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Applications of a High Density LED Array Unit Fabricated on a Silicon Microreflector

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SUMMARY A light emitting diode (LED) array unit for use as a light source in isolated power transmission and a display panel was fabricated using LED chips mounted on a silicon microreflector. The reflector was formed on a (100) silicon wafer by anisotropic chemical etching. An isolated power supply consisting of an infrared LED array unit and single silicon crystal solar cells had a maximum transmission efficiency of 2.3%. The silicon microreflector absorbs the heat generated by the LED chips and improves their light directive characteristics. A small, high-resolution, full color LED display panel can also be constructed using LED array units fabricated on silicon microreflectors. The LEDs in a unit are arrayed with a matrix structure and the electric contacts between the LED chips, the reflector and the upper cover glass are formed using conducting silver resin.

key words: *LED, silicon etching, reflector, isolated power unit, display*

1. Introduction

For most applications, surface light sources consisting of LEDs are assembled using many discrete LED lamps. This method has some disadvantages. The production cost is very high in proportion to the number of LED lamps, and the dimensions of the LED array are determined by the size and number of the LED lamps. This limitation impedes the realization of high-resolution displays and high-density light sources. The other problem is the heat generation from the LED chips. The heat produced in LED lamps is conducted through the lead wire or the plastic resin mold. The heat absorption of the LED lamps is not sufficient when they are assembled with a high density.

The LED array unit with a silicon microreflector developed in this study not only solves the problems of production cost, heat generation and size of LED light sources or displays, but also facilitates new applications, such as high-density light sources and small, high-resolution display panels.

2. Isolated Power Supply by Phototransmission

2.1 Design of Isolated Power Supply

Most phototransmission techniques have been developed in order to transmit information [1], [2]. Usually, the power sources driving these phototransmitters are transformers or dry batteries. Problems with the interference and leakage currents introduced by transformers or the sudden halt of operation at the end of battery life remain to be solved.

The phototransmission of power by electron-photon conversion is an ideal isolation system from the viewpoints of safety and electromagnetic compatibility (EMC). An isolated phototransmission power supply has no internal high frequency noise caused by excitation of the transformers used for DC-DC conversion. A silent power supply can be easily realized using an electron-photon conversion system.

Power transmission using photoenergy has not been put to practical use because of its low conversion efficiency. However, specific applications for which safety and low noise are considered important, such as medical equipment, do not necessarily require a transmission efficiency as high as that of transformers. Nakajima et al. [3] fabricated a power supply for biomedical measurement using silicon solar cells and LEDs. The unit supplies a maximum power of 90 mW with a transmission efficiency of 0.9%. However, in this unit, the wavelength at which the relative sensitivity of the solar cells was at its peak did not coincide with the center wavelength of the LEDs and the cooling system was not considered to be adequate.

Takahashi et al. [4] developed an improved phototransmission power supply using infrared LED lamps and silicon solar cells with a liquid cooling system. Although, using this power supply, a maximum phototransmission power of 400 mW with a transmission efficiency of 3.9% and a low capacitive leakage current were obtained, the power unit size of 5 cm × 8 cm × 9 cm was too large for practical use.

In this study, a small phototransmission power supply with a low capacitive leakage current has been developed using a high density LED array unit as a light source.

2.2 Device Selection

Single-silicon-crystal solar cells have a comparatively high conversion efficiency and the wavelength at which their relative sensitivity is at its peak is about 800 nm. The latter characteristic is suitable for LEDs because

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the conversion efficiency of light emission is superior at longer wavelengths. The center wavelength of the emission from GaAlAs infrared LEDs is around 800 nm and the light emission efficiency is about 20%. It is expected that a higher power transmission efficiency can be achieved by using a combination of these devices.

The solar cells used in this study were 200 AS (Photovoltaic Devices), of which the open voltage is 0.54 V and the short circuit current is 200 mA under 100 mW/cm^2 irradiation. The LEDs used with these solar cells are DN304 (Stanley), which have a peak wavelength of 850 nm and emit light with an intensity of 15 mW at a forward diode current of 50 mA.

2.3 Structure of Microreflector

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

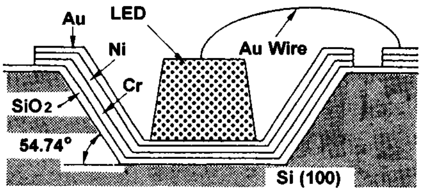


Fig. 1 Cross-section of a silicon microreflector.

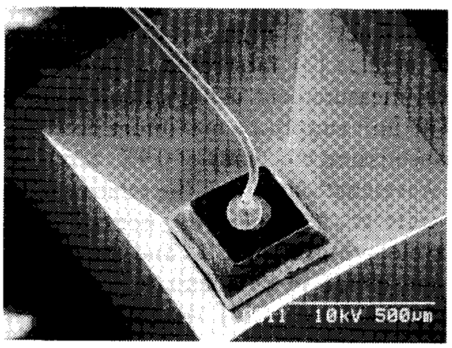
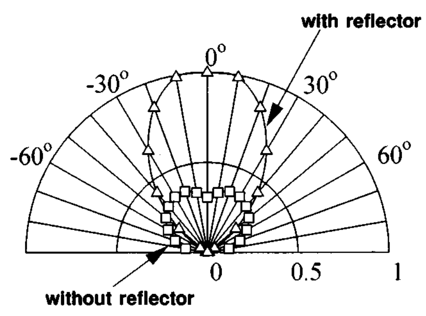


Fig. 2 Photograph of a silicon microreflector on which an LED chip is mounted.



Directive characteristic.

Fig. 3 Directive characteristics of a silicon microreflector.

The reflector is formed on a (100) silicon wafer. Using a mask to define the reflector pattern, silicon is etched using an anisotropic chemical etchant, KOH. After etching the wafer, SiO_2 is grown in order to electrically isolate the substrate. A thin metal Au/Ni/Cr film is deposited over the sides and bottom of the reflector to reflect light and form electrical connections with the LED electrodes. The light emitted from the side of the LED chip is reflected by the tilted (111) surfaces, and the direction of light propagation is upward. Figure 2 shows a silicon microreflector on which an LED chip is mounted. The length of the square reflector is 1 mm and its depth is 360 µm. The propagation directions of the light emitted from the LED mounted on the microreflector in Fig. 2 are shown in Fig. 3. The directive characteristics were measured using a photodiode and the light intensity of the LED was normalized by the maximum observed value. The half-width of the emitted beam is 72 degrees.

2.4 Power Supply Unit

A phototransmission power source supplying electric power of about 100 mW was designed. The LED array unit as the light source has 49 LED chips on a silicon microreflector substrate with dimensions of 10 mm × 10 mm and a reflector pitch of 1.7 mm. The maximum total irradiating light power is more than 700 mW at a forward diode current of 50 mA. The reflector substrate is mounted on an aluminum heat radiator as shown in Fig. 4. The dimensions of the solar cell are 30 mm × 20 mm. The LED array unit and the solar cell are mounted separately in parallel.

2.5 Characteristics

Figures 5 and 6 show the relationships between the input power to the LEDs and the maximum output power from the solar cells and the overall transmission efficiency measured at 25°C, respectively. The transmission efficiency is defined as the ratio of the maximum

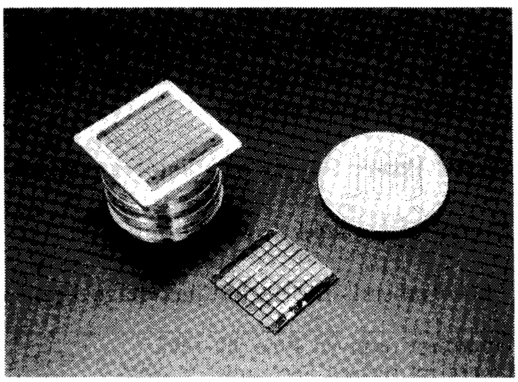


Fig. 4 Infrared light source fabricated using a high density LED array unit.

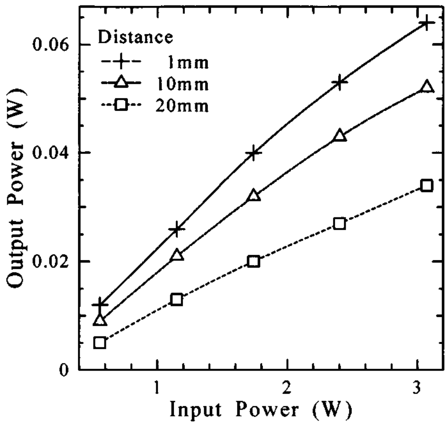


Fig. 5 Relationship between input power to LEDs and maximum output power of a solar cell.

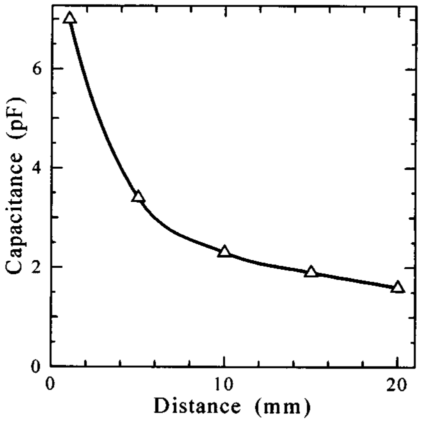


Fig. 7 Coupling capacitance between LED array unit and solar cell.

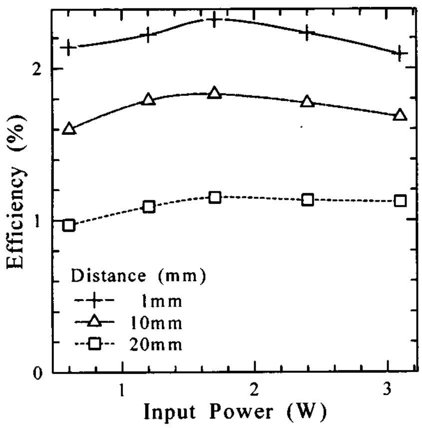


Fig. 6 Relationship between input power to LEDs and transmission efficiency.

output power from the solar cell to the input power supplied to the LEDs. The distance between the LED array unit and the solar cell is set variously at 1 mm, 10 mm and 20 mm. When the distance is 1 mm, the transmission efficiency is 2.1–2.3% for input powers of 0.6–3.1 W. The transmission efficiency is low compared to that of 3.9% reported in Ref. [4]. It is assumed that the directive characteristics of the light emission from the LED mounted on the silicon microreflector are broader than those of the LED lamp used in the reference, and all of the light emitted from the LED does not irradiate the solar cell. When the distance is 10 mm, the transmission efficiency decreases to 80% of that obtained at a distance of 1 mm. The coupling capacitance between the LED array unit and the solar cell was also measured at 100 kHz using a capacitance bridge. For this measurement, the solar cell substrates and the metal films on the silicon microreflector were used as the capacitance electrodes. The results are shown in Fig. 7. The coupling capacitance decreases markedly from 7 pF to 2.4 pF when the distance is changed from 1 mm to 10 mm. The value of 2.4 pF is less than that of a medical isolated power supply unit by DC-DC conversion using a magneticflux coupling, for example, 724 (Burr-Brown), which transmits power with an efficiency of about 60% and has a coupling capacitance of 3.5 pF.

3. Display Panel Using an LED Array Unit

3.1 LED Display

Display panels using LEDs have been assembled using many discrete LED lamps [5]. LED display panels have superior characteristics such as a long lifetime, high contrast and wide a viewing angle compared with plasma and liquid crystal displays. Nevertheless, this assembly method has some disadvantages. The production cost is very high 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. The conventional structure of LED displays impedes the realization of high resolution and low cost displays.

The use of LED array units with silicon microreflectors enables the realization of high density display panels at a low production cost. Since red, green and blue LEDs are now available, full color displays with high resolution can be achieved.

3.2 Structure of an LED Array Unit

The structure of the LED array unit for a full color display panel proposed in this study is shown in Fig. 8. The production sequence of the LED array unit is as follows. The silicon microreflector is formed in the same way as that for the phototransmission power

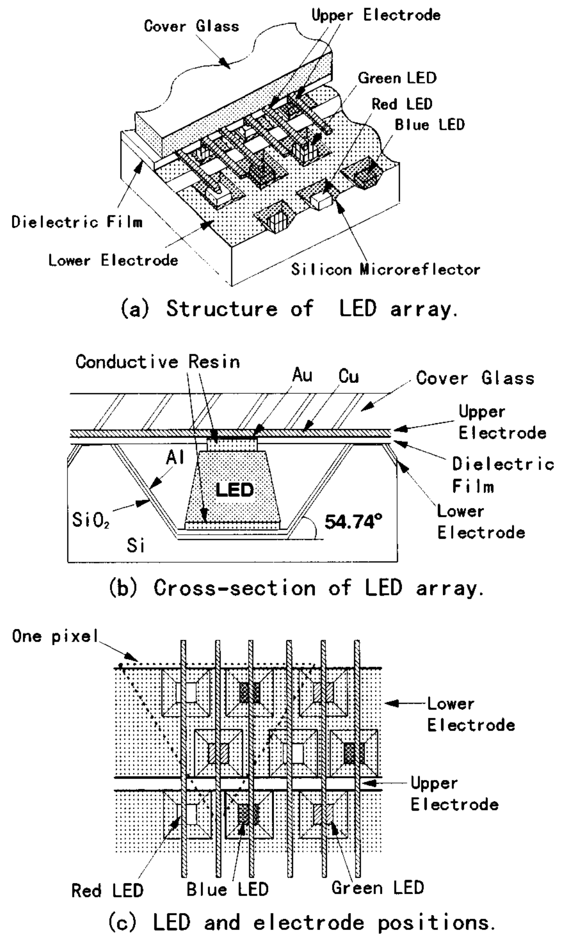


Fig. 8 Structure of LED array unit for full color display panel.

supply. Since LED chips are driven by a dot matrix method, the upper and lower metal electrodes connecting the LED contact pads electrically cross each other perpendicularly as shown in Fig. 8(c). The lower metal electrodes formed on the silicon microreflector are connected to three types of color LEDs (red, green and blue). The upper metal electrodes deposited on a glass plate and coated with a dielectric film for electrical isolation are placed in contact with LEDs. After the LED chips have been mounted on the bottom electrode of the silicon microreflector, the glass plate is placed over the LED array unit and the upper electrodes are connected to the LED contact pads as shown in Fig. 8(b). Conductive silver resin is used to form the electrical connections and to fix the LED chips to the two metal electrodes.

Figure 9 shows an LED array unit without the glass plate. The length and depth of the silicon microreflector are 700 μm and 300 μm, respectively. The pitch of the pixels which consist of red, green and blue color elements is 1.6 mm. The dimensions of an LED array unit with 10 × 10 × 3 LED chips are 16 mm × 16 mm. The characteristics of the LEDs used in the fabricated LED array unit are shown in Table 1.

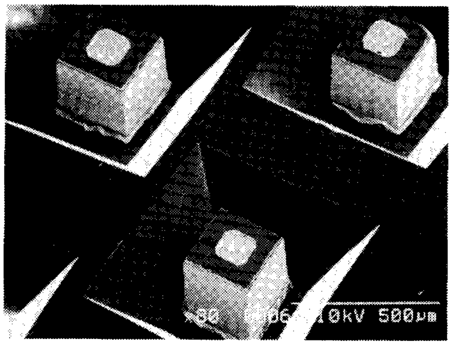


Fig. 9 Photograph of LED array unit without glass plate.

Table 1 Characteristics of three types of LED.

	Red	Green	Blue
Material	GaAlAs	GaP	SiC
Forward Voltage (V)	1.75	2.2	3
Brightness (mcd)	12	5	10
Peak Wave Length (nm)	660	565	470
Half Width (nm)	25	26	70
Responce Time (μsec)	20	50	200
Chip Size (μm)	270	270	260

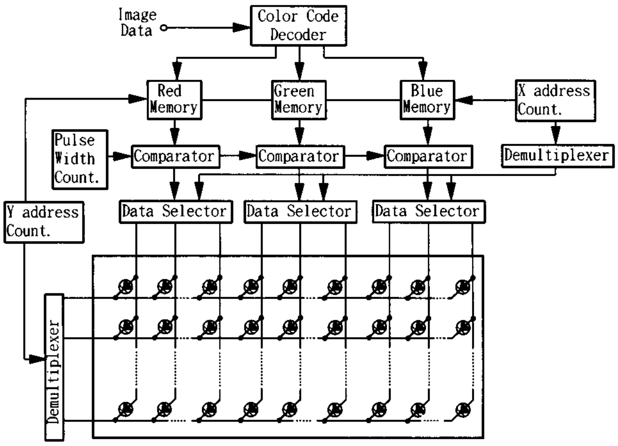


Fig. 10 Driving circuit of LED array unit for full color display.

Figure 10 shows the dot matrix method driving circuit used to transform a full color video signal to 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 a digital memory using 8 bits for each pixel. The LED is switched on via a demultiplexer which is controlled by the X and Y address counter. The data in the memory related to that address is read out at the same time. The pulse width which controls the brightness is determined using a comparator which compares the data in the memory with the value measured using the pulse width counter. The next frame of the picture is installed in the memory in a flyback time.

3.3 LED Display Panel

When display panels requiring many pixels, such as that in a TV which is used to display moving pictures containing neutral intensity or tints, are constructed with LEDs, it is necessary to switch the LEDs in a period of less than 20 ms in order to reduce flicker. If the LED array unit is constructed using 100 LED chips (10 × 10) and is driven using the circuit shown in Fig. 10, the duty ratio and the maximum duration of the current pulse for each LED chip are 1/100 and 200 μs, respectively. As the number of LEDs in the array unit increases, the duty ratio and width of the current pulse decrease. In order to construct a display panel with high resolution and to obtain sufficient brightness, many LED array units arranged on a motherboard like "tiles," and controlled independently and simultaneously using the control circuits shown in Fig. 10 are required. A video signal is distributed and stored in each of the memories contained in the control circuits. 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. If it is necessary to equalize the deviations of the light emission intensity of the LED chips, this can be achieved by compensating the pulse width using the emission intensity data for all of the LED chips stored in the memory.

3.4 Results

The image quality of a two-dimensional full color picture displayed on an LED array unit was estimated using a figure which was synthesized from 10 × 10 segmental photographs. The procedure for synthesizing the figure was as follows. After a digital picture in the computer had been divided into 10 × 10 segments, each segment was displayed on the LED array unit using 10 × 10 pixels and color photographs of the displayed image were taken. The LED array unit was driven by the control circuit shown in Fig. 10. After this operation had been repeated 100 times, the figure was reconstructed using the photographs of the 100 segments. An example of a synthesized picture is shown in Fig. 11. The figure is equivalent to a 9-inch display panel with 100 × 100 pixels.

From this figure, it can be seen that a full color image is obtained using the LED array units. However, the color balance is not perfect in the parts of the picture which contain blue because the slow response time of the blue LEDs limits the light intensity. The electric characteristics of SiC blue LEDs are inferior to those of other LEDs. In particular, the brightness, the half width of the emitted light wave and the response time are not suitable for use in a full color display with high brightness. Although a ZnCdSe LED for green and blue light emission has excellent brightness and color purity, its short lifetime is not suitable for practical applications. Recently, a blue LED with an InGaN/GaN double heterostructure has been developed [6], with a brightness of 2 cd. Using this LED instead of a SiC LED, a display with high brightness can be realized.

Fig. 11 Full color picture synthesized from 10 × 10 segmental photographs of images displayed on LED array units.

4. Conclusions

An LED array unit mounted on a silicon microreflector has been developed. This unit has the following advantages. (1) Since the silicon microreflector acts as a heat sink, the LED chips are adequately cooled. (2) A high-density LED array unit for use in phototransmission power supplies and LED display panels can be realized at a low production cost because a batch process can be used to fabricate the LED array units.

A phototransmission power supply consisting of silicon solar cells and an infrared LED array unit has been fabricated. The transmission efficiency of the power supply is more than 2%. The coupling capacitance of the power supply can be decreased considerably by increasing the distance between the solar cells and the LED array unit with less degradation of the transmission efficiency. This power supply is preferable to dry batteries as a power source in the long-term monitoring systems used in CCUs (coronary care units) or ICUs (intensive care units).

A new application of LED array units for full color LED displays has been developed. If the control circuits are integrated on the silicon microreflector, the active matrix driving method can be applied to increase the brightness of the LEDs. The structure of the LED display proposed in this study can be further improved. A higher density LED array unit can be constructed if small, shallow silicon reflectors and thinner LED chips are used. By using blue LEDs with a high output power instead of SiC LEDs, a LED display with high brightness can be obtained.

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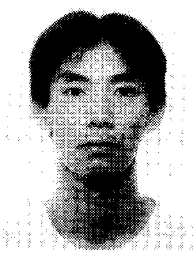

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