Blazed GxL^{TM} Device for Laser Dream Theatre at the Aichi Expo 2005

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

Abstract

A blazed GxL^{TM} device is described as having high optical efficiency (> 70% for RGB lasers), and high contrast ratio (> 10,000:1), and that is highly reliable when used in a large-area laser projection system. It has 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 is 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. At the 2005 World Exposition in Aichi, Japan 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) was demonstrated.

Keywords : GLV, GxL, Blaze, MEMS, Laser Projector

1. Introduction

GxL^{TM} is SONY's laser projection display technology that uses the Grating Light Valve^{TM} (GLV^{TM}) devices. A GLV is a diffractive MEMS (Micro-Electro Mechanical Systems) light modulator that was originally reported by Prof. David Bloom group at Stanford University as a two-dimensional array 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] and single diffraction beam in an attempt to achieve a higher contrast ratio, a higher efficiency and a smaller optical system than normal 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. Experiments

2-1. Blazed GxL design

The structure and principle of a blazed GxL is shown in Fig. 1. As each pixel consisted of six ribbons, each GxL device had more than 6000 ribbons. Each ribbon was 4.25 μm in pitch, 3.85 μm in width, and 200 μm in length. Diffraction occurs by the electrostatic displacement of every other ribbon in the case of the "ON state". As each ribbon tilts properly, light diffracts in only one direction. Therefore, a blazed GxL only needs one Schlieren filter, whereas a flat GxL needs two. The contrast ratio of a blazed GxL is potentially twice as high as that of a flat GxL. The optical system of a blazed GxL should be smaller than the flat GxL.

The mechanism of ribbon tilting is shown in Fig. 2. 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-

---

Manuscript received January 18, 2007; accepted for publication June 15, 2007.

Corresponding Author : Yasuyuki Ito
[a] Semiconductor Technology Development Division, Semiconductor Business Group Sony Corporation 4-14-1, Asahi-cho, Atsugi-shi, Kanagawa, 243-0014 JAPAN
[b] Core Technology Development Group, Sony Corporation 6-7-35 Kitashinagawa, Shinagawa-ku, Tokyo 141-0001 JAPAN
E-mail : yasuyuki.ito@jp.sony.com **Tel** : +81 46-230-5175
Fax : +81 46-230-5945

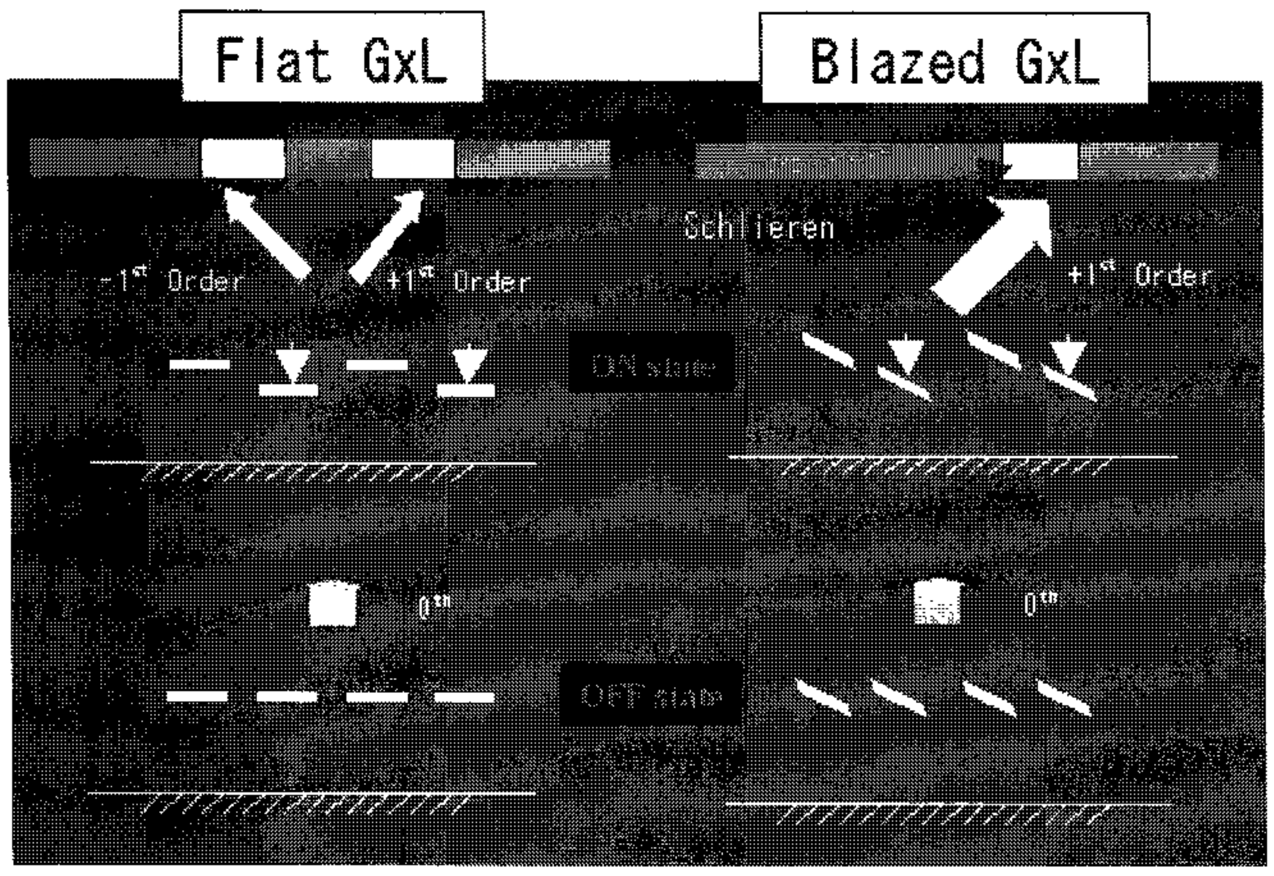

Fig. 1. Comparison between flat GxL and blazed GxL.

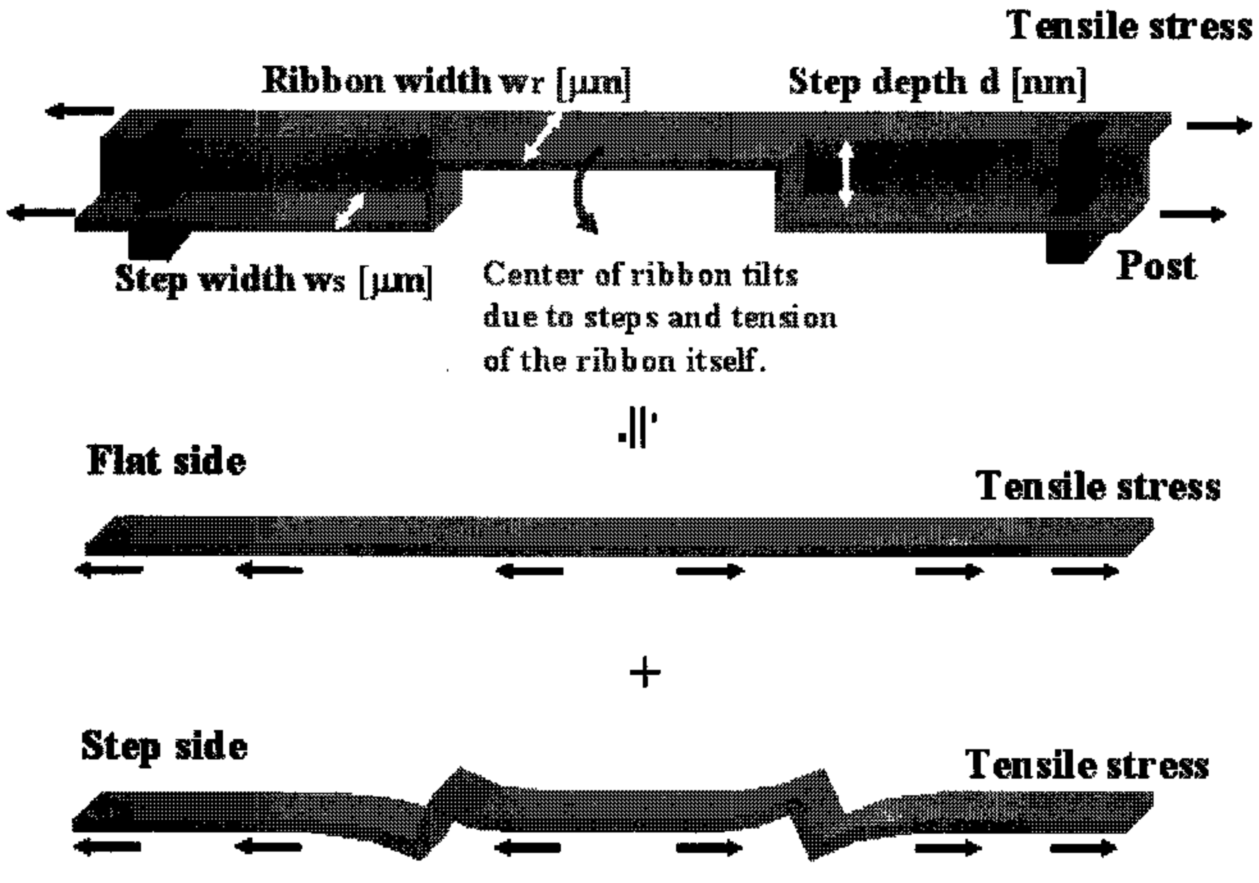

Fig. 2. Mechanism of ribbon tilting.

etched region dimension is very important for achieving a high contrast ratio. The shape of the ribbon also strongly affects the diffraction efficiency [7].

2-2. Bow reduction

We need to precisely control the shape of the ribbons to obtain a high efficiency. Fig. 3 shows a cross-sectional view of blazed GxL ribbons. A blazed GxL ribbon has three important requirements for obtaining a high efficiency; the bow, the tilt, and the gap width.

The bow reflects the distortion of the ribbons and therefore should be reduced as much as possible. Fig. 4 shows the variation of the simulated normalized efficiency with the bow value for the RGB lasers. The bow value needs to be reduced to less than 10 nm.

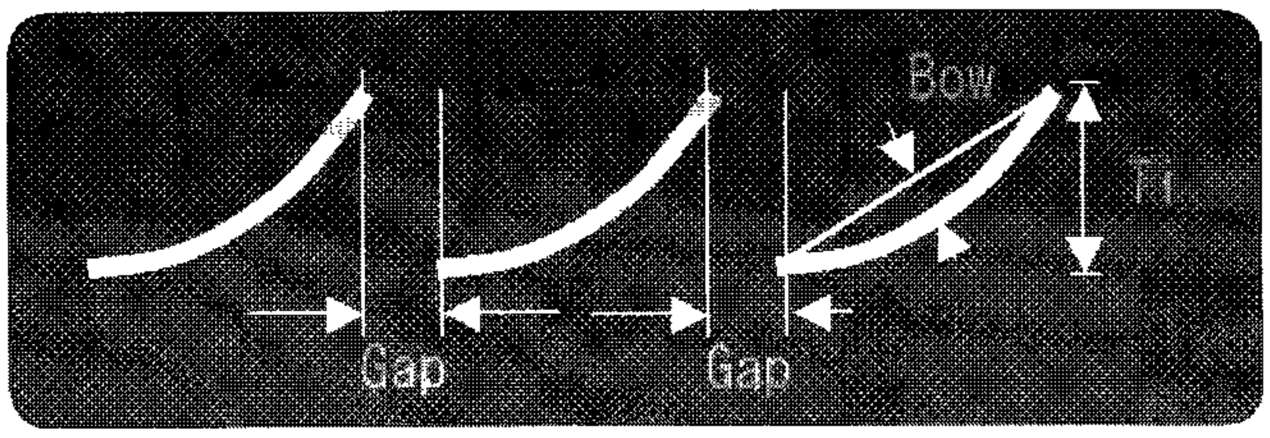

Fig. 3. Cross sectional view of blazed GxL ribbons.

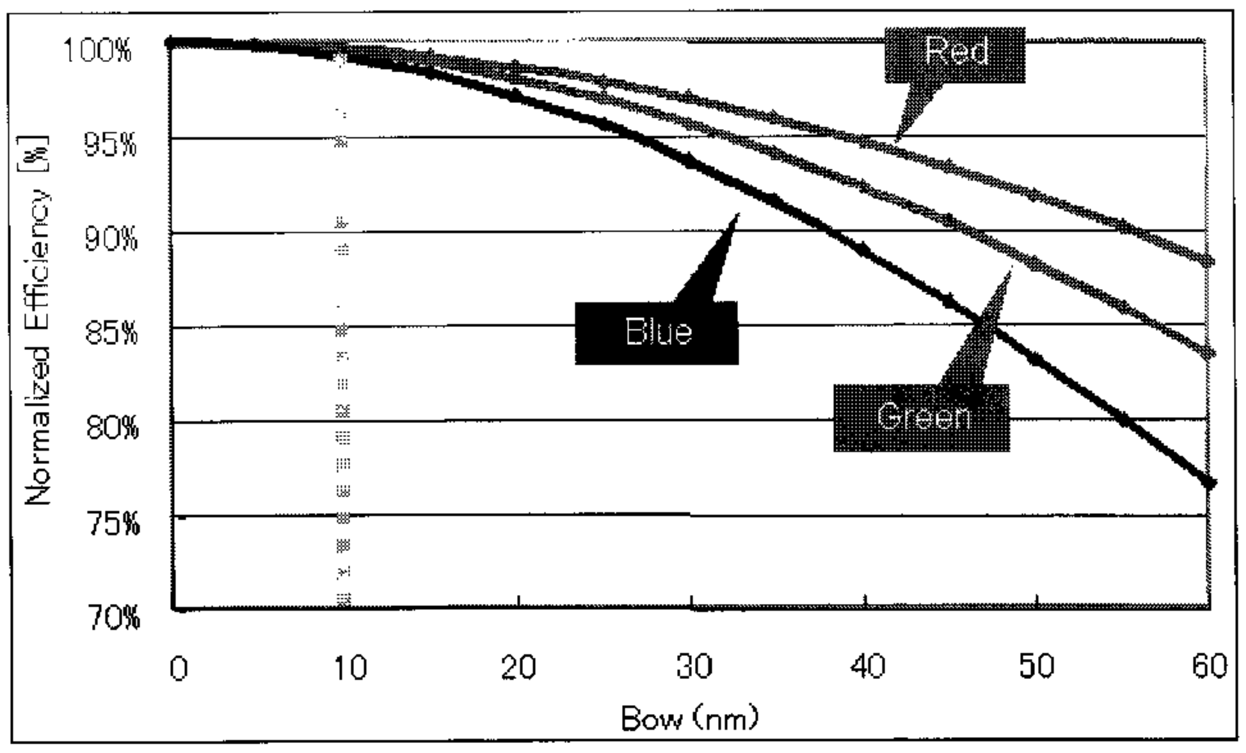

Fig. 4. Efficiency vs. bow for RGB lasers.

Fig. 5 shows a cross-sectional film structure and the measured atomic force micrograph (AFM) profile of blazed GxL ribbons. A bilayer-structured ribbon consists of a 100-nm thick LP-SiN film as the base and a 75-nm thick Al-Cu film as a reflective layer. As the thermal expansion coefficiency of an Al-Cu film is more than ten times larger than that of a LP-SiN film, a 57 nm bow occurred due to the bimorph effect. 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 shown in Fig. 5 (b). 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.

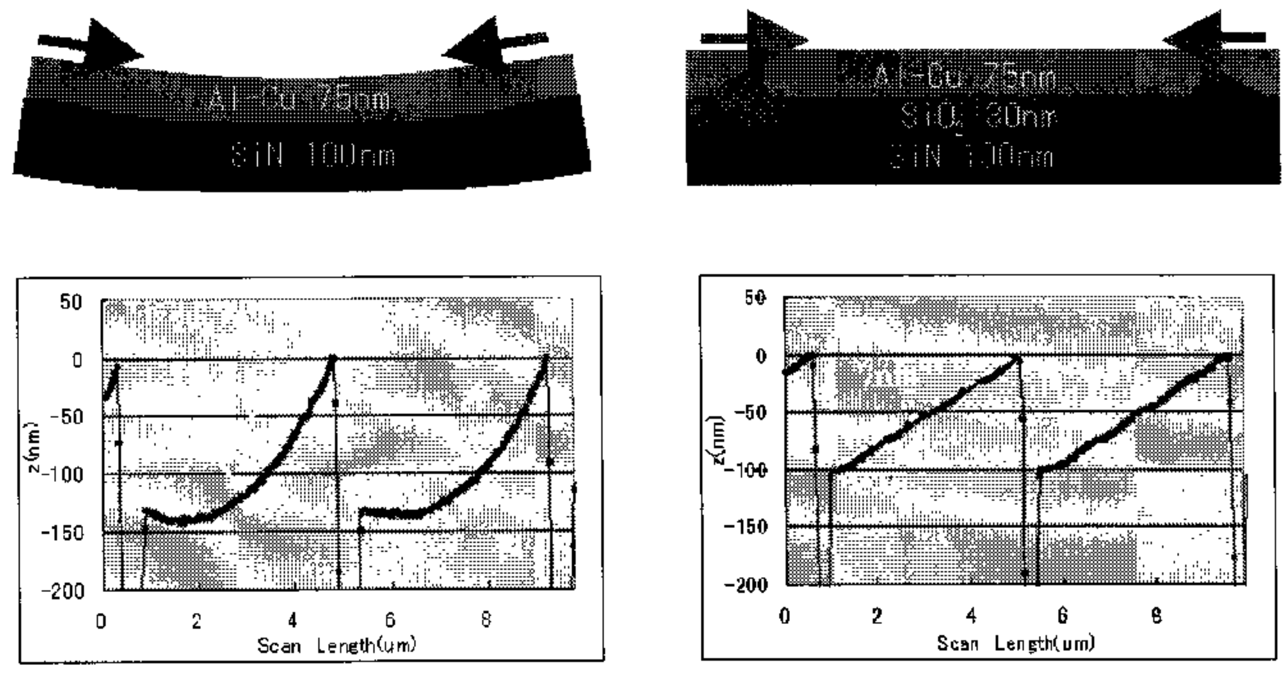

Fig. 5. Film structure and measured AFM profile of blazed GxL ribbons.

2-3. Tilt optimization

Many of the ribbon parameters affect its tilt, such as stress, thickness, step depth, step width, post position, and post shape. Fig. 6 shows the relationship between the simulated diffraction efficiency and the tilt value for the RGB lasers when the bow was 7 nm. Apparently, the tilt value should be controlled within 110 +/- 10 nm to achieve efficiency greater than 70 % for RGB lasers. 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.

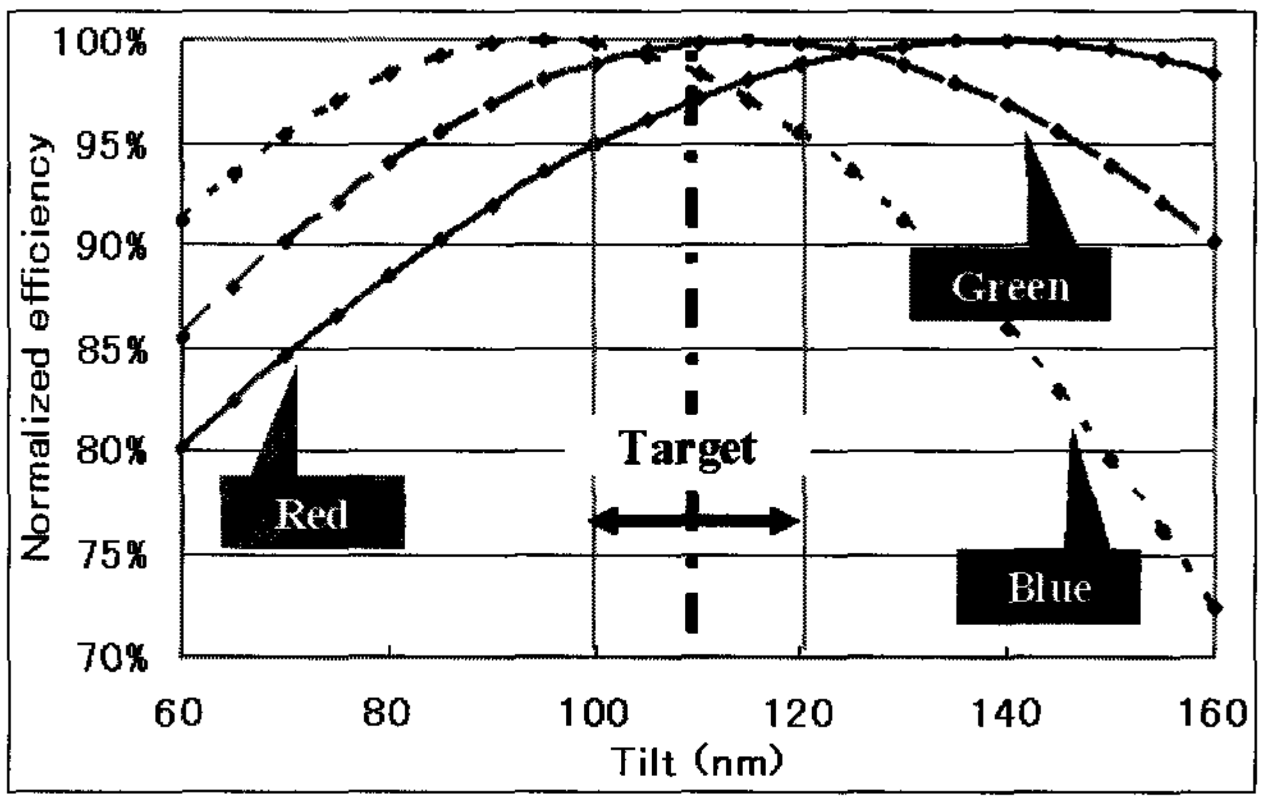

Fig. 6. Diffraction efficiency vs. tilt value for RGB lasers.

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. Fig. 7 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 could be maximized.

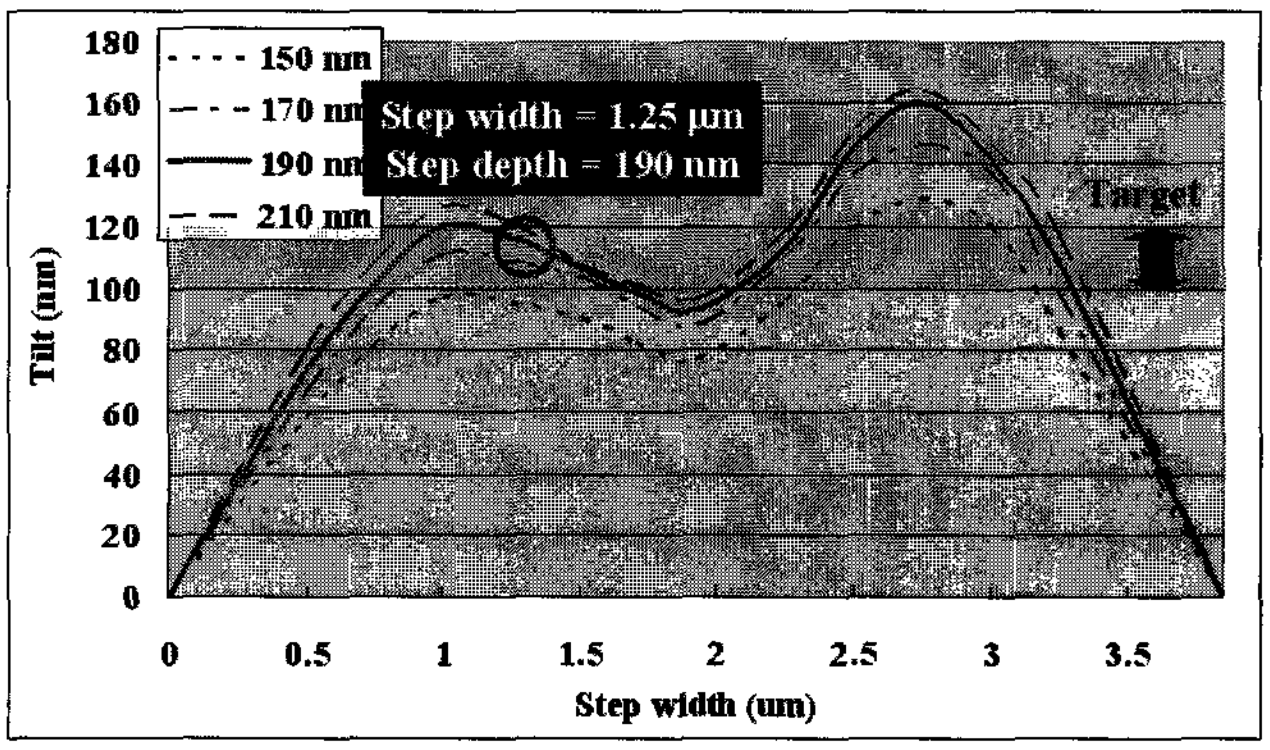

Fig. 7. Tilt vs. step width for various step depths.

3. Results and Discussion

3-1. GxL device properties

The diffraction efficiency was measured before and after the optimization of bow and tilt. 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. 8.

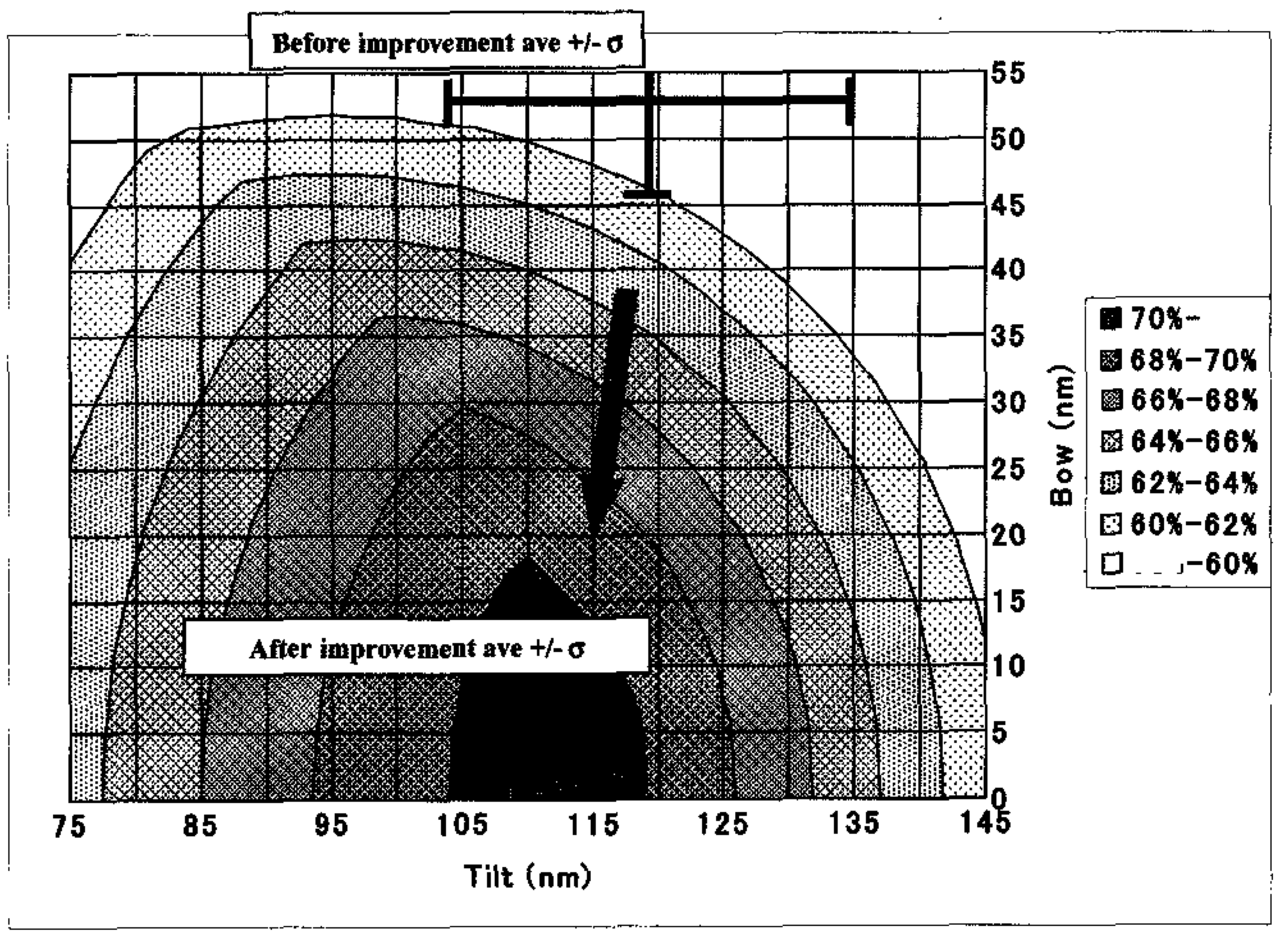

Fig. 8. Diffraction efficiency improvement.

Fig. 9 shows the measured photo-detector signal level of a dark (off) state blazed GxL device using a green laser. This corresponds to a mean contrast ratio of greater than 10,000:1, which means that more than 6,000 ribbons were very uniform. Actually, the height fluctuation of 6,000 ribbons should be controlled so that it is less than 0.8 nm to achieve the contrast ratio of 10,000:1.

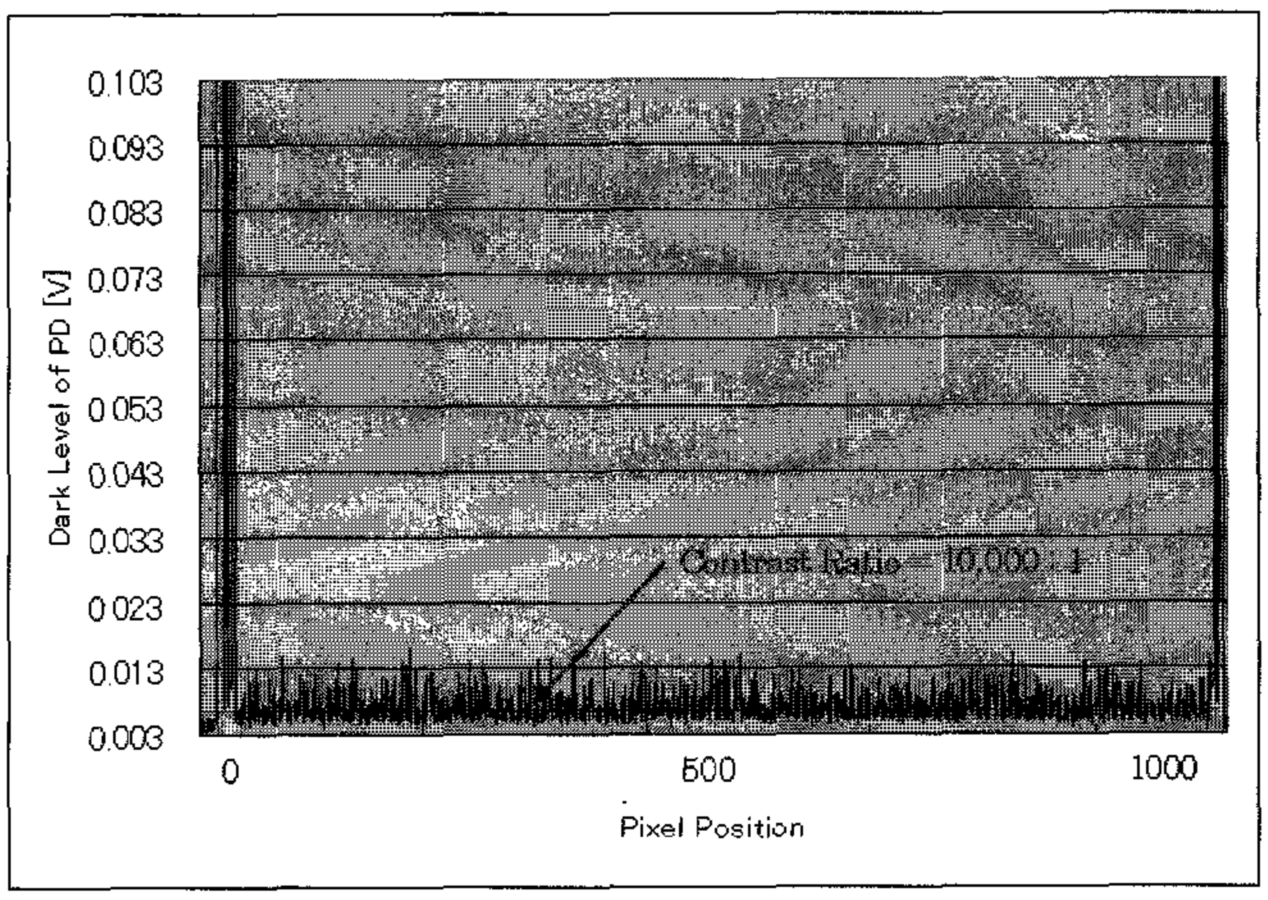

Fig. 9. Dark scan for blazed GxL device.

3-2. Reliability against high-power laser

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, a color change of the ribbon surface and the following hillock formation were observed. This was more evident in the Al-Si reflective layer than with Al-Cu reflective layer. The Al-Si reflective layer thickness in the color change region was much thinner after irradiation. It is possible that Al self-diffusion to the outer side occurred due to the laser profile. One can speculate that as the self-diffusion coefficient of the Al-Cu film was smaller than that of the Al-Si film, thinning of the Al-Cu film did not occur [9, 10].

3-3. Reliability

To achieve high reliability for large-area laser projector, thermal design of the module is also very important. Fig. 10 shows a photograph of the GxL module. The GxL device is assembled directly onto the heat spreader for better cooling [11].

Fig. 11 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 blazed GxL module was observed. So, the stability of the blazed GxL module should be good enough for a 5,000 lumen projector.

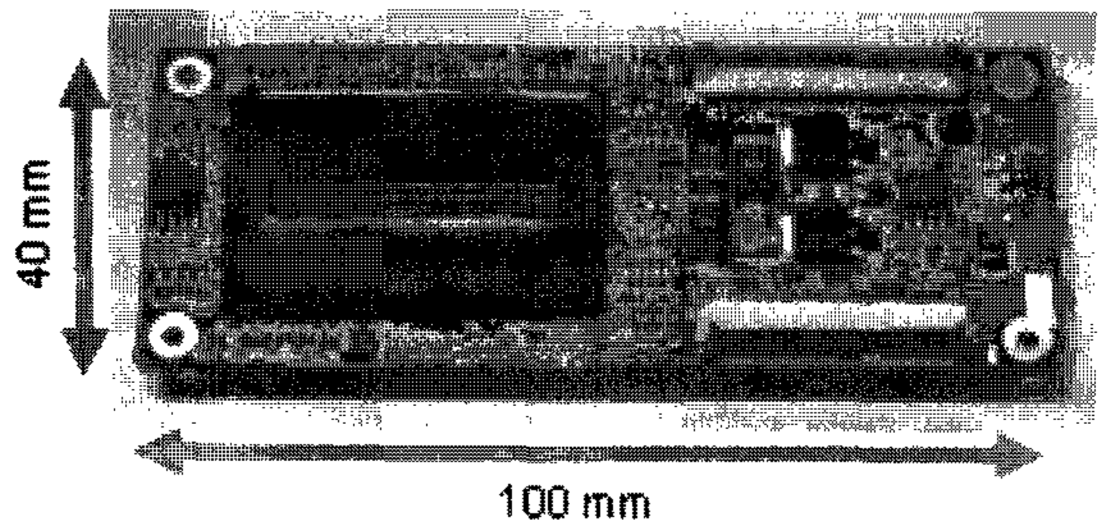

Fig. 10. Photograph of blazed GxL module.

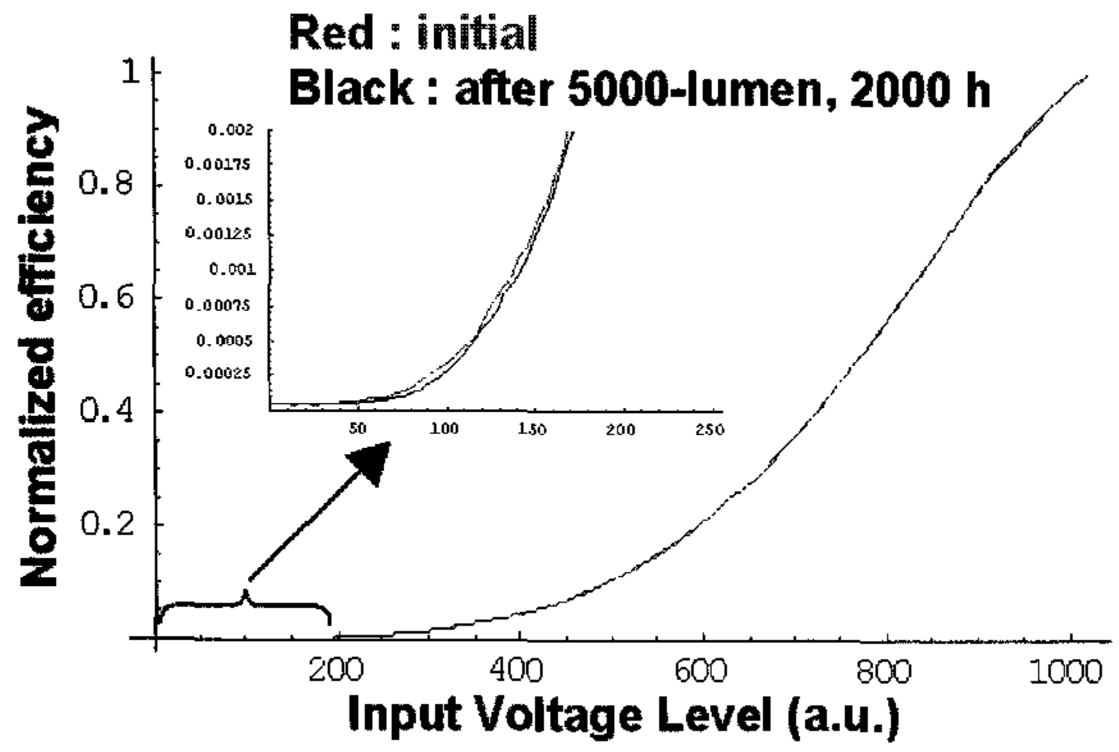

Fig. 11. Normalized efficiency vs. input voltage level of GxL module.

We also conducted 2,000 temperature cycling tests at -20°C and +80°C and did not observed any serious failure.

3-4. 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. 12[12]. 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 a 11.1-ch surround system. More than 2 million people enjoyed watching beautiful movies at the Laser Dream Theatre during the World Exposition, and there was no problems through the 6 months of operation.

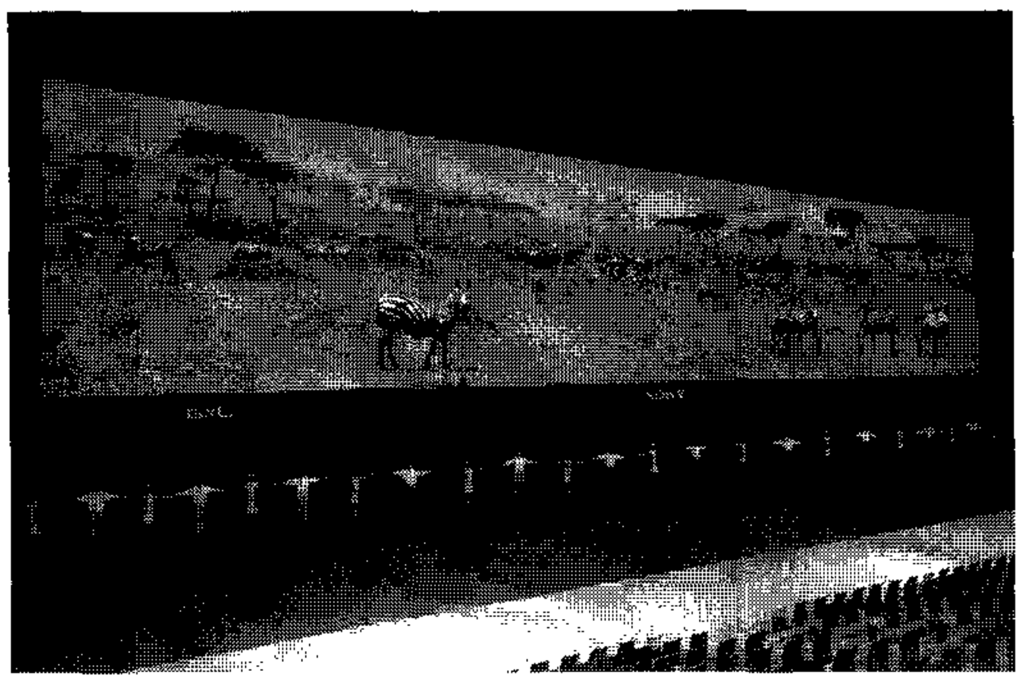

Fig. 12. Laser Dream Theatre at the 2005 World Exposition using SONY's GxL technology.

4. Conclusions

We successfully developed a high performance and highly reliable blazed GxL device with high optical efficiency (> 70% for RGB lasers) and a high contrast ratio (> 10,000:1). The device demonstrated superior resistance against a high power laser, which is suitable for a large-area laser projector. 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. We operated the world's largest laser projection screen using this device at the 2005 World Exposition in Aichi, Japan, problem free.

References

[1] O. Solgaard, F. S. A. Sandejas, D. M. Bloom, Optics Letters, Volume 17, Issue 9, 688 (1992).

[2] D. T. Amm and R. W. Corrigan, Projection Displays V Symposium, SPIE Proceedings Volume EI 3634-10 (1999).

[3] R. W. Corrigan, D. T. Amm, P.A. Alioshin, B. Staker, D. A. LeHoty, K. Gross, B. R. Lang, SID Symposium (1999).

[4] S. Kubota, Optics & Photonics News, 50 (2002).

[5] Naoya Eguchi and Shigeo Kubota, IDW02, Hiroshima, Japan, Dec.4-6 (2002).

[6] David Amm *et al.*, USP6829092.

[7] K. Saruta *et al.*, Technical Digest of IEEE MEMS2006, 842 (2006).

[8] T. Taniguchi *et al.*, Ext. Abst. of 2002 SSDM, 686 (2002).

[9] S. Vaidya, T. T. Sheng, A. K. Sinha, Appl. Phys. Lett. 36, 464 (1980).

[10] F. M. d'Heurle, Metal Trans. 2, 683 (1971).

[11] H. Tamada *et al.*, Digest of Technical Papers ICCE2006, 133 (2006).

[12] Y. Ito *et al.*, Proc. of SPIE, Vol. 6114, 611401-1 (2006).