Blazed GxL™ Device for Laser Dream Theater at the Aichi Expo 2005

Yasuyuki Ito, Kunihiko Saruta, Hiroto Kasai, Masato Nishida, Masanari Yamaguchi, Keitaro Yamashita, Ayumu Taguchi*, Kazunao Oniki*, and Hitoshi Tamada*

Semiconductor Technology Development Group, Semiconductor Business Unit

***Core Technology Development Group, Core Component Business Unit**

Sony Corporation

4-14-1, Asahi-cho, Atsugi-shi, Kanagawa, 243-0014 JAPAN

Phone: +81 46 230 5175, E-mail: yasuyuki.ito@jp.sony.com

Abstract

We successfully developed a high performance and highly reliable blazed GxL device with a high optical efficiency and a high contrast ratio. The device demonstrated superior resistance against a high power laser, which is suitable for a large-area laser projector. We operated the world's largest laser projection screen using this device at the 2005 World Exposition in Aichi, Japan, problem free.

1. Introduction

GxL™ is SONY's laser projection display technology that uses the Grating Light Valve™ (GLV™) devices. A GLV is a diffractive MEMS (Micro-Electro Mechanical Systems) light modulator that was originally reported as a two-dimensional array by Prof. David Bloom group at Stanford University in 1992[1]. The system was demonstrated as a full-HD (1,080 × 1,920 pixels) laser projector in the form of a one-dimensional array (1,080 pixels) utilizing a scanning architecture by Silicon Light Machines (SLM) [2,3]. The advantage of this technology is its supreme color reproduction, high speed, high resolution, and high contrast ratio. Since Sony commenced GxL development in 2000, we have been developing one-dimensional GxL devices suitable for full-HD laser projectors [4,5]. In particular, we have been focusing on blazed GxL devices [6-8] and single diffraction beam in an attempt to achieve a higher contrast ratio, a higher efficiency and a smaller optical system than normal flat GxL devices.

This paper presents a blazed GxL device that has a high optical efficiency (> 70% for RGB lasers), and a high contrast ratio (> 10,000:1), and that is highly reliable when used in a large-area laser projection system.

2. Results

2-1. Blazed GxL design

The mechanism of ribbon tilting is shown in Fig. 1. A blazed GxL has a step-etched region on the ribbon surface, which can cause the ribbon tilting by the tension of the film after the sacrificial layer release process. This design is very simple and reproducible. The precise control of the step-etched region dimension is very important for achieving a high contrast ratio. The shape of the ribbon also strongly affects the diffraction efficiency [6,7].

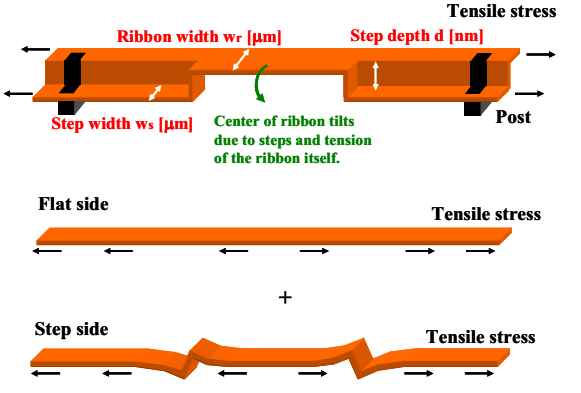

Figure 1 Mechanism of ribbon tilting.

2-2. Bow reduction

GxL ribbon consists of a 100-nm thick LP-SiN film as a base and a 75-nm thick Al-Cu film as a reflecting layer. In such a two-layer structure, some bow occurs due to the bimorph effect. A

blazed GxL ribbon is affected by bow more strongly than a flat GxL, and a 50-nm bow causes an 18% loss of efficiency for a blue laser, as shown in Fig. 2.

To reduce the bow, we inserted a 30-nm thick CVD-SiO_2 stress-balanced layer between the Al-Cu and LP-SiN films. As the SiO_2 film is under compressive stress and the Al-Cu and LP-SiN films are under tensile stress, the bow value of this triple-layer structure was only 7 nm, as shown in Fig. 3.

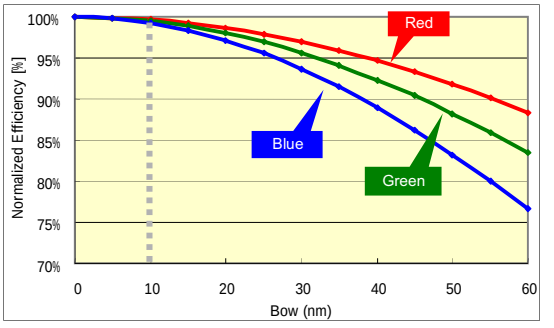

Figure 2 Optical efficiency vs. bow.

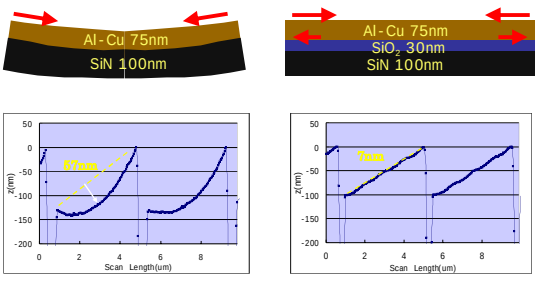

Figure 3 AFM profile of ribbons.

2-3. Tilt optimization

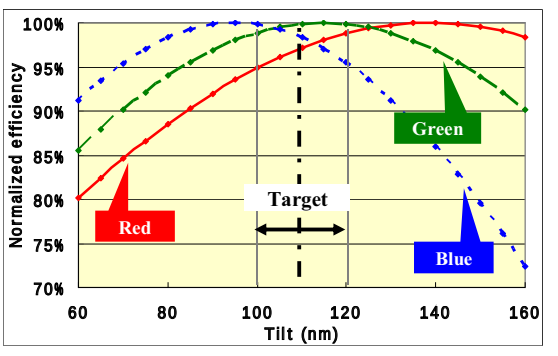

Figure 4 Efficiency vs. tilt value.

Many of the ribbon parameters affect its tilt, such as stress, thickness, step depth, step width, post position, and post shape. Figure 4 shows the relationship between the simulated diffraction efficiency and the tilt value for the RGB lasers when the bow is 7 nm. The tilt value should be controlled within 110 +/- 10 nm to achieve an efficiency greater than 70 % for RGB lasers [6,7]. As the stress and thickness for each layer were already fixed due to bow reduction, the step depth and width were varied to optimize the tilt.

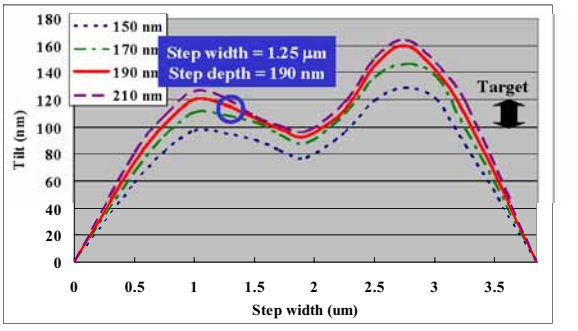

Figure 5 Tilt vs. Step width and step depth.

Curiously, the tilt obtained a maximum value when the step width was a quarter or three quarters of the ribbon width, and had a minimum value when the step width was a half of the ribbon width. Figure 5 shows the relationship between the simulated tilt value and the step width for various step depths. We fixed the step width at 1.25 µm and the step depth at 190 nm so that the process margin was maximized.

2-4. GxL device properties

The diffraction efficiency was measured before and after the optimization of bow and tilt.

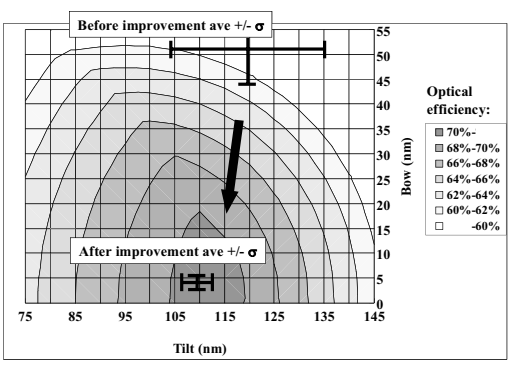

Figure 6 Improvement of efficiency.

As a result, the diffraction efficiency improved from 55 % to 70 % for the RGB lasers with optimized bow and tilt value, as shown in Fig. 6.
Figure 7 shows the measured photo-detector signal level of a dark (off) state blazed GxL device using a green laser. This corresponded to a mean contrast ratio greater than 10,000:1, which means that more than 6,000 ribbons were very uniform. Actually we should control the height fluctuation of 6,000 ribbons within less than 0.8 nm to achieve the contrast ratio of 10,000:1.

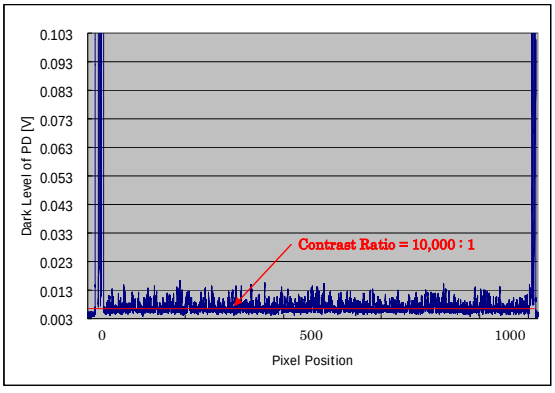

Figure 7 Dark scan for GxL device.

2-5. High-power laser duration

We need to use a high-power laser to achieve large-area laser projector. Therefore, the long-term reliability against high power laser irradiation is a requirement for a blazed GxL device. When a high-power laser irradiated a GxL device with Al-Si reflective layer, a color change of the ribbon surface and the following hillock formation were observed. But in case of Al-Cu reflective layer, no change was observed for 2,000 hours with 5,000-lumen laser irradiation [6,8].

2-6. Reliability of GxL module

To achieve high reliability for large-area laser projector, thermal design of the module is also very important. Figure 8 shows a photograph of the GxL module. The GxL device is assembled directly onto the heat spreader for better cooling [8].
Figure 9 shows the variation in the normalized diffraction efficiency with increasing input voltage level of a blazed GxL module before and after a 5,000 lumen projector was operated for 2,000 hours. No degradation in characteristics of a

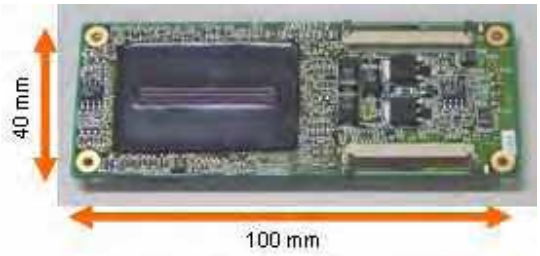

Figure 8 Photograph of GxL module.

blazed GxL module was observed. So, the stability of the blazed GxL module should be good enough for a 5,000 lumen projector.
We also conducted 2,000 temperature cycling tests at -20ºC and +80ºC and found that no serious failure occurred.

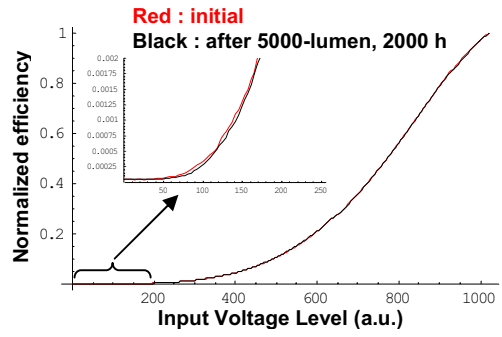

Figure 9 Efficiency vs. input voltage level.

2-7. Demonstration at world exposition

The world's largest laser projection screen using GxL technology, "Laser Dream Theatre", was demonstrated at the 2005 World Exposition, in Aichi, Japan, as shown in Fig. 10.

Figure 10 Laser dream theatre at Expo.

The screen size was 2005 inches, i.e. 50 m in width and 10 m in height. The total number of

pixels was 6 million (1,080 × 5,760), and total laser power was 60,000 ANSI-lumen. The sound system was 11.1-ch surround. More than 2 million people enjoyed watching beautiful movies at the Laser Dream Theatre during the World Exposition, no trouble occurred during the 6 months of operation.

3. Conclusion

A blazed GxL device was realized for the first time that had high optical efficiency (> 70% for RGB lasers), and high contrast ratio (> 10,000:1), and that was highly reliable when used in a large-area laser projection system. The key features were a robust design and precise stress control technology to maintain a uniform shape (bow and tilt) of more than 6,000 ribbons, a 0.25-μm CMOS compatible fabrication processing and planarization techniques to reduce fluctuation of the ribbons, and a reliable Al-Cu reflective film that provided protection against a high-power laser. No degradation in characteristics of the GxL device was observed after operating a 5,000-lumen projector for 2,000 hours and conducting 2,000 temperature cycling tests at -20°C and +80°C. Consequently, we operated the world's largest laser projection screen with a size of 2005 inches (10 m × 50 m) and 6 million pixels (1,080 × 5,760) using this device at the 2005 World Exposition in Aichi, Japan, problem free.

4. References

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