Laser scanning display as an emerging technology

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Abstract
We report the laser scanning display as an emerging technology. We show demonstration system of laser TV. Video image is made by using a high speed MEMS scanning mirror and a direct-modulated red diode laser. We designed and fabricated MEMS scanning mirror. The first demonstration system showed a NTSC-resolution video image with the image size of 5 inches. The successful development of compact laser TV will open a new area of home application of the laser light.

1. Introduction
As the multimedia society has come, the needs for large area displays get increased more rapidly. So many kinds of projection displays have been developed. Although flat panel displays, like LCD and PDP, increase its size very fast, projection displays still have merits of cost and simplicity of structure in large area displays.

LCD and DLP are now used for front projectors and rear projection TVs. LCoS is now trying to come into consumer market. And GLV (Grating Light Valve), which is very useful system when it uses lasers as the light sources, is being developed. And laser scanning display is also being developed as one of the future projection displays.

2. What is the laser display ?
It is well known that conventional displays using phosphors or a lamp as a light source can express only about 30 % of all visible colors. Recently various efforts to expand color gamut of displays are being tried. The most efficient one is the laser display which is realized with lasers as the light source. Since lasers have the most saturated colors, the laser display has wider color gamut than that of the conventional displays using phosphors or a lamp. Its color gamut is almost three times wider than that of the conventional displays [1, 2]. So the trials to use lasers as light sources have been continued. Figure 1 and Figure 2 show the comparison of color gamut between the conventional displays (sRGB) and laser display. With three lasers of RGB colors, up to 83 % of human visible color area can be expressed while color gamut is only 36 % in the conventional displays.

In spite of this excellent characteristic, laser TV for the commercial displays could not be realized yet, for the lack of laser-related technologies. One of the most obstacles for a home theater of the laser display is the delay of the development of compact, high power blue and green laser sources. Until now for commercial products, only red diode lasers are small and cheap enough. Green diode lasers are not developed yet and the power of blue diode lasers is still too low. Blue and green DPSS lasers are still too expensive. It is however clear that we can use compact RGB laser sources within several years.

There are several kinds of methods to make a video image with laser sources. We have been studying a scanning type laser display which has a relatively simple structure. Figure 3 shows the schematic drawing of the laser scanning display. Scanning type laser display is mainly composed of lasers, modulators and scanners. Laser beams are modulated according to the video signals and then a combined beam is projected to the screen by scanners.

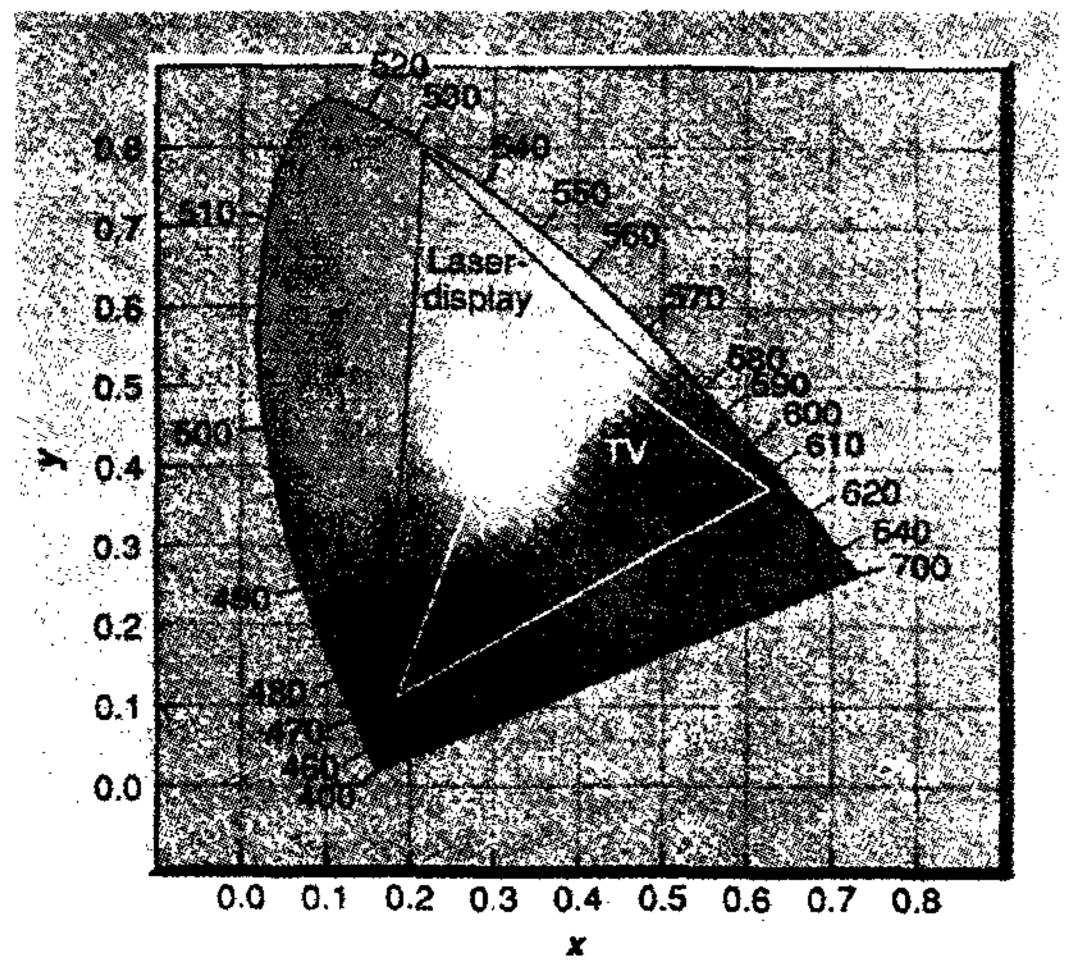

Figure 1 Color coordinates and color gamut

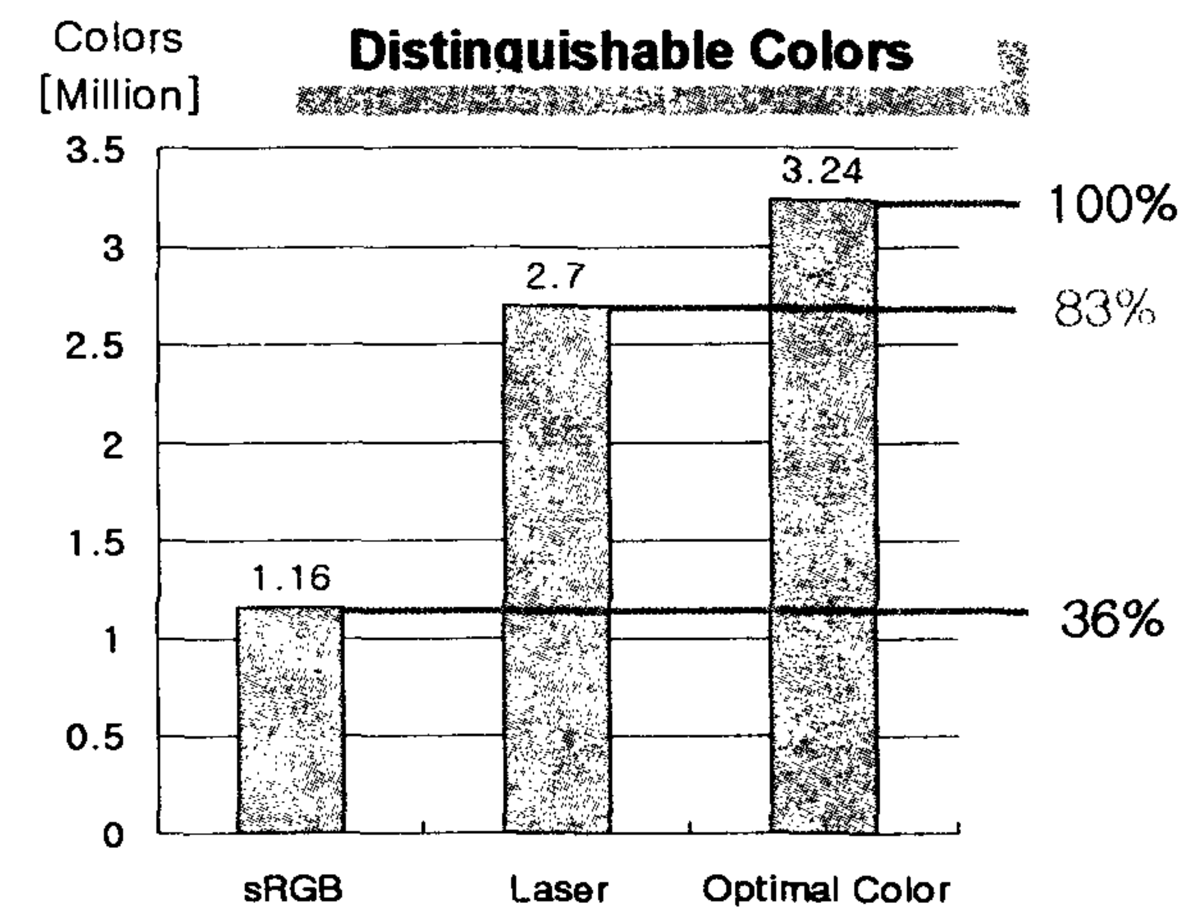

Figure 2 Comparison of color gamut between conventional display (sRGB) and laser display

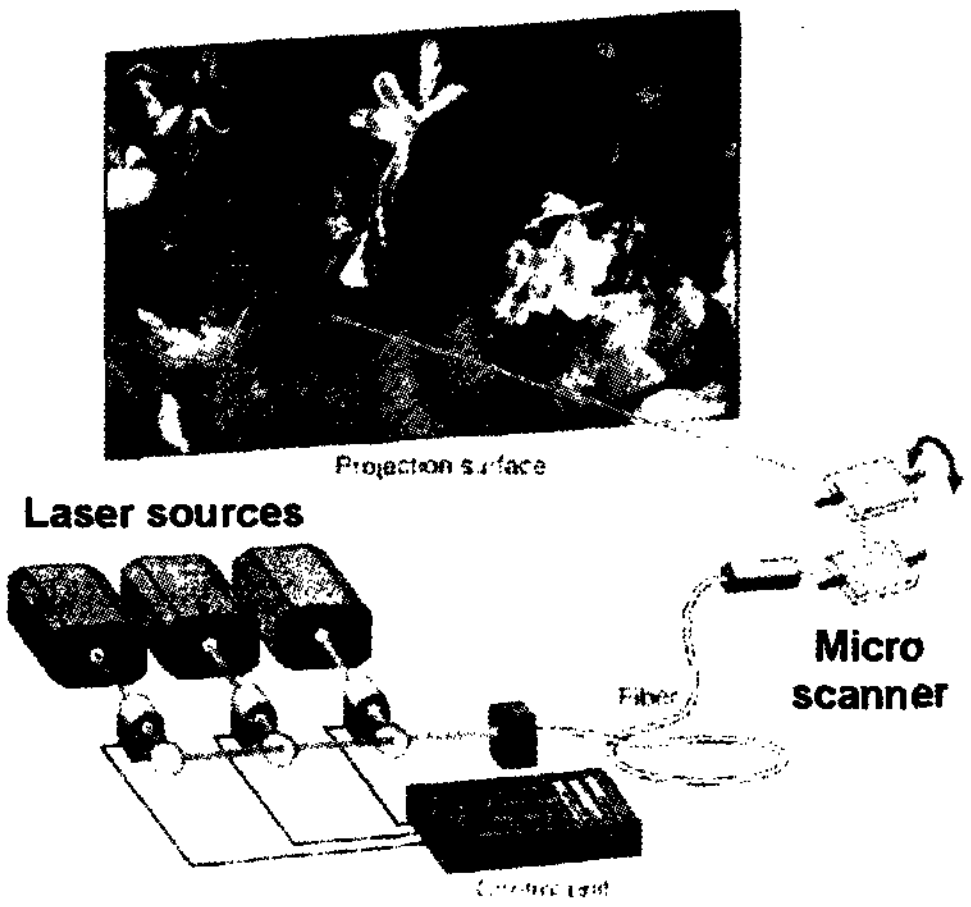

Figure 3 Schematic drawing of laser scanning display

Compared to the light valve type projection displays such as LCD and DLP, it has advantages that it can be reached extremely small system volumes and has the highest optical efficiency in case of using directly modulated lasers.

In 2002, we developed the laser TV using blue, green DPSS lasers, a red diode laser, three acousto-optic modulators, a polygon scan mirror and a galvanometer [3]. The image size of 80 inches with high-brightness and VGA resolution (640 x 480 Progressive scanning) was obtained. The size of the laser TV was 64 cm (*l*) x 46.5 cm (*w*) x 45 cm (*h*). Figure 4 shows the laser TV prototype and the projected image. Since collimated laser beam was scanned by the rotating mirror, we had a video image at any distance of the screen.

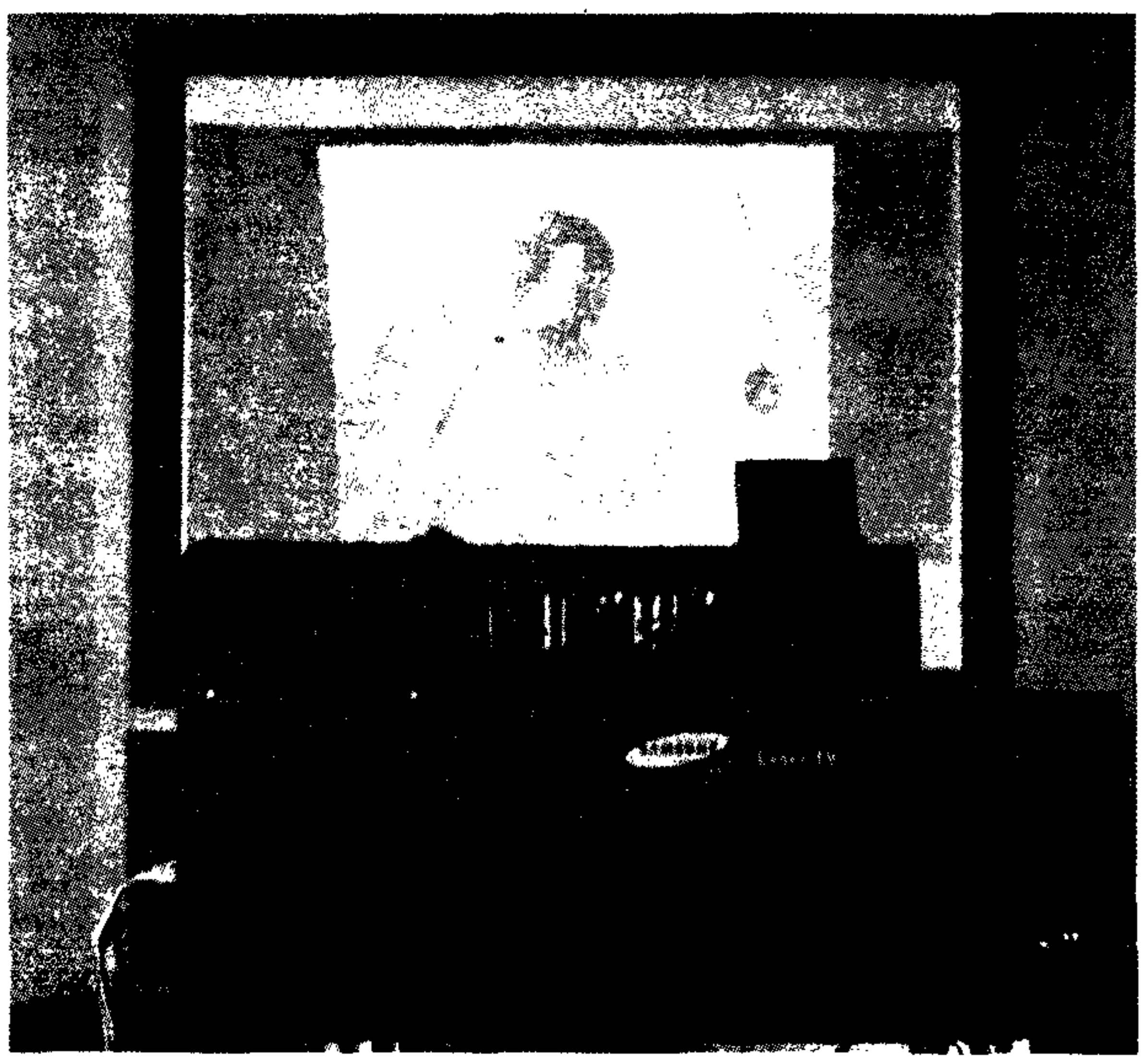

Figure 4 Photograph of laser TV prototype and projected image

Our ultimate goal is a palm-top-sized laser TV for targeting consumer electronics. As a first stage, we developed the demonstration system of the compact laser TV using a high speed MEMS scanning mirror and a direct-modulated red diode laser. The successful development of compact laser TV will open a new area of home application of the laser light.

3. Results and discussion

3.1 MEMS scanning mirror

Scanning type laser display has merits of simple structure and high optical efficiency. So it has a big advantage of a compact-sized system. For a palm-top-sized laser TV, we need small components of lasers and scanners. Typical mechanical scanners are not proper for such compact consumer applications because of the large size and high cost. MEMS scanners have a very high potential of acquiring the small size and low cost. And it doesn't make any sound noise unlike mechanical rotating mirror.

In the case of laser scanning display, linear scanning of a laser light is important to get an undistorted image, so the scanning mirror having vertical comb fingers has been designed and fabricated [4, 5]. Figure 5 shows the schematic drawing of the MEMS scanning mirror. The electrostatic driving force is only related to the square of the applied voltage in the same electrode gap, so this scanning mirror can be controlled very linearly according to the applied voltage. This scanning mirror is used as a horizontal scanner to make the laser TV compact.

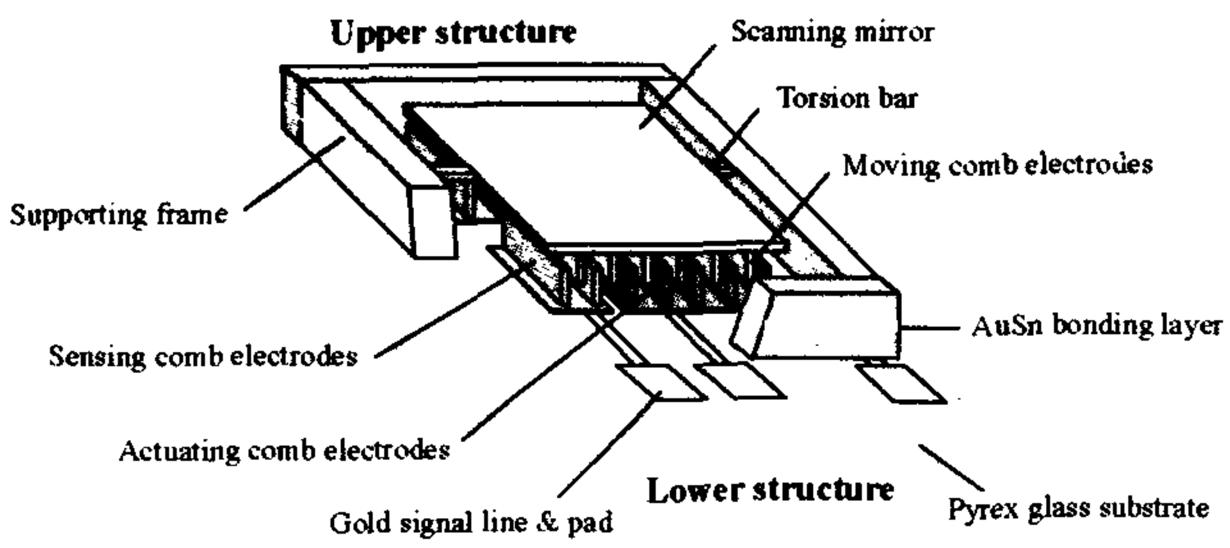

Figure 5 Schematic drawing of MEMS scanning mirror

The size of a scanning mirror plate is 700 μm x 500 μm, and the rotation hinges are square torsion bars, each measuring 55 μm in length, 8 μm in width and 10 μm in thickness. The thickness of the mirror plate is the same as that of the torsion bars. Figure 6 shows the MEMS scanning mirror prototype.

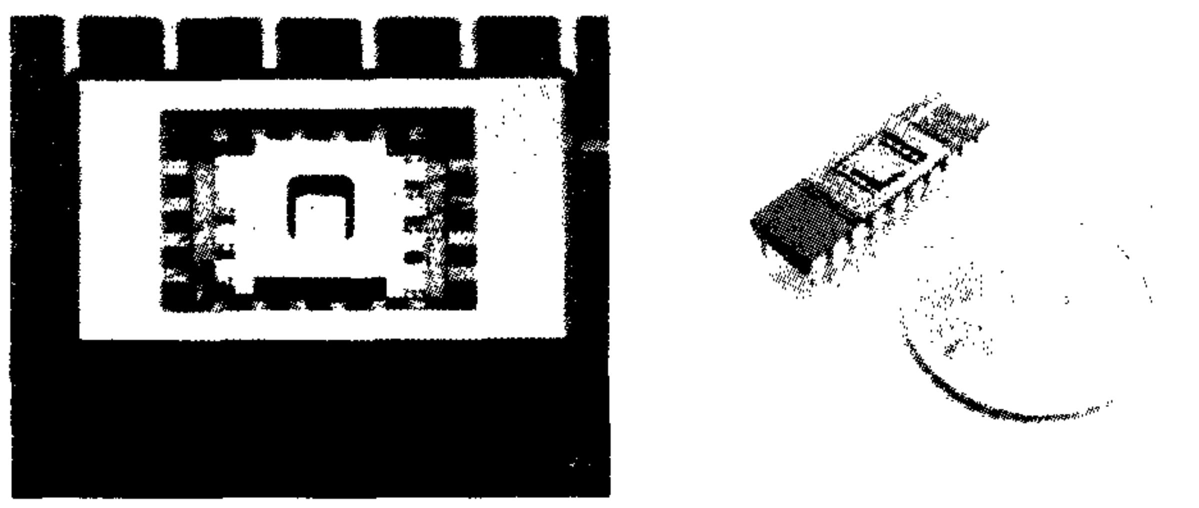

Figure 6 MEMS scanning mirror prototype

We acquired the resonant frequency of 12 kHz. This scanning mirror is operated at the frequency of 7.875 kHz to provide a NTSC-resolution by the bi-directional scanning method. Figure 7 shows the optical scanning angle of the scanning mirror according to the driving voltage with the bias voltages. As the driving voltage was increased, the scanning angle was also increased linearly. The characteristic of linear control can be explained by the linear control scheme [6]. When the dc bias voltages are applied to both comb electrodes of the lower structure with the opposite signs and the driving voltage is applied to the moving comb electrode of the upper structure, the net moment (force) of the scanning mirror can be expressed by

$$\tau = \tau_1 - \tau_2 = \alpha(V_{control} + V_{bias})^2 - \alpha(V_{control} - V_{bias})^2 = 4\alpha V_{control} V_{bias},$$

where, α, $V_{control}$ and V_{bias} are force constant, control (driving) voltage and bias voltage, respectively. When the scanning mirror is driven according to the control voltage, the bias voltages are maintained constant. Thus the net moment, which is directly related to the scanning angle, is only controlled by the control voltage, linearly. Using this scanning mirror, we acquired the optical scanning angle of 10° when driven by 73 V ac control voltage with 100 V dc bias voltages.

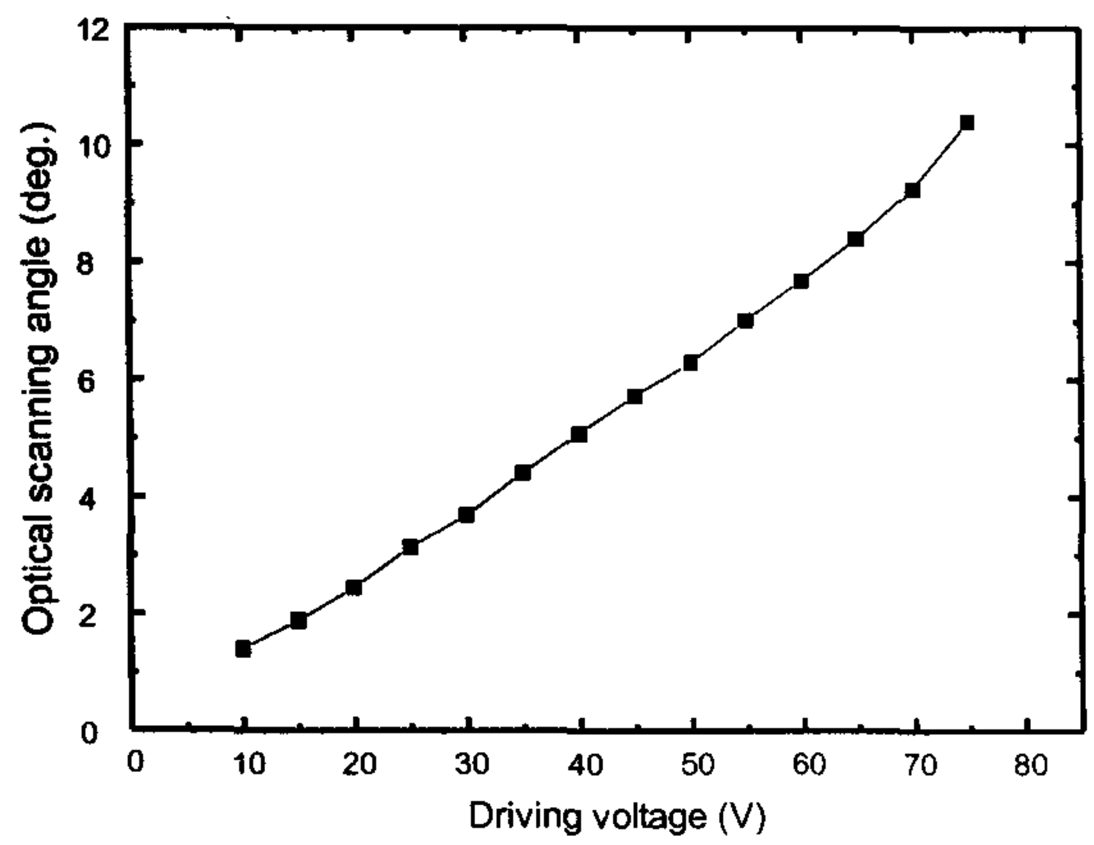

Figure 7 Optical scanning angle according to the driving voltage

3.2 Laser TV

Raster scanning type laser TV is mainly composed of lasers, modulators and scanners. In this compact laser TV demonstration system, 30mW red diode laser with a wavelength of 635 nm, a MEMS scanning mirror and a galvanometer was used as a light source, horizontal and vertical scanners.

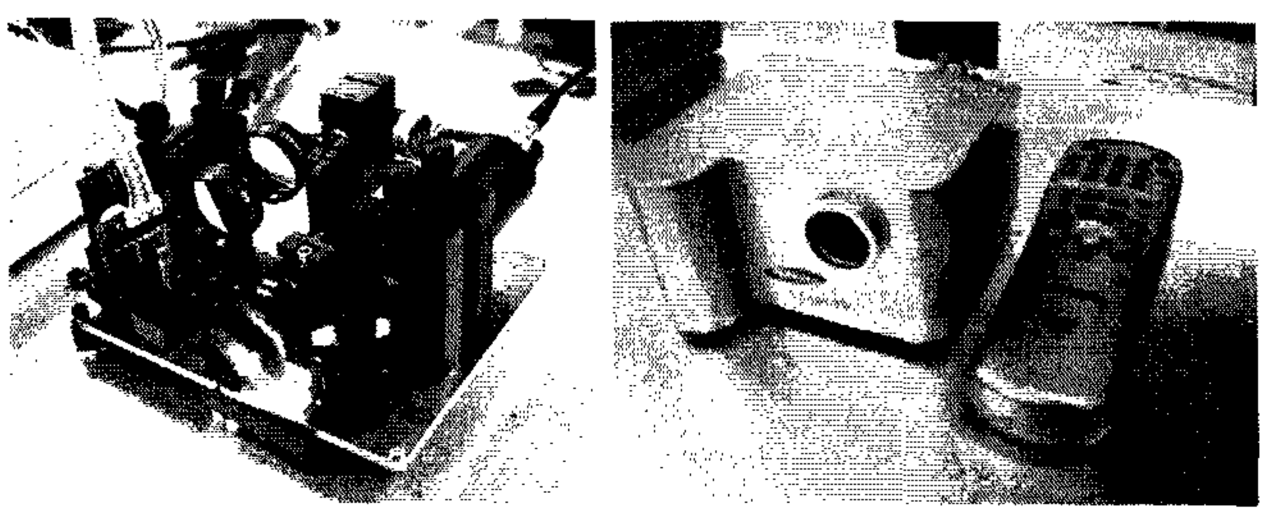

Figure 8 Compact laser TV demonstration system

We used a direct-modulated diode laser instead of using an external modulator to make a compact system. Figure 8 shows the compact laser TV demonstration system. The size of optic part is 12 cm × 10 cm × 8 cm.

We adopted bi-directional scanning method considering the driving characteristics of the MEMS scanning mirror. We used the buffer memory to process the video signals. On the forward sweeping time, the data in the memory is read in FIFO (first-in-first-out) mode, and on the reverse sweeping time, the data is read in FILO (first-in-last-out) mode for scanning. Figure 9 shows the timing diagram of the driving signal.

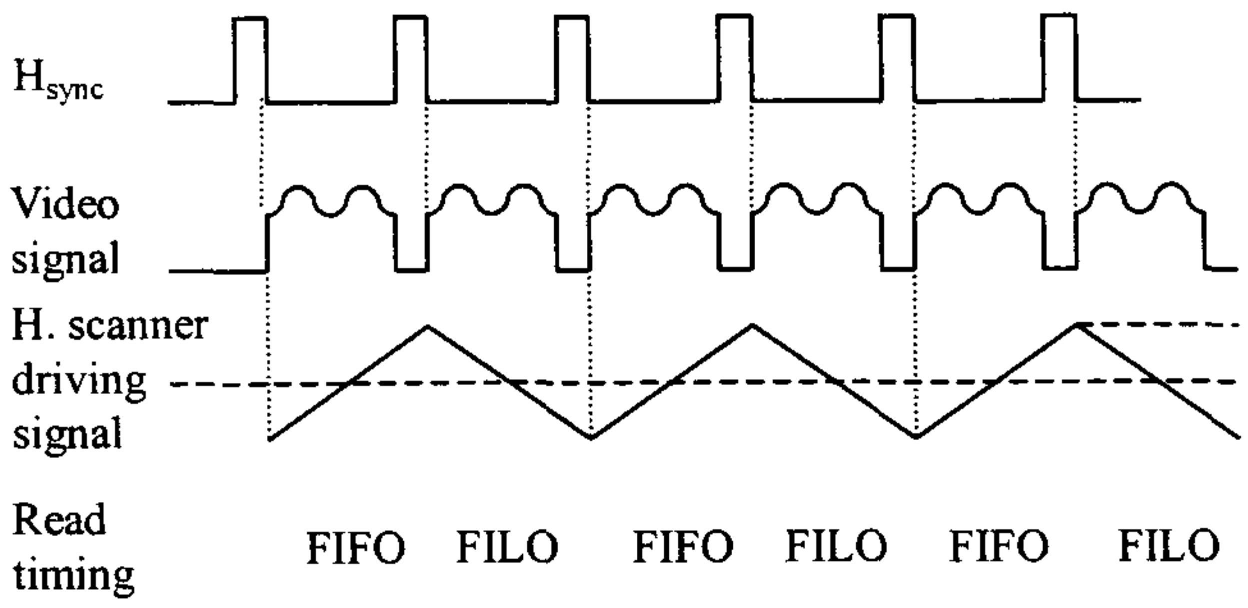

Figure 9 Timing diagram of driving signal

Figure 10 shows the laser video mono image. The first demonstration system showed a NTSC-resolution video image with the image size of 5 inches. The image size was small and the system size was not sufficiently compact since it wasn't optimized yet. We can increase the image size with the proper projection optics and high power laser sources.

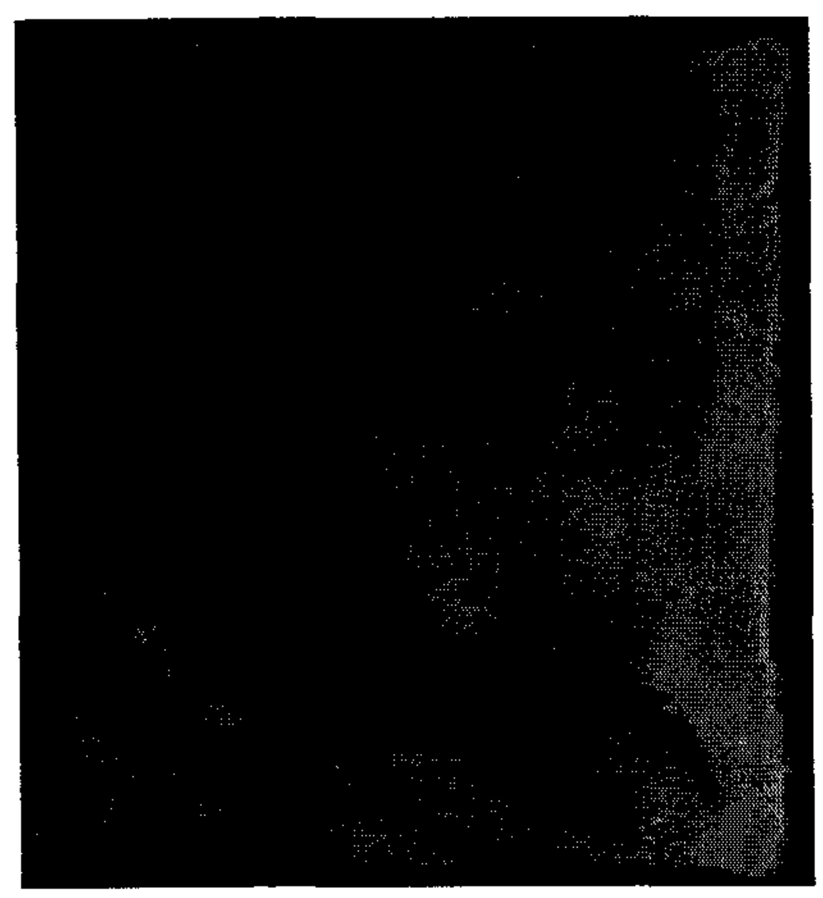

Figure 10 Laser video mono image

4. Conclusion

A small laser TV was demonstrated successfully using the MEMS scanning mirror. To actualize the laser TV for home theater, Laser TV must have a compact size, low cost and low power consumption. Our ultimate goal is a palm-top-sized laser TV, and it can be accomplished by making small components of lasers and scanners. As a first step, the laser TV prototype using a direct-modulated red diode laser and a MEMS scanning mirror was developed. The scanning mirror was fabricated using MEMS technology for a compact size, low cost, low power consumption and lightweight. In the near future, if the compact blue and green lasers are successfully developed and become commercially available, laser TV can occupy home as the main media.

5. References

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