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High Density Two Dimensional LED Arrays Using Single Crystal Semiconductor Thin Films

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1. Introduction

Light emitting diodes (LEDs) are widely used as light source, e.g. lighting and display. In these applications, LEDs are often fabricated with single crystal semiconductor materials (inorganic LED), because LEDs are required to provide much higher brightness and longer lifetime. Most of LED displays using inorganic LEDs are of large panels; LEDs are arrayed in a pitch of the order of mm or centimeter. Even in a small LED-display using bare LED chips, the LED array pitch is larger than 1 mm; wirings by wire bonding limits the LED array pitch.

We have developed epi film bonding (EFB) technology for integrating LEDs and silicon integrated circuit drivers using inorganic thin film LEDs and metal thin film wirings [1, 2]. If the thin film LEDs can be arrayed in two dimensions in a fine pitch and are metal thin film wirings are formed, we will be able to fabricate much higher density two dimensional (2D) LED arrays than conventional LED displays. Development of technology for high density (HD) 2D LED arrays will provide new applications of inorganic LEDs.

Flexibility and light weight are key characteristics in some kinds of small high density displays, such as a wearable display and a portable display. Because the thin film LEDs prepared by EFB is flexible, technology of two dimensional LED array by EFB on a flexible substrate will lead to new flexible device applications of inorganic LEDs.

In this paper, fabrication and characterization of the HD 2D LED array on a glass substrate using EFB is described. The HD 2D LED array on the flexible plastic substrate by EFB is also fabricated. Based on the test results of the HD 2D LED arrays on the glass and plastic substrates, fabrication of super high density 2D LED array by EFB is discussed.

2. HD 2D LED arrays on glass substrates

2.1. Design

Figure 1 shows the schematic drawing of the LED in the HD 2D LED array that is developed in this study. The LED is of III-V compound semiconductor thin film of a thickness of 2 μm (area: 300x300 μm^2) The array pitch of the LEDs is 600 μm. Taking into account display of characters on the 2D LED array, 24 x24 LEDs are disposed. In order to individually drive each LED, 24 cathode thin film metal wiring lines and 24 anode thin film metal wiring lines are formed on the substrate and each LED is connected to the anode and cathode wiring lines that are adjacent to each LED as shown in Fig. 1.

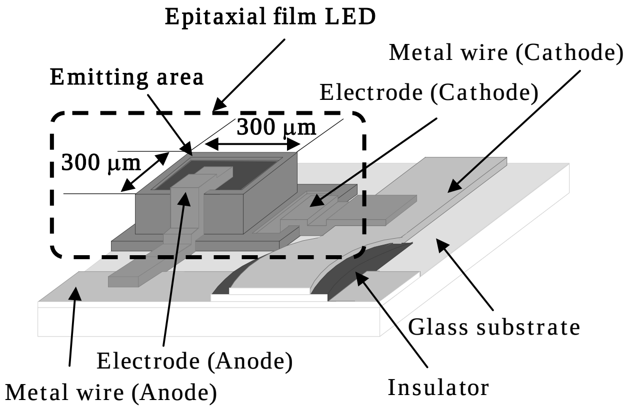


Figure 1. LED structure of 2D EF LED array

2.2. Fabrication process

The 2D HD LED array was fabricated by EFB[1,2]. The compound semiconductor layers including double hetero structure ($Al_xGa_{1-x}As/Al_yGa_{1-y}As/Al_xGa_{1-x}As$) were epitaxially grown (epi film layer) on the GaAs substrate. A sacrificial layer was formed between the epi film layer and the GaAs substrate. The epi film layer was released by etching selectively the sacrificial layer.

The released epi-films were bonded on a glass substrate in two dimensions by intermolecular force. The bonded epi films were mesa-etched to form the 2D LED array. The p-type side and n-type side contact electrodes of the LEDs were formed and connected to the anode and cathode wiring lines as shown Fig. 1. The LED fabricated with the epi film is called epi film LED (EF LED).

2.3. Characteristics

The 2D LED array developed in this study is shown in Fig. 2. All the EF LEDs are well bonded on the glass substrate and no defects are observed on the EF LEDs. This proves that the EFB conditions are actually optimized for fabricating the EF LED array on the glass substrate.

Figure 3 (a) shows the typical current-voltage (I-V) curve of the EF LED. The I-V curve of the EF LED is equivalent to that of the conventional LED formed on the GaAs substrate. This indicates that the fabrication process of the HD 2D LED array has no influence on the electical characteristics of the LEDs. Figure 3 (b) shows typical curren-power (I-P) characteristic of the EF-LED. The LED power linearly increases with increasing LED current in the measured current range. This means that emitted light powers in the 2D LED array are well controled by adjusting the current in the wide current range.

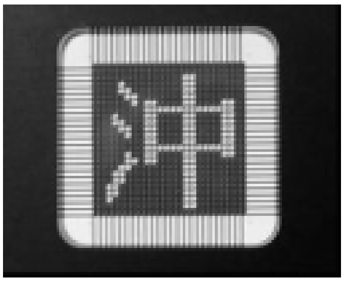
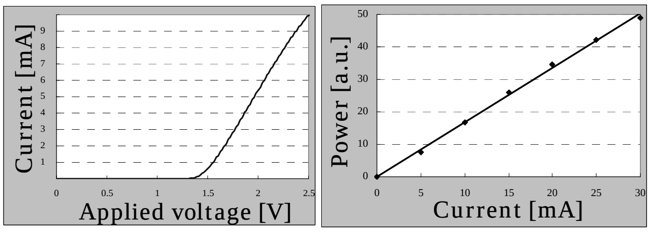


Figure 2. HD 2D LED array on the glass substrate



(a) I-V characteristic (b) I-P characteristic

Figure 3. Characteristics of EF LED

3. HD 2D LED arrays on a plastic substrate

We have succeeded in fabricating the HD 2D LED array on a plastic substrate. The 2D LED array on the plastic substrate has roughly equal structure to that on the glass substrate described in the section 2.1. It is the key point that 2D LED array on the plastic substrate is fabricated in the temperature range below the softning temperature of the plastic substrate. Becase the maximum temperature of the LED fabrication process is higher than the softning temperature of the plastic substrate, we have optimized process sequence and conditions of the 2D LED array fabrication on the plastic substrate to meet the softening temperature of the plastic substrate. The EF LEDs including the LED electrodes are formed on the GaAs substrate before the EFB proces. The EF LEDs on the GaAs substrate are released from the GaAs substrate and bobded on the plastic substrate. After EFB process, the LED contacts are connected to the wiring lines on the plastic substrate in the similar way described in the section of 2.1. The LEDs on the plastic substrate show equal I-V and I-P characteristics to those of the LEDs on the glass substrate. The weight of this LED array is 1/9 of that on the glass substrate. The 2D LED array on the plastic substrate displays good characters and no damage on the EF LEDs are observed in the measured plastic-substrate-curvature range below 50 mm. This shows that the EF LED can be also applied as the flexible devise; 2D LED array on the flexible substrate is one of the suitable application targets of the EF LEDs.

4. Discussion

In this section, we show possibility to fabricate the super HD 2D LED array, such as a 600 dot-per-inch (dpi) array (array pitch is 42.3μm).

Figure 4 shows the 600 dpi LED aray (light emitting area is 20x20μm^2) that is integrated with IC drivers using EFB technology for an LED printhead [1,2]. As shown in Fig. 4, no defects are observed in the 600 dpi EF LED array. Figure 5 shows the emited light power distribution of the 600 dpi EF LED array chip. As shown in Fig. 5, the emitted light power variation is very small and is within 4%.

The test results of the HD 2D EF LED array and the 600 dpi EF LED array suggest that super HD 2D EF LED array can be fabricated by using both technologies of 2D EF LED array and 600 dpi EF LED array.

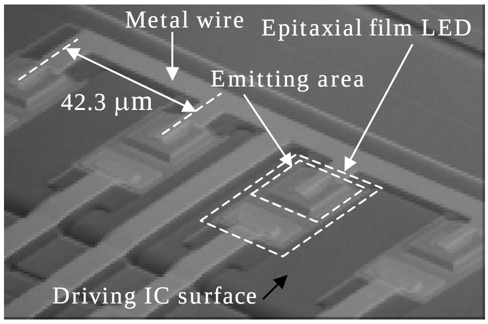


Figure 4. SEM image of high density LED printhead

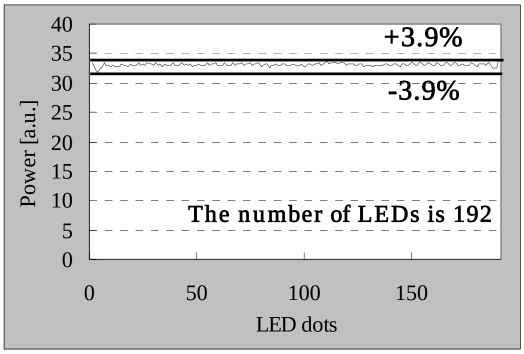


Figure 5. Power distribution of the EF LED array chip.

5. Conclusion

We have succeeded in fabricating the HD 2D LED arrays on both of the glass substrate and plastic substrate using EFB technology. The results of this study suggests that the 600 dpi 2D EF LED array can be fabricated using both technologies of the 2D EF LED array and 600 dpi EF LED array. 600 dpi 2D EF LED array fabrication is now in progress. The 2D EF LED array on the plastic substrate also shows that the EF LEDs can be applied as flexible devices.

References

[1]T. Suzuki et al., SSDM2006, pp258-259, 2006
[2]M. Ogihara et al., Electron. Lett. 42, 881, 2006