration and theory of color multiplexing of the D-ILA™ Hologram Device. Pixel electrodes are formed on a CMOS silicon substrate, and the basic configuration is the same as the D-ILA™ device with the alignment layer, liquid crystal layer, alignment layer and transparent electrode; however, by placing the HCF on top of the transparent electrode layer, the RGB sequential sub-pixels that correspond to each white pixel are formed. The incident white light is diffracted through the hologram filter, and enters at a different angle for maximum light

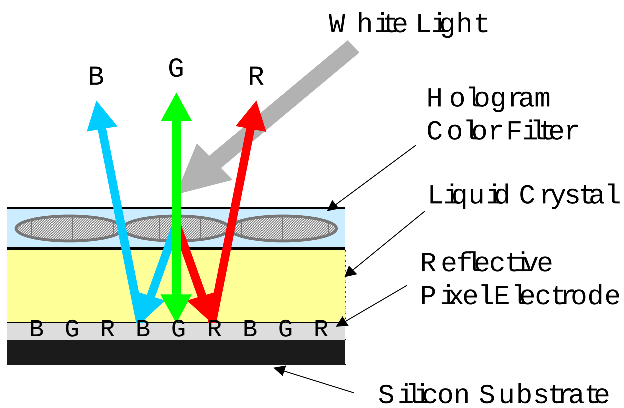

Figure 6. Cross sectional schematic of D-ILA™ Hologram Device.

collection efficiency for each color. Thus, the white light is separated into RGB components depending on optical wavelength, and after passing through the liquid crystal layer the color components will converge onto their respective color pixel electrode. The RGB light is reflected from the pixel electrode, returning through the liquid crystal layer and reaching the HCF. This light enters perpendicular to the HCF, resulting in very little diffraction, and proceeds through the HCF. As explained for the D-ILA™ device, optical modulation takes place in response to the input signal level while the light passes in and out of the liquid crystal layer, and projection light is generated in accordance with that level of modulation.

Creation of a full color image using this hologram device requires three times the number of pixels necessary for a desired resolution, and this was accomplished for the first time by using the high pixel density characteristics possible with the D-ILA™ device.

Configuration of the Signal Panel Projector with D-ILA™ Hologram Device

The conceptual structure of the single panel projector utilizing the D-ILA™ hologram device is shown in Figure 7. The white light from the lamp passes through the cold mirror, and after the condenser lens has collected the visible light, the light exits the PBS as linearly polarized light and enters the D-ILA™ hologram device at an angle. Only light that has been rotated in response to the level of image modulation of the liquid crystal is projected onto the screen after passing through the projection lens.

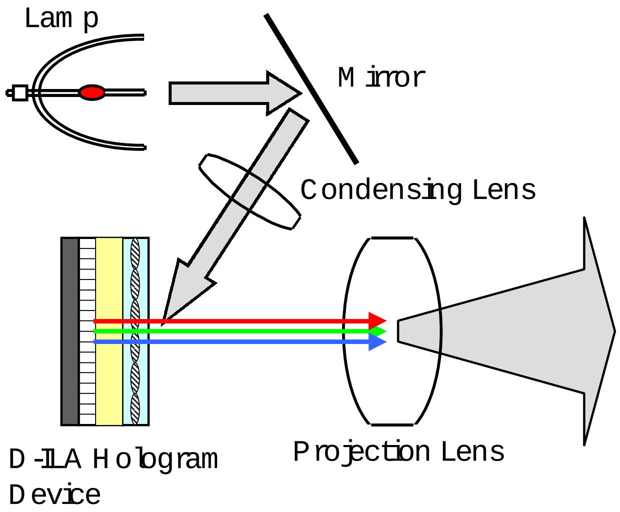

Figure 7. Basic Design Concept of Single D-ILA Projector.

Table 1. Device Specifications

	D-ILA™ SXGA device	D-ILA™ Hologram device
Device size (diag.)	0.907 inches (4:3)	1.22 inches (16:9)
Pixel numbers	1,365(H)×1,024(V)	1,280×3(H) ×1,028(V)
Pixel pitch	13.5um(H)×13.5um(V)	7um×3(H)×14.8um(V)
Aperture ratio	93 %	88 %
Contrast ratio	>1,000 : 1	>1,000 : 1
Response time	<16 m sec	<16 m sec

Specifications of the current D-ILA™ device and D-ILA™ hologram device are shown in Table 1.
The hologram device has achieved a horizontal pixel pitch of 21÷3=7 μm, thus creating a device with highest pixel density, and achieving an aperture ratio of 88%.

Making full use of the vertical alignment of the liquid crystal, the device by itself can achieve a contrast ratio greater than 1000:1. The projector can also achieve a contrast of 1000:1, although the actual system contrast ratio will depend on the optical system utilized.

Future Evolution of D-ILA™

Since the D-ILA™ device is configured on a silicon substrate through the standard CMOS process, scaling is easily done, and its high flexibility in pixel size makes it suitable for high density pixel structures. Therefore, there is ample room left for development of more compact or higher resolution devices.

The current device size (display area diagonal) is 0.9” for SXGA panel (4:3) and 1.22” for a single panel system (16:9). The pixel pitch is 13.5 μm for the 0.9” device; however, as mentioned earlier the single panel system has achieved 7 μm.

Therefore, it can be said scaling can be done without difficulty when pixel pitch is within the range of 7 μm and 13.5 μm in further development of D-ILA™ device.

Compact Devices

D-ILA™ scaling can be expressed simply as a straight line when the pixel pitch is taken to be the parameter, as shown in Figure 8 where the horizontal axis refers to device size and the vertical axis refers to resolution (number of horizontal pixels). Scaling for an aspect ratio of 4:3 and 16:9 is shown in (A) and (B), respectively.

Current SXGA resolution can easily be achieved with a pixel pitch of approximately 10 μm and device size of 0.7” and experiments have already proven this. If a 7 μm pixel pitch is used, SXGA resolution is possible with a 0.5” device and this has become the goal of future development.

Accordingly, as the devices become smaller, it brings us one step closer to achieving more compact and low cost D-ILA™ projectors while maintaining high resolution.

High Resolution Required for Electronic Cinema

Great advantages in film production, distribution and exhibition can be expected in Electronic Cinema where 35 mm film is digitized and replaced by video signals.

The key technology enabling electronic cinema is the projector, and in order for it to replace the film projector inside movie theaters it must meet some stringent demands with regard to resolution, picture quality and brightness.

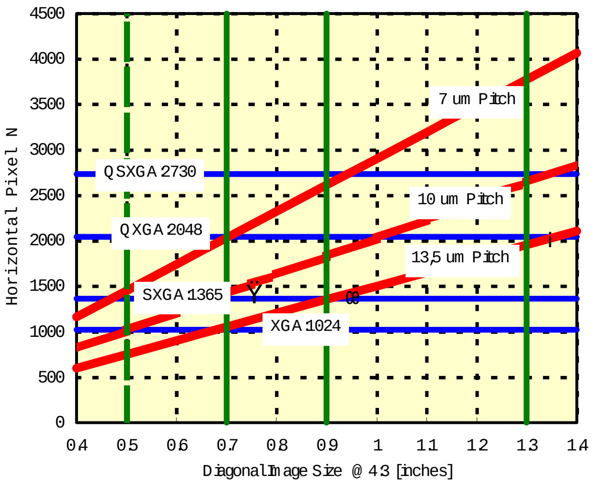

Figure 8. (A) Scaling at 4:3 aspect of D-ILA Device

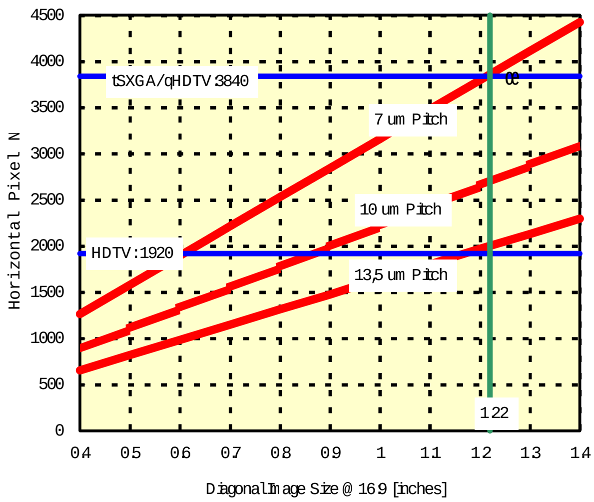

Figure 8. (B) Scaling at 16:9 aspect of D-ILA Device.

In April 1997 at the NAB show, Hughes-JVC Technology, responding to these stringent requirements, demonstrated the ILA-12K projector for electronic cinema. The ILA-12K delivers a maximum of 17,000 lumens, horizontal resolution greater than 2000 TV lines and a contrast ratio exceeding 1500:1. Since this projector is capable of reproducing a film-like non-pixelized image, a feature of the ILA® device, it received unprecedented praise from those involved in the film industry. Since then, this ILA® Projector has been utilized at various events as the standard projector for electronic cinema, and has become the development target for other projector companies.[9]

On the one hand, other companies are experimenting with SXGA (1280 x 1024) panels using anamorphic lenses to enlarge the image for the purpose of achieving simple and easy electronic cinema projectors. In this case, failure to meet the High Definition (HD) full spec (1980 x 1080) resolution, which is said to be the minimum application requirement, is apparent, and even if the projector is tolerated for animation, it is said to be unsatisfactory for displays of actual pictures.

At JVC, the thinking is that the resolution exceeding HD full spec is necessary for the genuine electronic cinema and the development of a 1.3" D-ILA™ device with QXGA (2048 x 1536) resolution is underway and a prototype panel has already been tested.

If this QXGA D-ILA™ device is used, it makes enable HD full spec with a 16:9 aspect ratio without question.
Simultaneously it makes possible electronic cinema with high resolution images exceeding the standard ILA-12K projector if QXGA resolution compressed to 4:3 aspect ratio is addressed and projected on to the screen with anamorphic lens to expand the image.
Then the growth to 1.3" in device size also helps to increase the light collection efficiency from lamp to panel, and this makes it easier to obtain the high brightness necessary in electronic cinema.
If greater importance is attached to a compact and high resolution projector rather than high brightness, then the fact that QXGA resolution is possible with a 0.7" size device can be easily understood from Figure 8 (A).

The Path to Super High Resolution

According to scaling shown in Figure 8 (A), further improvements in high resolution are possible for the D-ILA™. The 1.3" device has the potential to achieve Q-SXGA (2730 x 2048) resolution, which has quadruple the pixel density of 4:3 SXGA (1365 x 1024) resolution, adopting a pixel pitch of under 10 μm at most. When this is applied to 16:9 aspect ratio, it is possible to achieve the ultimate super high resolution of 4000 x 2000.

This is not mere wishful thinking, but as shown in Figure 8 (B), the existing single panel hologram device has 3840 pixels horizontally, thus already achieves twice the HD full spec. Therefore, the device that has quadruple the high pixel density of HD full spec with the tentative name Q-HDTV (3840 x 2160) is within our reach, and it is our next development goal. It is almost impossible for another device with competing technologies to achieve this kind of super high resolution, and only the D-ILA™ device has the prospect of achieving it.

Furthermore, if this super high resolution Q-HDTV is used in electronic cinema, one can expect a totally new dimension in electronic cinema opening up, exceeding the quality of present release print of 35 mm film, as mentioned below.

First of all, twice the sampling for pixels of HD full spec enables to display exceptional images, and theoretically would minimize the sampling phase error and the pixel artifact caused by the pixel structure thereby enabling faithful image reproduction.

While it is said that original 35 mm prints have a horizontal limiting resolution of 2035 TV lines (at MTF 5%)[9] basically requiring a resolution of 4000 x 2000 to display this , actual showing in theater is, however, limited to 1000 TV lines due to the vertical jitter of film moving through the gate. The same applies to the telecine, and here lies the one of the constraints of movie film.

Contrary to film, if electronic cinema utilizes the 3840 x 2160 resolution of Q-HDTV and the complete digital system where digital image capturing without use of film is configured through the entire process from production to

distribution, super high resolution images should be displayed without degradation at all, enabling presentation of wonderful crisp images never seen before on screen.
Therefore it is anticipated that when this happens, the electronic cinema will go beyond movie showings as it stands today, playing a vital role in bringing about the world of virtual reality.

Summary

The D-ILA™ device that incorporates the ILA® technology's homeotropic alignment of liquid crystal, is a reflective mode liquid crystal device with a high aperture ratio. It has the highest pixel density format compared to other devices, and it is a device that produces high contrast while achieving both high resolution and high luminance.

Initial D-ILA™ Projector products started with SXGA resolution, however, on a daily basis the market demands more compact, higher resolution and higher picture quality projectors. In order to meet such market demands, we are currently working to design and fabricate 0.7" panels and new D-ILA™ devices with QXGA resolution.

Furthermore, the D-ILA™ technology has high potential for further development, and it is the only technology that can accommodate resolution requirements of electronic cinema or super high resolution of 4000 x 2000, which will become the standard for next generation large screen displays. Thus, D-ILA™ technology will come the stand for large screen display technology of the 21st century.

References

1. W.P. Bleha "Progress in Liquid Crystal Light Valves" LASER FOCUS/ELECTRO-OPTICS, 2394, Vol.19, No.10 p. 111, Oct.1983
2. S. Nakagaki, W.P. Bleha "ILA Video Projectors" ITE REPORT Vol. 17 No.10 p.11 (Jan.1993)
3. T. Miyoshi "High Brightness, High Definition ILA Projectors" JSAP, OSJ, Gp. of Micro Opt. 1994.10/17 Vol.12 No.3 p.31
4. W.P. Bleha "Image Light Amplifier (ILA) Technology for Large-Screen Projection" SMPTE Journal, Oct. 1997 p.710
5. A. Nakano et al, "Reflective active matrix LCD : D-ILA" Photonics West 98 Projection Display IV Proceedings of SPIE volume 3296.(1998)
6. H. Kurogane et al, "Reflective AMLCD for Projection Displays: D-ILA" SID98 p. 33 (1998)
7. F. Tatsumi et al, "Optical System Using 3 Pieces Of D-ILA Panel Module" IDW'98 p.753 (1998)
8. F. Tatsumi et al, "Optical System For Projection Systems Utilizing D-ILA Panels" ITE JOURNAL Vol.53 No.8 p. 1122 (1999)
9. R.D. Sterling, W.P. Bleha "Electronic Cinema Using ILA Projector Technology" SID99 DIGEST p.216 (1999)

Acknowledgments

I wish to thank to Mr. Y. Omori, Director, Member of Board, for giving me the opportunity to write this paper. In addition, I thank Mr. K. Doi, General Manager of the ILA Device Business Center, for providing reference material on the device technology, Mr. T. Miyoshi, General Manager of the General Planning Department, for his assistance in gathering various other reference materials. I also extend my sincere appreciation to all the people who assisted me in many ways in writing this paper.