

# A High Density Full Color LED Display Panel on a Silicon Microreflector

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A high-density full-color LED (light-emitting diode) display panel has been developed using LED array units which have many LED chips mounted on a silicon microreflector. The reflector is formed on a (100) silicon wafer by anisotropic chemical etching. The silicon microreflector absorbs the heat generated by the LED chips and improves their light-directive characteristics. The three types of LEDs (red, green and blue) in a unit are arranged in a matrix structure. Electric power to LED chips is supplied through side-wall wiring formed on the silicon microreflector substrate. This wiring structure allows the construction of a high-density LED display panel.

**Keywords:** LED, Display, Micro reflector, Array unit

## 1. Introduction

Recently, blue LEDs of GaN with high brightness were developed [1]. Using blue LEDs, it is possible to realize a full-color LED display. LED display panels have superior characteristics such as long lifetime, high contrast and a wide viewing angle compared with plasma and liquid crystal displays.

For most applications, LED panels are assembled using numerous discrete LED lamps [2, 3]. However, this assembly method has some disadvantages. The production cost increases in proportion to the number of LED lamps, and the dimensions of the LED array are determined by the size and number of LED lamps. This limitation impedes the realization of high-resolution displays. Another problem is the heat generation from the LED chips. The heat produced in LED lamps is conducted through a lead wire or a plastic resin mold. The heat absorption of the LED lamps is not sufficient when they are assembled with a high density.

The developed LED array unit with a silicon microreflector eliminates the problems of production cost and heat generation [4, 5]. In this study, a new wiring method for an LED array unit mounted on a silicon microreflector substrate has been developed in order to realize a high-density LED display panel.

## 2. Structure of LED Array Unit

Figure 1 shows a cross section of the silicon microreflector on which the LED chip is mounted. The reflector is formed on a

(100) silicon wafer by anisotropic chemical etching. The bottom length and depth of the reflector are  $320\ \mu\text{m} \times 620\ \mu\text{m}$  and  $240\ \mu\text{m}$ , respectively. The lower electrode is a thin metal Au/Ni/Cr film deposited on the sides and bottom of the reflector. This electrode reflects light and supplies a current to the LED. The

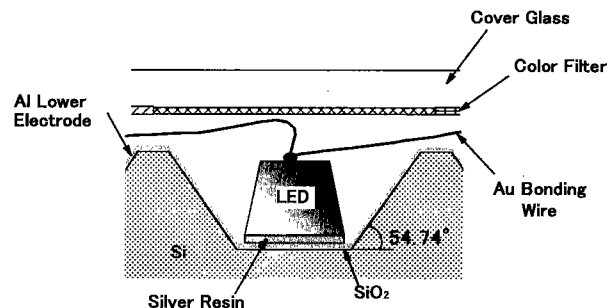


Fig. 1 Cross section of LED array.

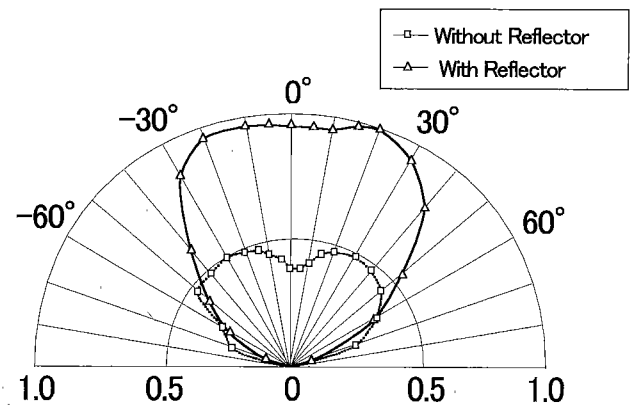


Fig. 2 Directive characteristics of a silicon microreflector.

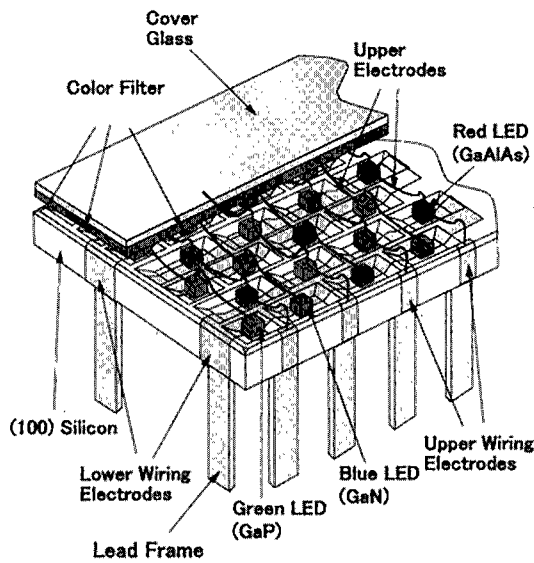


Fig. 3 Structure of full color LED array unit.

light emitted from the side of the LED chip is reflected by the tilted (111) surfaces and is propagated upward. Figure 2 shows the light-directive characteristics of a silicon microreflector. The microreflector improves the light-directive characteristics of an LED up to 100 degrees. The brightness of the LED with a microreflector doubles approximately.

Figure 3 illustrates the structure of an LED array unit. Using a manual chip mounter with a vacuum collet, three types of color LEDs (red, green and blue) are mounted on the microreflectors which are arranged in a matrix structure with a pixel pitch of 1.6 mm. The alignment error of the central position between the LED chip and the microreflector is less than  $50 \mu\text{m}$ . This value little influences on the light-directive characteristics. A cover glass with color filters of red, green and blue is mounted on the microreflectors in order to prevent degradation of the contrast due to the reflection of external light rays.

The lower and upper electrodes are formed on the front side, the side-wall and the backside of the Si substrate. Lead wires mounted on the backside are connected to both electrodes electrically. The wiring details are shown in Fig. 4. The procedure of wiring formation is as follows. The silicon substrate with thermal  $\text{SiO}_2$  is covered by a metal mask that has the wiring pattern and is placed in the vacuum evaporation chamber as shown in Fig. 5. By evaporating Al from the direction of 45 degrees to the mask, the wiring is formed on the front side and the side-wall of the substrate simultaneously. This procedure is repeated four times on the front side and the back side for the

upper and lower electrodes. After side-wall wiring, a lead frame is attached on the backside of the array unit as shown in Fig. 6. This wiring method allows the construction of a tile-style LED display panel with narrow gaps between LED array units. Figure 7 depicts a fabricated LED array unit with side-wall wiring. The unit size with  $16 \times 16 \times 3$  LED chips is 25.6 mm x 25.6 mm squares and 1.5 mm thick. The number of lead wires for the upper and lower electrodes is 48 and 16, respectively. If a VGA display panel ( $640 \times 480$  pixels) is constructed using the fabricated LED array units, the panel of 50 inch is realized.

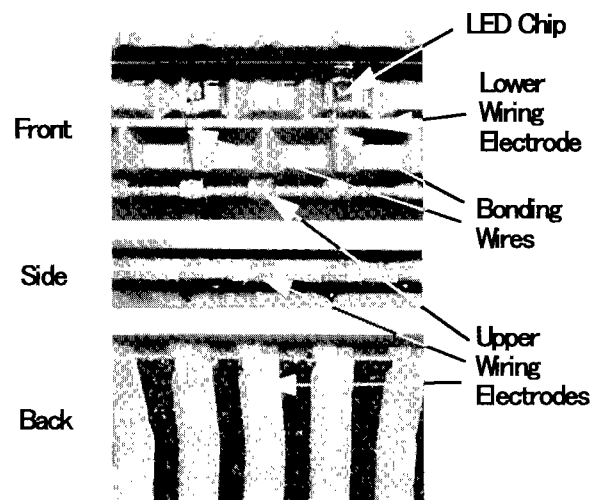


Fig. 4 Side-wall wiring.

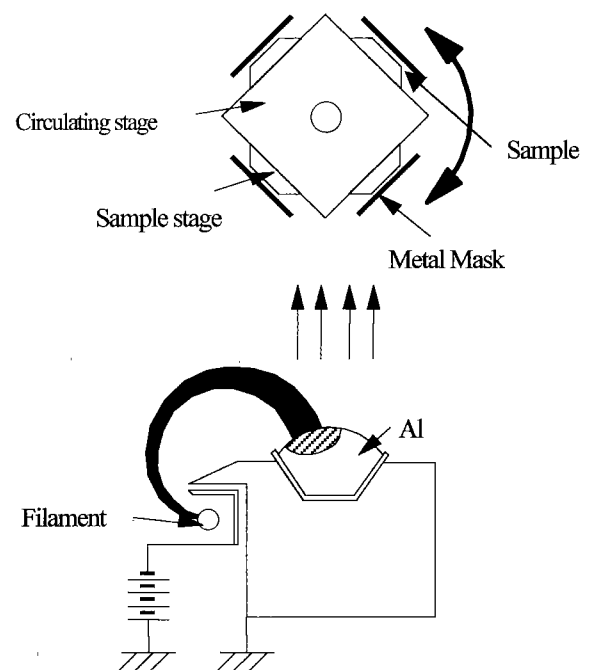


Fig. 5 Slanting evaporation.

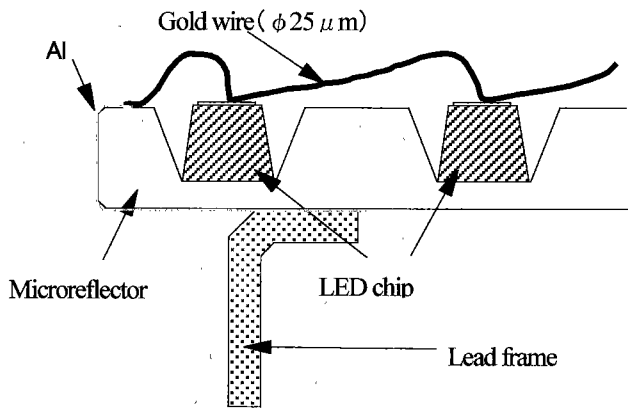


Fig. 6 Structure of side-wall wiring.

The characteristics of the LEDs used in the array unit are listed in Table 1. The brightness of green-LED is lower than that of red- and blue-LEDs. As mentioned later, we can expect to realize an LED array unit with higher luminance using GaN green-LEDs.

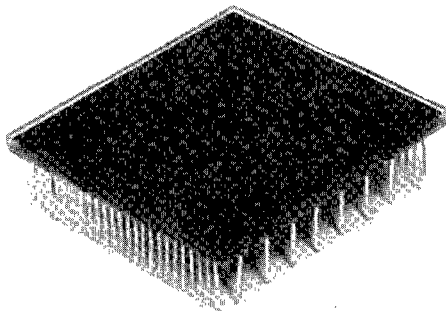


Fig. 7 Photograph of full color LED array unit.

Table 1. Characteristics of three types of LED

	Red	Green	Blue
Material	GaAlAs	GaP	GaN
Forward Voltage (V)	1.8	2.2	4.5
Brightness (mcd)	12	5	100
Peak Wave (nm)	660	565	432
Half Width (nm)	25	26	65
Chip Bottom Size ( $\mu\text{m}$ )	275	280	300
Forward Current (mA)	20	20	30

### 3. Driving System

Figure 8 depicts the driving circuit developed by the line matrix method in a common cathode in order to transform a full-color video signal into a two-dimensional moving picture. Only the LED chip between the upper and lower wires to which voltage is applied is illuminated. A video signal for one frame, resolved into the three primary colors, is stored in the 8-bit register prepared for each matrix column. The LED cathodes are switched in order on via a demultiplexer. The pulse width that controls the brightness is determined using a comparator, which compares the data in the register with the value measured using the pulse-width counter. The picture data for the next line is installed in the register within a light emission time of the previous line.

The luminance distribution of the array unit depends on not only the spread of the brightness and the forward voltage of every LED chip but also a voltage drop caused by the wiring resistance. Especially, green LED chips have a wide brightness distribution.

It is essential to equalize the deviations of the brightness of the LED chips in order to realize an LED display panel with uniform luminance. This can be achieved by compensating the light emission time using the brightness data of all of the LED chips stored in the computer. The effect of brightness compensation to all LED chips on an array unit in a state of white at full luminance is shown in Fig. 9. Following compensation, the luminance distribution in the array unit containing 768 LED chips decreases by 10%.

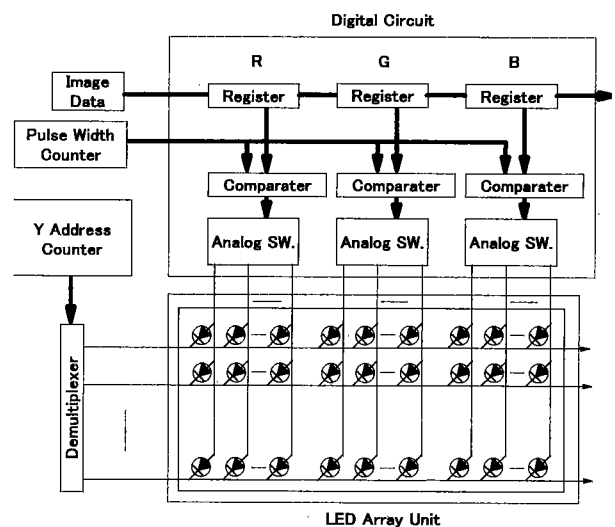


Fig. 8 Driving circuit for LED array unit.

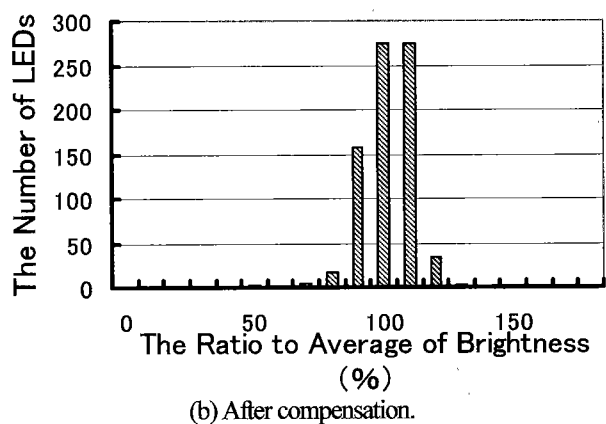
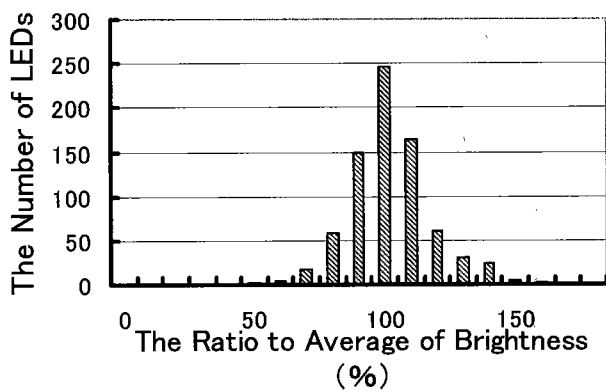


Fig. 9 Brightness compensation.

Since LED chips are mounted on a silicon microreflector, which has a high thermal conductivity, the heat generated in every LED chip conducts in the substrate and radiates from the backside surface, the temperature of the substrate is equalized. The luminance distribution by the thermal effect is estimated within 5% because the maximum temperature difference on the substrate is 5°C and the brightness of LED decreases by  $-1\%/^{\circ}\text{C}$ .

#### 4. LED Display Panel

When display panels which require many pixels, such as those in a TV used to display moving pictures, which contain neutral intensity or tints, are constructed with LEDs, it is essential to switch the LEDs within 20 ms in order to reduce flicker. If the LED array unit is constructed using 256 LED chips (16 x 16) and is driven using the circuit depicted in Fig. 8, the duty ratio and the maximum width of the current pulse for each LED chip are 1/16 and 12.5 ms, respectively. As the number of LEDs in the array unit increases, the duty ratio and width of the current pulse

decreases. The driving system depicted in Fig. 10 can avoid this limitation and realize high resolution and sufficient brightness. A large number of LED array units are arranged in two dimensions and controlled independently and simultaneously by each control circuit depicted in Fig. 8. A video signal is distributed and latched in each of the registers contained in the controller.

In order to construct an LED display panel with a high resolution, as shown in Fig. 10, many LED array units must be arranged in a tile pattern, as shown in Fig. 11. LED array units with the side-wall wiring developed in this study can be assembled on the motherboard in full contact without clearance since the lead wires of the units are situated on the inside edge of the unit. The control circuits for each LED array unit are mounted on the opposite side of the board. Electric connections between both sides are achieved with through holes. The structure of this panel has the advantage of enabling the assembly of a defect-free panel using LED array units, the display operation of which is tested before assembly on the motherboard.

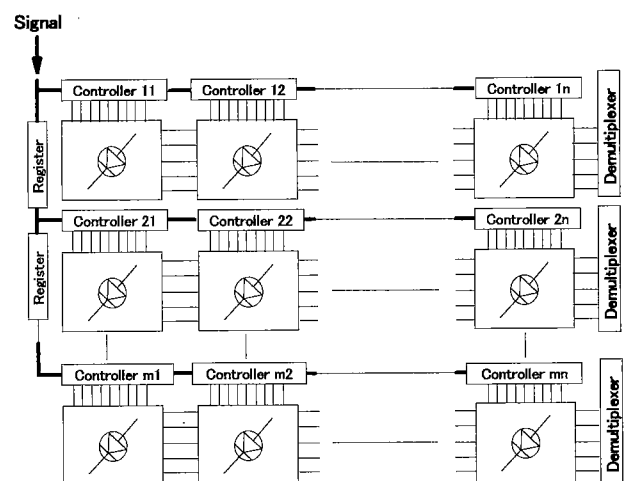


Fig. 10 Driving system for LED display panel.

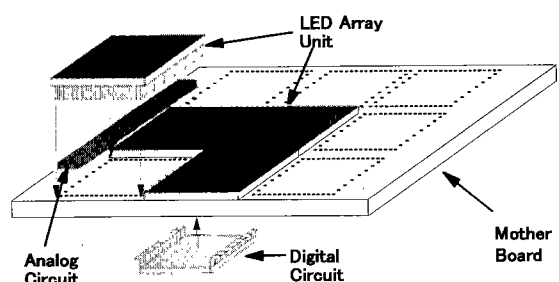


Fig. 11 Structure of LED display panel.

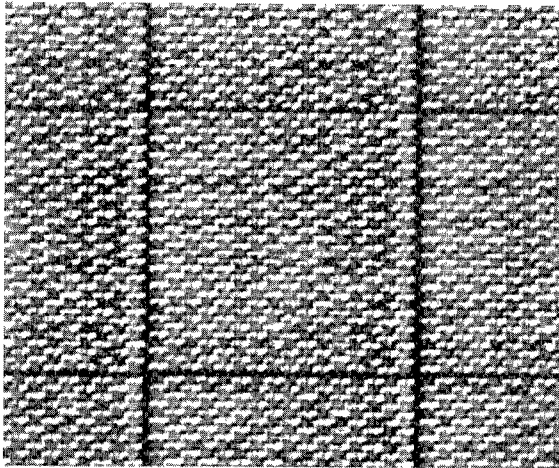


Fig. 12 LED display panel in a white screen at full luminance.

Figure 12 shows the LED display panel constructed on the mother board when all LED chips at full luminance. The gaps between the array units are 1 mm and narrower than the pixel pitch of 1.6 mm. The maximum brightness of 200 cd/m<sup>2</sup> has been achieved in a white screen. From this result, the efficiency of 0.1 lm/W is calculated. This value is less than that of PDP (plasma display panel), which is about 1 lm/W. If red- and green-LED are replaced by one with a high brightness being equal to that of GaN blue-LED, the luminance and the efficiency are expected to be more than 2000 cd/m<sup>2</sup> and 3.7 lm/W, respectively.

## 5. Conclusions

A full-color LED display panel using LED array units with side-wall wiring was developed. This unit has the following advantages. (1) Since the silicon microreflector acts as a heat sink, the LED chips are adequately cooled. (2) The side-wall wiring method in an LED array unit allows the construction of a high density LED display panel. (3) By arranging a driving circuit beneath each LED array unit, an LED display panel of any size can be constructed. (4) LED display panels can be produced at a low cost.

A higher-density LED array unit can be constructed if small, shallow silicon reflectors and thinner LED chips are used. Using green-LEDs with a high output power, an LED display with higher brightness can be obtained.

A LED display cost now mainly depends on the LED chip price, especially the blue LED chip. If the LED chip price gets lower in future, a LED display will occupy the field of flat panel display with a picture size of more than 50 inch.

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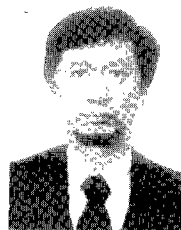
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