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Review Article

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Laser display technologies and their applications

Abstract: Laser displays have been attractive because extremely wide color expression can be realized by choosing the wavelength of laser sources. The high efficiency and small etendue of laser sources contribute to downsizing, and a long lifetime is also another merit for users. In this paper, laser display technologies using efficient red, green, and blue lasers are reviewed. Also, applications of laser displays using these laser display technologies are introduced.

Keywords: laser display; laser diode; laser projector; speckle noise.

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1 Introduction

A laser projection technology was proposed in 1965 [1]. The system requires red, green, and blue (RGB) lasers. It remained too costly to be used in commercially viable consumer products and too poor in performance such as very low-efficiency and large-size externals due to water-cooled Ar ion laser systems. Therefore, efficient and compact RGB lasers have been expected to realize the practical laser display [2–5].

By achievement of air-cooled RGB lasers including a red laser diode (LD), a blue LD, and a green second-harmonic-generation (SHG) laser, an advanced laser projection engine was developed in 2004 [6]. The laser projection display using the engine showed low electric consumption and wide color gamut (over 130% NTSC ratio). Figure 1 shows a color gamut of a typical laser display. Mitsubishi Electric Co. developed a commercial laser projection TV [7] in 2008 and a laser liquid crystal display (LCD) TV [8] in 2012 for home use.

As high brightness and high power efficiency of lasers contribute to downsizing systems and improving electric efficiency, the laser projection displays are expected to bring us big displays anywhere and anytime. Therefore, microlaser projectors [9, 10] are hot topics now and have already been commercialized [11].

Table 1 shows the comparison of lasers, LEDs and UHP lumps. The laser display is attractive because of their low electric power consumption and the wide range of colors that can be realized. The high efficiency and small etendue of laser sources are advantageous for downsizing display systems [12].

2 Optical configurations

Figure 2 shows two different approaches for optical configurations of laser displays. A scanning-type laser projection engine is shown in Figure 2A. The projection display system

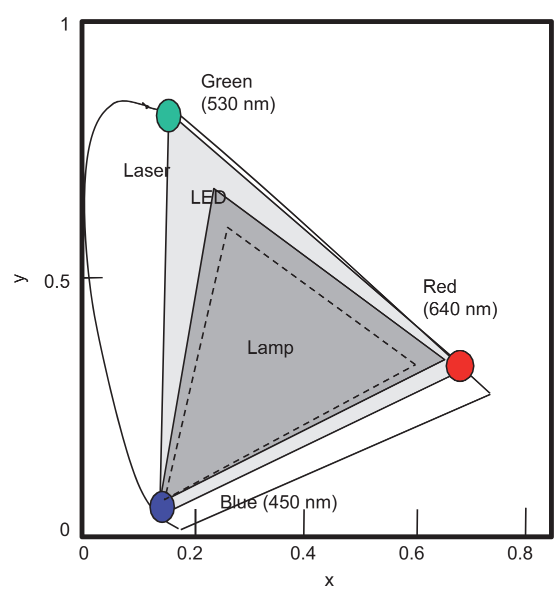


Figure 1 Color gamut of typical laser display.

	Laser	LED	UHP lamp
Color gamut (NTSC ratio)	130~140%	100%	70~80%
Luminescence area	2~100 μm²	10^5 μm²	10^5 μm²
directivity (Divergence angle)	~0°	180°	360°
Polarized light use	○	×	×

Table 1 Comparison of lasers, LEDs, and UHP lamps for display use.

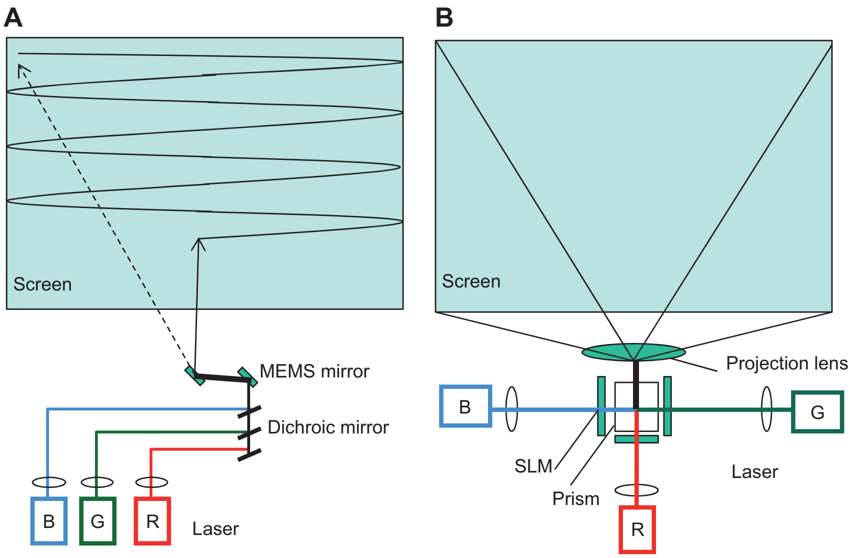


Figure 2 Two different approaches for optical configurations of laser displays.
(A) Scanning-type laser projection engine. (B) 2D spatial light modulator-type laser projection engine.

includes a laser source emitting a laser beam, and a reflecting mirror system for scanning the laser beam over an image to illuminate the image [9, 10]. The reflecting mirror system can be one or more Micro Electro Mechanical Systems (MEMS) scanning mirrors that rotate to raster scan the laser beam over the image. As the reaction of the human eyes is not quick, the image can be reconstructed on a screen.

A 2D spatial light modulator (SLM)-type laser projection engine is shown in Figure 2B. Conventional SLMs such as the digital mirror device (DMD), liquid crystal, and liquid crystal on silicon (LCOS) are used. In this configuration, RGB lasers are used as a back light [6].

3 Technologies for laser displays

Laser displays require RGB lasers. Blue and red LDs are commercially available. On the other hand, there are no commercially available green LDs except for products with low output power. Instead, the SHG of lasers can be used to provide the green wavelengths [13–15]. In 2009, green LDs are first demonstrated as 515-nm continuous wave [16] and 531-nm pulse [17] operation by InGaN. In 2011, green LDs were mass produced by Nichia Co. (Anan-shi, Tokushima, Japan) and the improvement of those characteristics is progressing.

Speckle noise is the result of the interference of many waves on the screen due to the coherency of the laser source [18] as shown in Figure 3. Speckle is considered to be a problem in laser projection, and it is usually quantified by the speckle contrast. Speckle contrast reduction is essentially the creation of many independent speckle patterns, so that they average out on the retina. This can be achieved by wavelength diversity, angle diversity, or polarization diversity. Figure 4 shows some approaches of speckle contrast reduction. For example, by varying the incident angle of the ray to the SLM, both the reduction of speckle contrast and uniform intensity distribution are achieved. The optics constructed with a rotating lens array and a rod integrator illuminated a SLM. The rotating lens array set just in front of the rod integrator varied an angle of a laser

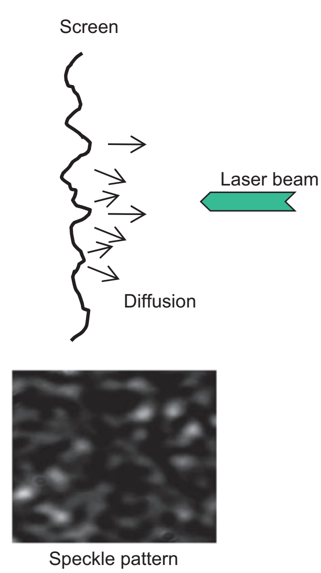


Figure 3 Speckle pattern image.
Speckle pattern occurs as the result of the interference of many waves on the screen.

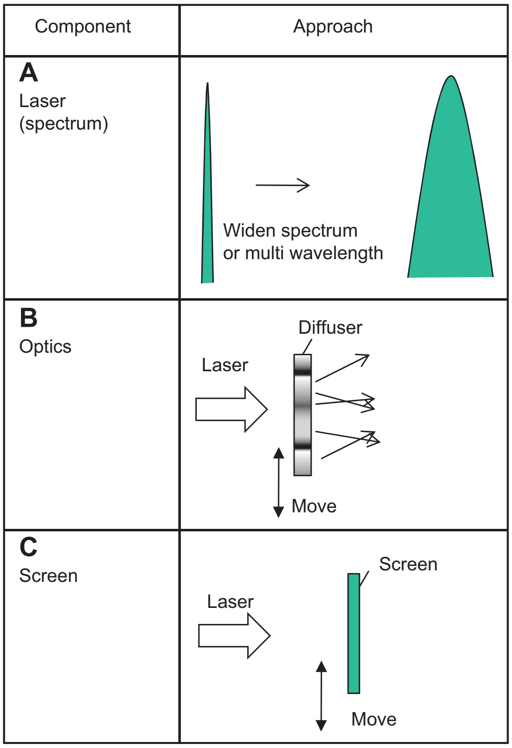


Figure 4 Representative approaches of speckle noise reduction. (A) By laser spectrum; (B) by optics; (C) by screen.

beam and made a different wavefront in each time. The speckle contrast was suppressed by averaging these configurations. A moving screen technique is another solution. The laser TV by Mitsubishi Electric Co. [7] used such a moving screen to reduce the speckle noise.

4 Applications of laser displays

Various applications of laser displays are proposed as shown in Figure 5. Here, the laser display includes laser lighting. Table 2 shows the advantages of various laser displays. The laser display systems and applications of the laser display are introduced below.

4.1 Laser projector

Compact and low electric power projection engines are a key technology with the potential to significantly enhance the experience of viewing visual information from mobile apparatus such as handy phones. High brightness and high efficiency of lasers contribute to downsize systems and improve electric efficiency.

Microprojection display modules based on MEMS scanning mirrors and RGB laser diodes are hot topics now. MicroVision Inc. has commercialized the microprojector with 100 cm^3 size and over 15 lm [11].

Applications of the scanning-type laser projection will extend to handy computers, embedded projector modules for mobile devices, and automotive head-up displays (HUD)

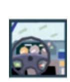
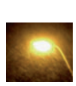
Application	Product	Optical scheme
Projector 	Mobile projector 	Scanning-type SLM-type
	for Laptop PC for Pocket PC	SLM-type Scanning-type
	Data projector	SLM-type ＊Hybrid source can be used
	Head up display (HUD) 	Scanning-type
TV 	Rear projection TV	SLM-type
	LCD TV 	Optical guide + Backlight
Head mount display (HMD) 	Glasses-type HMD	Scanning-type for retina
Laser lighting 	Head light Laser illumination	Fluorescence excitation by laser RGB laser

Figure 5 Various applications of laser displays. It is classified into projectors, TVs, head mount displays, and laser lightings.

	Low power consumption	Wide color gamut	Ultra compact	High brightness	Focus free
Mobile projector	◎		◎		◎
Data projector	○		○	◎	
Home projector	○	◎	○		
Pocket computer	◎		◎		◎
HMD	○		◎		○
HUD	◎	○	○	○	
Laser TV	◎	◎	○		
3D	○	○	○		○
Lighting	○		○	○	

Table 2 Advantages of various laser displays which include laser lighting.

[11]. HUD with the laser display engine offers high contrast and brightness image to the windshield of an automotive. This system can reduce driver distraction at driving.

Embedded laser projectors by RGB lasers (including SHG green lasers) and small LCOS devices were developed. Excellent beam quality is not required for SLM-type laser projectors. A bright image over 100 lm was obtained for the 50 cm^3 size of the laser projection engine [19]. Excellent projection efficiency of 20 lm/W was also demonstrated. The laser projection engine is installed in laptop PCs.

On the other hand, a high brightness laser projector (7000 lm) with ultrashort throw distance has been reported [20]. The throw ratio of 0.28 for an image of 100–150 inches was attained.

4.2 Laser TV

A laser rear projection display with a screen diagonal of over 60 inches was developed with the laser projection engine including a green SHG laser and advanced illumination optics for speckle noise reduction [21, 22]. In each light pass of RGB lasers, the rotating lens array and the rod integrator were set. SLMs of the engine were three LCD panels. Compact RGB laser units with W class light power were realized and were set in the laser projection engine. The wide color gamut, which was over 130% of NTSC ratio, brought us colorful and impressive images. As a commercial laser TV, almost the same structure was introduced [7]. By using the efficient green SHG laser and the illumination optics, the electric consumption of the display for light sources was as small as about 140 W, which is 1/3 of a conventional LCD display.

A laser LCD display [8], which has a LCD panel and a laser backlight system is also attractive because it brings us a low power consumption, a wide color gamut, and a thin light guide plates. In order to increase the efficiency of the optical system, light guide plates, which carry out polarization maintenance have been reported [23].

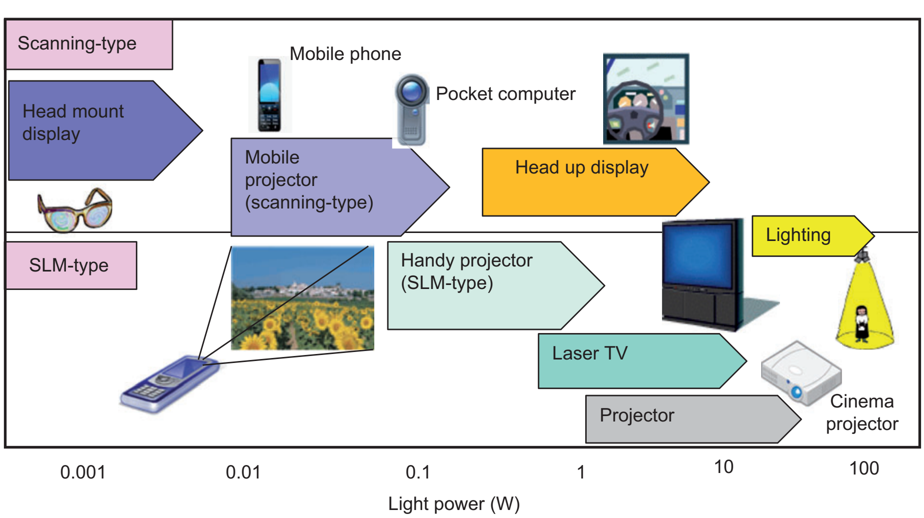


Figure 6 Classification of applications as a function of laser power.

	Research target	Efficiency (display)
1965~	– Large size (screen) – High definition	0.01 lm/W
1995~	– Wide color gamut	1 lm/W
2005~	– Low electric power consumption – Compact size (laser engine)	20 lm/W
Future	– Monolithic RGB lasers	50 lm/W

Table 3 Transition of the former and the future on research target of laser displays.

4.3 Head mount display

A head mount display (HMD) can create a big screen experience for small personal devices. It is demonstrated by a laser direct writing technique to the retina [24]. The head-mounted display system includes RBG laser diodes and a MEMS device. The MEMS device creates laser images from the laser light transmitted through an optical fiber. To novel virtual experiences, it delivers a new mobile scene.

4.4 Other applications

Various applications of the laser display technologies are proposed [12]. They include laser lightings and laser illuminations. Laser lighting technologies will extend the usability of lighting devices. A laser headlight and a spot lighting by a laser are examined. A laser plant factory and a fishery are promising applications of the laser lighting in the future.

Figure 6 shows the classification of applications as a function of laser power. Laser display technologies will find wide applications by an increase of the laser power.

Summary

Laser displays such as laser projectors, HMDs, HUDs, and laser TVs were developed with low electric power consumption and wide color gamut by using efficient and compact RGB lasers. Table 3 shows the transition of the former and the future on research target of laser displays. Considering a further reduction of electric power consumption, the efficiency of the display part is important and should be as high as possible. By achieving more efficient RGB lasers, a laser TV with the electric consumption power of about 10 W and a microprojection engine with a size of 1 cm^3 will be realized in the near future. The laser display will find wide and innovative applications instead of traditional display and lighting systems.

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