MOBILE PROJECTORS: THE REVIEW OF NON-LASER AND LASER TECHNOLOGIES

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ABSTRACT

Considering recent end-user markets, there are many commercial projectors, whose sizes and prices are barely larger or more expensive than smart phones, available from various manufacturers. Whereas the very first generation of pocket projectors is based on traditional LED light sources, many researchers as well as electrical companies tend to increasingly put their attention to laser light sources whose characteristics theoretically encourage the ideas of mobile projection and projector mobile phones. Nevertheless, in practice, both laser and non-laser engines own some advantages and disadvantages. To date, it is still not clear which engines (or both of them) will become dominant for future mobile projectors.

In this article, we introduce main projection technologies that have been widely used for mobile projectors available in end-user markets. This includes three non-laser based and three laser based technologies. Our review involves brief details regarding their internal mechanisms, advantages, disadvantages, and comparison. Discussion about their present and future are also written at the end of this article.

Index Terms - Mobile projector; pico projector; laser projector; LED projector

1. PROJECTOR, A SMALL DEVICE WITH BIG DISPLAY

Since many decades ago that trends of miniaturization have continuously dominated many technology products, particularly mobile phones and mobile computers. Recent features of mobile phones and mobile computers allow us to work in a ubiquitous manner with only slight efficiency degraded compare with non-mobile models. Nevertheless, because of the emerging of smartphones, our life has changed and our activities as well as works have been relied more on these small devices. At this point, the small physical size that makes these devices so fascinating at the beginning has become their major limitation as Internet browsing, text reading, keying with an on-screen virtual keyboard, and

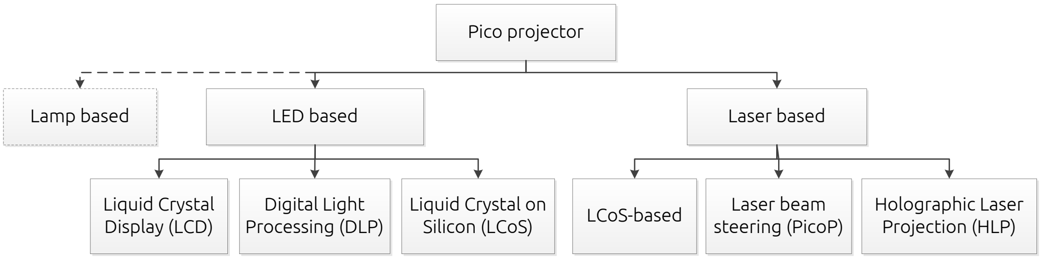

Figure 1. Projection technologies used in recent pico projection engines.

group information sharing cannot be done conveniently on these small devices with tiny display screens..

For now, e-book readers (e.g., Kindle) and tablet computers (e.g., iPad, Galaxy Tab, Galaxy Note) seem to be suitable solutions for this problem as their sizes and weights fall between contemporary smartphones and laptop computers. These post-PC tablet computers have already proved themselves to be useful, particularly when iPad was given the name of being *"Children's toy of the year"* in 2010 — less than a year after its first release. This conveys the fact that bigger display screens do play important roles for users.

As a matter of fact, there is another solution for the problem regarding tiny display screens which does not involve increasing device's physical size at all — that is using projection-based displays. Unlike traditional screen-based displays whose display sizes are strictly bounded by device's physical size, projection-based displays allow a big display despite of its small form factor. It has been more than a decade already that projectors have been continuously developed so that their engines have become smaller in shape, brighter in light, and better in projection quality, in contrast to their cheaper price. Since 2008, several models of pocket-sized standalone projectors have been released commercially as consumer products – many refer to them as *"pico projectors"*. Lately some world-leading companies have included or hinted about their future mobile products with embedded pico projectors. For example, Samsung Galaxy Beam (commercially released in 2012) which is a smartphone with an embedded projector, and Apple Inc. patents regarding future iOS devices with an internal projector [1].

Recent pico projectors have been developed based on two major light sources -- LED (Light-Emitting Diode) and laser; each includes three main sub-technologies as illustrated in Figure 1. In the following sections, we explain our review regarding each technology in details. Section 2 first introduces three non-laser based (i.e., LED-based) technologies together with their advantages, disadvantages and comparisons. Section 3 presents advantages of laser-based projection for mobile devices and explains three laser-based technologies that have been proposed for pico projectors so far. Section 4 then discusses some interesting issues regarding present and future of laser-based projection engines; comparisons between three types of light source (lamp, LED and laser as illustrated in Figure 1) are included in this section. Finally, Section 5 concludes this review article.

2. LED-BASED TECHNOLOGIES

This section explains in details about three non-laser projection technologies of pico projectors that usually involve using Light-Emitting Diode (LED) as light sources. Section 2.1 briefly describes their internal mechanisms while Section 2.2 introduces some undesired projection effects regarding the three technologies. Section 2.3 then compares the three technologies and concludes this section.

2.1. Internal mechanism

2.1.1. Liquid Crystal Display (LCD)

The internal mechanism of LCD projectors is simple, as shown in Figure 2. The white light passes through prisms that separate it to three lights (corresponding to each color component). The separated lights are then redirected to three silicon LCD panels — each one for the red, green, and blue components of the projected light. As the red, green and blue light components pass through the LCD panels, individual pixels on the panels are opened to allow light to pass or closed to block the light, allowing creation of a wide range of colors and shades in the projected image.

This mechanism is called a transmissive technology where each pixel of LCD panel is responsible for either transmitting or blocking the light in order to create the desired projected image.

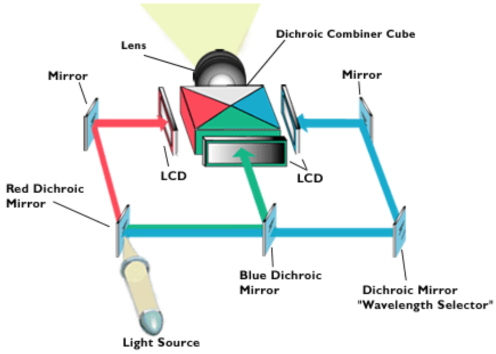

Figure 2. Internal mechanism of LCD projectors. [Image source: http://www.ustudy.in/node/4907]

2.1.2. Digital Light Processing (DLP)

Unlike LCD technologies, DLP technologies of Texas Instruments Inc. are reflective technologies that use either single-ship or three-chip. The three-chip DLP delivers higher projection qualities but is usually limited to higher-end projectors selling for home theatre purposes. Figure 3 shows the internal mechanism of a single-chip DLP technology consisting of three main components, namely, the light source, the color wheel and the DMD (Digital Micromirror Device) chip. While the light source is used to provide an original white light for projection, the color wheel spinning at a very fast speed is responsible for coloring the white light to a color corresponding to the color segment (of the color wheel) through where the white light passed. The DMD chip consists of tiled micro-mirrors whose flipping angles are controllable. These micro-mirrors are responsible for reflecting the colored light to or away from the surface, thereby they decide how much the light is transmitted to the surface at each moment.

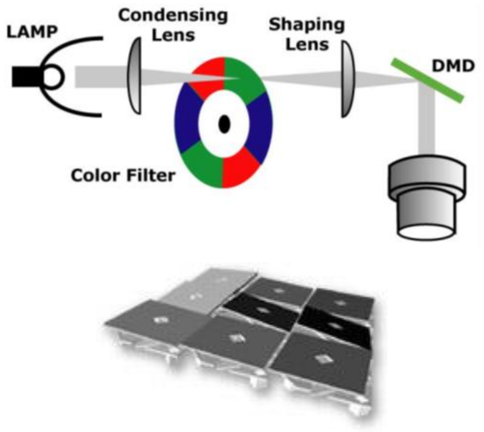

Figure 3. Internal mechanism of DLP projectors and DMD chip. [Image source: http://www.audioholics.com and http://www.dlp.com]

DLP mechanism typically sends the original white light through the spinning color wheel and then to the DMD chip and to the surface respectively. The spinning color wheel is responsible for coloring the white light as described earlier, whereas the DMD chip controls the amount of light transmitted to the surface. According to color-wheel characteristics, it means that DLP projectors project colors in a sequence. For instance, if the color wheel consists of red, green and blue segments, the projected colors will be red, green and blue, respectively. However, as the cycle of spinning is very fast, human generally sees the combined result as a single RGB image.

2.1.3. Liquid Crystal on Silicon (LCoS)

LCoS is a technology that combines the concepts of both LCD and DLP. While it uses liquid crystals like LCD, it is considered a reflective technology like DLP. The internal mechanism is shown in

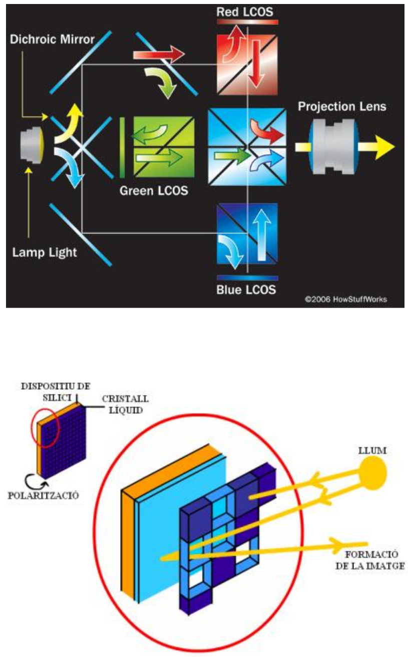

Figure 4. Internal mechanism of LCoS projectors. [Image source: http://electronics.howstuffworks.com, http://it.wikipedia.org]

Figure 4; as the liquid crystals open and close, the light is either reflected from the mirror below, or blocked.

2.2. Undesirable projection effects

Before continuing to the comparison of three LED-based technologies, there are two undesirable projection effects we would like to introduce, namely, the screen door effect and the rainbow effect.

2.2.1. Screen door effect

"The screen door effect or fixed pattern noise (FPN) is a visual artifact of the projection technology used in digital projectors, where the fine lines separating the pixels of projector become visible in the projected

Figure 5. The screen door effect. [Image source: http://en.wikipedia.org]

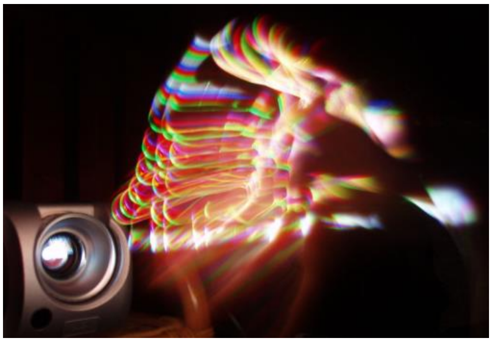

Figure 6. The rainbow effect. [Image source: http://fr.wikipedia.org]

image" [2]. It is the effect when we can see the black lines forming fabric-like pattern of pixel structure, as shown in Figure 5. This effect is caused by the fact that projector optics typically have significantly higher resolution than the image they project. Hence, these fine lines which are much smaller than the pixels themselves, can be seen.

In LCoS-based technologies, the pixels are very fine already so there is no concern about the screen door effect. For DLP technologies, this effect is almost invisible unless looking closely and also there are ways to reduce this effect specifically for DLP projectors. The first alternative is to set the projected image slightly out of focus in order to blur the boundaries between each pixel and its neighbors. This minimizes the screen door effect by filling the black pixel perimeters with adjacent light. The second alternative, which has been implemented recently in newer DLP chips, is to reduce spacing of the micro-mirrors.

LCD-based projection is a technology where the screen door effect is the most visible. Nevertheless, recent models of LCD projectors have significantly reduced this effect; although it is not as invisible as DLP and far behind LCoS, the issue of screen door effect between recent LCD and DLP projectors are now very small and insignificant.

2.2.2. Rainbow effect

The rainbow effect is related directly to a sequential color projection characteristic of DLP projectors. It is an effect when a viewer sometimes sees a rainbow of colors (as shown in Figure 6). This is caused by an inadequate spinning speed of the color wheel, typically about 120 Hz for normal projectors, which is relatively slow compared to the DMD chip operated at much higher speed of about 10,000 Hz.

To solve this problem, there are two main alternatives – either increasing the spinning speed directly as in higher-end DLP projectors or duplicating the same set of color segments in the color wheel. The first alternative is straightforward whereas the latter solves the problem by faking the higher speed. For instance, if the original color wheel consists of three segments (i.e., red, green

Table 1. Comparison of three LED-based projection technologies [3, 4].

	LCD	DLP	LCoS
Image formation	Project all colors concurrently	Project each color in a sequence	Project all colors concurrently
Screen door effect	Most visible	Invisible unless looking closely	Barely not visible
Rainbow effect	Not related at all	Noticeable for some users	Not related at all
Power consumption	Low	Medium	Slightly higher than DLP
Size	Bigger than DLP as there are three LCD panels	Tend to be the smallest (for single-chip models)	Relatively the biggest
Price	Relatively cheap	Relatively cheap	Very expensive
Usage	Available for most scenarios from mobile to theatre projections	Available for most scenarios from mobile to theatre projections	Mostly found in high-end projectors
Product	Massive products	Massive products	Relatively few products
Image quality	- Low contrast - High color saturation - High sharpness - Very bright (compared with DLP of the same wattage)	- Highest contrast - Low color saturation (caused by the white segment in the color wheel) - Relatively low sharpness	- Low contrast - High color saturation - High sharpness - High resolution - Image as smooth as silk (analog like)

and blue, respectively), the manufacturer may increase it to six segments (i.e., red, green, blue, red, green and blue, respectively). With two set of red-green-blue segments in the same color wheel, the output speed can be deceived as being doubled.

Nevertheless, while some users frequently sense this effect, some have never felt it. This effect is most noticeable if a viewer moves their eyes quickly or performs white projection on a black background.

2.3. Comparison

Comparison between the three LED-based projection technologies is summarized in Table 1 [3, 4]. Despite of low contrast image qualities, LCoS is said to deliver the best image qualities among the three. Unfortunately, its high price has limited its products to very high-end projectors only. As for LCD and DLP technologies, recent models from both might be considered equivalent. They both are varied from mobile to theatre usages and from very cheap to very expensive prices. The screen door effect of LCD and the rainbow effect of DLP are also said to make no significant difference between the two technologies lately.

3. LASER-BASED TECHNOLOGIES

Compared with non-laser light sources (i.e., lamp and LED), laser light sources have several advantages, particularly for a small mobile device. First, laser technologies deliver images with better contrast and wider color gamut. This includes Helmholtz-Kohlrausch effect [5] which Niesten [6] said that "*The Helmholtz-Kohlrausch effect causes saturated colors in very narrow wavelengths to be perceived as up to 50% brighter than broader wavelengths of colored light, such as those produced by light-emitting diodes*". This means that by the use of laser light sources, brightness of the display can appear about 50% brighter than broad spectrum light sources like LED. The second advantage of laser projection is that lampless laser engines eliminate the need of expensive lamp replacement and projectors are allowed to become smaller. Another advantage is about power consumption, as laser engines are said to consume less power than LED engines do, thereby prolonging usage hours for mobile devices.

After all, the most attractive aspect of laser may be that light from a laser has a high coherency making their projected image stays focused over a

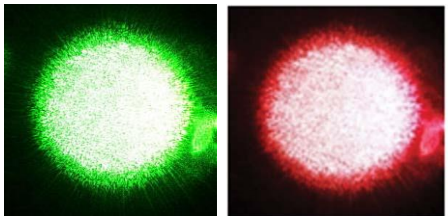

Figure 7. Speckle in laser-based displays. [Image source: http://en.wikipedia.org, http://www.deskeng.com]

long distance. This is opposite to light from lamp or LED which tends to diffuse quickly so that constantly refocusing is unavoidable in a mobile situation. In other words, it means that images projected by laser- based projectors always remain sharp and in focus at any distance on any shape of surfaces. This characteristic of laser projection significantly encourages the concepts of mobile and ubiquitous projection promoted for pico projectors and projector mobile phones, as an ideal flat surface with a static projection distance could not be assumed for these devices.

Before continuing to the three laser-based technologies recently found in pico projectors, we would like to introduce the "speckle" problem which is a problem shared by all laser-based displays, including projectors. "*Speckle is a random intensity pattern produced by the mutual interference of a set of wavefronts*" [7]. It basically means that there are shiny dots visible all over the image (as shown in Figure 7) and makes that image looks a bit metallic. Speckle is said to be less visible in videos than in static images.

The following sections explain in details about three laser-based projection technologies that

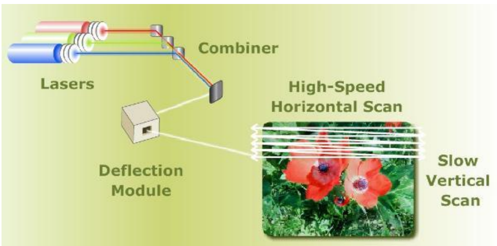

Figure 8. Internal mechanism of PicoP projection technology. [Image source: http://www.smartertechnology.com]

have been proposed recently for pico and mobile projectors.

3.1. LCoS-based laser

In February 2010, AAXA Technologies Inc. introduced the first consumer pico-projector, named AAXA L1, featuring a laser-based LCoS light engine. The overall mechanism of this engine is not much different from the LED-based LCoS projection explained earlier in Section 2.1.3. Instead of LED light source, AAXA L1 involves laser light sources and performs projection by bouncing red, green and blue laser lights off its LCoS chip.

In addition to light source replacement, AAXA introduced the PCOS laser light engine which integrates a revolutionary laser light source, proprietary despeckling technology, and an LCoS imager.

3.2. PicoP Laser-beam Steering

In March 2010, MicroVision Inc. released their first consumer pico-projector named SHOWWX which is operated with proprietary PicoP engine [8, 9]. The internal mechanism of PicoP engine, as shown in Figure 8, is not similar to any existing projection technology. First, the generated red, green and blue lasers are combined into a single modulated light path that represents a full pallet of colors. Then, light output from the combiner optic is directed to the MEMS (Micro Electro-Mechanical System) scanning mirror which reproduces the desired image pixel-by-pixel in a left-to-right top-to-bottom order.

The interesting aspect of PicoP is its potential ability for extreme miniaturization and high optical efficiency. Besides, using this beam steering technology means that the entire projected image appears uniformly in brightness, intensity and color saturation from the center to the edge of image.

3.3. Holographic Laser Projection (HLP)

Proprietary HLP [10] which was introduced in 2008 by Light Blue Optics Ltd. (LBO), is a very interesting projection strategy. Unlike previous technologies that display an image on an illuminated micro-display, HLP illuminates the diffraction pattern (i.e., hologram as an example shown in Figure 10.a) in order to get the result image. Note that the word “holographic” here is not referred to 3D projection but the way projected image is generated.

The overall mechanism of HLP technology, shown in Figure 9, mainly includes three laser light sources and a phase modulating LCoS micro-display. A desired image is first converted into sets of holograms by LBO’s proprietary algorithms and then displayed on the micro-display which is time-sequentially illuminated by red, green and blue laser lights. The subsequent diffraction pattern passes through a simple demagnification lens pair and the final output image is generated.

One problem of this mechanism is that resolution limitation of LCoS micro-display causes noise in the result image as shown in Figure 10.b. To achieve high image quality, a fast micro-display is used to display N holograms per video frame within the very short temporal bandwidth of the eye. Although each hologram produces a resultant image with noises, the time-averaged percept over N subframes is noise free, as shown in Figure 10.c. In this way, the high quality output is achieved when viewed.

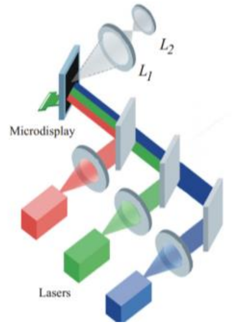

Figure 9. Internal mechanism of HLP projection technology. [Image source: [10]]

3.4. Comparison

Table 2 [11, 12] shows some comparison between three latest models of laser projectors offered by the three companies. In conclusion, except for the biggest size, products utilizing HLP seem to be the best in many aspects, for instance, brightness, speckle, and image quality. Only one problem is that almost evaluations based on HLP technology are now provided by LBO themselves. Therefore, it's hard to point out major drawbacks of this technology.

Figure 10. Relationship between hologram, subframe and resultant frame of HLP projection technology. [Image source: [10]]

4. Discussion

This section shows some interesting discussions related to laser-based pico projectors.

4.1. Eye safety concern

All lasers and laser-based displays, including laser-based projectors and laser pointers, have intrinsic dangers. Laser is a more directional light source than any other fixed light. The higher the output power of the laser, the greater the potential hazard. Even relatively small amount of laser light can lead to permanent eye injuries. Therefore, the sale and usage of lasers are typically subject to each government's regulations.

Laser safety is the safe design, use and implementation of lasers to minimize the risk of laser accidents, particularly those involving eye injuries. According to IEC 60825-1 Standards [13], lasers are classified into seven classes; Class 1 is

Table 2. Comparison of three latest projector models from three laser-based technologies [11, 12].

	AAXA L1 v2	MicroVision SHOWWX+	LBO LightWork
Technology	LCoS-based laser	PicoP laser-beam steering	Holographic Laser Projection
Dimension	10.6 x 5.3 x 3 cm	11.7 x 6 x 1.4 cm	12.2 x 8.4 x 3.8
Weight	170 g	122 g	250 g
Brightness	20 ANSI lumens	15 ANSI lumens	35 ANSI lumens
Laser safety classification	Class 1	Class 2	- Class 1 for symbology applications - Class 2 for line-generating applications
Speckle	- Less than PicoP - Include internal despeckling techniques	- Severe speckles - Difficult to integrate with external time-varying speckle reduction (because of its high laser modulation frequency and lack of image plane)	- Relatively low speckles because of its low frequency modulation lasers - Support future integration with speckle reduction techniques (as the entire image is formed at once)
Image quality	Lower contrast than PicoP	Projected image is entirely uniform from center to edge	High quality and high resolution (self-claimed)
Other note	-	Scalable (providing higher resolution without growing in size)	- Low cost implementation for laser, micro-display and optic - Highly tolerate to micro-display defects and pixel failures

the safest ("*safe under all conditions of normal use*") and Class 4 is the most dangerous ("*can burn the skin, involve potentially devastating and permanent eye damages, may ignite combustible materials*"). Note that most of laser pointers currently used are Class 2 products ("*safe because the blink reflex limits the eye exposure to no more than 0.25 seconds*").

Looking at Table 2, it can be seen that PicoP laser engine from MicroVision Inc. is based solely on Class 2 while the others can be safely operated in Class 1. Studies in [11, 12] show some experimental results saying that because of the eye-safety concern, the laser-beam steering technology is limited to the output of only 1 ANSI lumen for Class 1 and between 11 – 15 ANSI lumens for Class 2, whereas the LCoS-based laser engines (currently used by AAXA and LBO) could provide Class1 products with 10 – 20 ANSI lumens and Class2 products with several hundreds ANSI lumens. Consequently, this means that the latest SHOWWX+ of MicroVision Inc. has reached its maximum brightness of 15 ANSI lumens already where the other two technologies still have a long way to go on the war of projection's brightness. Unless MicroVision Inc. does something with this limited brightness problem, they may risk losing their future position in pico projector markets as the study in [11] also mentioned that the panel-based (i.e., LCoS-based) laser systems can now provide the same advantages as those of laser-beam steering, namely, small in size, efficient optical architecture, long depth of field and wide color gamut.

4.2. Non-laser vs. Laser technologies

To date, there are three types of light sources mainly used in recent projectors (include non-mobile projectors) – lamp (high-pressure mercury-vapor metal halide arc lamp), LED and laser. Most manufacturers tend to move from lamps to either LEDs or lasers. This is not only because lampless light sources (i.e., LED and laser) allow shrinking in projector's size but also because lamps have several disadvantages themselves. For instance, lamps are large, power hungry, easily broken, generate enormous amounts of heat and include expensive replacement.

At present LED is less expensive than laser; however, due to recent increase in the number of laser suppliers as well as anti-laser-speckle module suppliers, it might be expected that laser will become cheaper than LED in the future together with improved image qualities. At this moment, although LED is less expensive and involves no concern about eye safety, its limited focus and brightness are inadequate under normal lighting conditions and mobile scenarios. Using (currently) expensive laser light sources, on the contrary, deliver infinite focus, high contrast and wide color gamut whereas consume less power. Nevertheless, as mentioned earlier, eye-safety limitation prevents some laser technologies from increasing their brightness.

Judging from current technologies and trends, it's still not clear either LED or laser will become a dominant light source for future pico projectors. Although lasers seem to attract lot of attentions from people by its infinite focusing, LED is likely to have better chances in the long run as the output brightness is always one of important factors for projection products. If one day, LED can completely defeat laser in the aspect of output brightness, it is then interesting that which technology will be preferred more by consumers – the brighter but limited focus LED-based projectors or the dimmer but infinite focus laser-based projectors. Note that recent LED-based pocket projectors (e.g., Optoma PK320, LED-based DLP projector with the weight of 200 g) have provided the brightness up to 100 ANSI lumens already.

4.3. DLP-based pico laser projectors

So far there are many people questioning about why Texas Instruments Inc. has not released any model of laser-based DLP pico projectors while there are many LED-based DLP pico projectors and laser-based non-mobile DLP projectors. Many possibilities and reasons have been discussed regarding this issue. For example, using laser cannot reduce size of DLP technology; although the color wheel can be removed because of red, green and blue laser generators, millions of micro-mirrors are still requires in order to produce the desired resolution. Some have been guessing that it is because using laser cannot solve the power-consumption problem in DLP, or even makes it worse. This is due to the fact that in DLP technology, the light source must be “ON” all the times (when doing black projection, micro-mirrors will redirect the light away from the surface), thereby it might shorter the life of laser engine.

One of the assumptions said that the reason is because recent LED-based DLP pico projectors still deliver higher quality of images compared to recent laser-based pico projectors. Also, in terms of price, performance and safety, it is still unclear whether laser is truly better than LED. In many people’s opinions, they believe that if laser can prove itself to outperform LED regarding pico projectors, Texas Instruments Inc. will then take advantages of laser and use it in their pico projection engines as well.

5. CONCLUSION

This article reviews six main projection technologies found in recent pico projectors. Three technologies are non-laser LED-based technologies, namely, LCD, DLP and LCoS. The other three are laser technologies, namely, LCoS-based, PicoP and HLP; all from different manufactures. We explain their internal characteristics, advantages, disadvantages and comparisons.

After all these surveys, we are convinced that a laser projector will definitely play an important role in future pico projectors, as its infinite focus, small size and low power consumption are exactly what required by mobile devices, particularly in interactive mobile projection scenarios. However, LED-based technologies are not likely to fade from pico projector markets in the near future as there are still a large gap for laser to catch up with LED in terms of image qualities and brightness.

REFERENCES

[1] Patently Apple. (2011). *Apple reveals big plans to integrate projectors into iOS devices* [Online]. Available: www.patentlyapple.com

[2] *Screen-door effect* [Online]. Available: http://en.wikipedia.org/wiki/Screen-door_effect

[3] E. Powell. (2002). *The great technology war: LCD vs. DLP* [Online]. Available: http://www.projectorcentral.com/lcd_dlp.htm

[4] (2006). *Demystifying DLP, LCD, and LCoS* [Online]. Available: http://www.aboutprojectors.com/news/2006/06/23/demystifying-dlp-lcd-and-lcos/

[5] R. L. Donofrio, “Review paper: The Helmholtz-Kohlrausch effect,” *Journal of the Society for*

Information Display, vol. 19, no. 10, pp. 658-664, 2011.

[6] M. Niesten *et al.*, "Picoprojectors: Nanosecond modulation makes cell-phone projectors possible," *Laser Focus World 45 (International Resource for Technology and Applications in the Global Photonics Industry)*, no. 9, pp. 1-3, 2009. Available: http://www.laserfocusworld.com

[7] J. C. Dainty *et al.*, *Laser speckle and related phenomena*, Springer-Verlag, 1975.

[8] M. Niesten *et al.*, "Scanning Laser Beam Displays," *Photonics in Multimedia II*, in *Proc. of SPIE*, vol. 7001, pp. 70010E-70010E-10, 2008.

[9] M. Freeman *et al.*, "Scanned Laser Pico-Projectors: Seeing the big picture (with a small device)," *Optic & Photonics News*, 2009.

[10] Light Blue Optics Ltd., "Rear-view virtual image displays," in *Proc. SID Conf. 16th Annu. Symp. Vehicle Displays*, 2009.

[11] E. Buckley, "Eye-safety analysis of current laser-based LCOS projection systems," *Journal of the SID*, vol. 18/12, 2010.

[12] E. Buckley, "Eye-safety analysis of current laser-based scanned-beam projection systems," *Journal of the SID*, vol. 18/11, 2010.

[13] "Safety of laser products – Part 1: Equipment classification and requirements" (2nd ed.), *Int. Electrotechnical Commission (IEC)*, 2007.