Designing optically isolated LED arrays embedded in Si Micro-cup substrates

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ABSTRACT

A 16 × 16 array micro-LED display was fabricated by using Si micro-cup substrates. Emission patten exhibited apparent reduction of lateral spread of light in case of the micro-LEDs embedded in the Si micro-cup. The micro-LEDs with the Si micro-cups were found to work as vivid pixels.

1 INTRODUCTION

The liquid-crystal-display (LCD) and the organic light-emitting display (OLED) have already been widely used for smartphone and digital signage, etc. However, they are unsuitable for outdoor use because of their low brightness and visibility [1]. Behind them, micro-LED display using tiny LED chip is attracting attention because of high brightness and high luminous-efficacy [2]. We have succeeded in fabricating micro-LED array using the Si micro-cup substrate [3]. The use of Si substrate has another potential to combine the display with Si-based integrated circuits. However, there exists technical issues in their fabrication processes such as chip mounting, driving circuit formation, cross-talk, etc. In this study, 16 × 16 arrays of micro-LED display are fabricated by using the Si micro-cup substrates. And, their light emission properties are evaluated to quantitatively show their benefits.

2 EXPERIMENT

In order to fabricate Si micro-cup substrate, photo-resist (TOK, OFPR-800LB 100 cp) was coated on 1.5 cm-square (100) p-type Si substrate, and 16 × 16 arrays of 220 μm × 320 μm square-shape openings were patterned using photolithography. Then, the deep-reactive-ion-etching (DRIE) was conducted using the BOSCH process, where SF_6 and C_4F_8 gases were alternatively supplied for etching and forming passivation layer, respectively. The gas flow rates were 130 and 85 sccm for SF_6 and C_4F_8, respectively. One hundred and two hundred cycles of BOSCH process led us to form 16 × 16 arrays of square-shape trenches. Then, 90 μm-thick, 200 μm × 300 μm square-shape blue LED chips were mounted in 3 × 3 arrays of Si micro-cup substrates. Emission patterns of LEDs mounted in the Si micro-cup substrates were evaluated by analyzing the surface pictures.

3 RESULTS AND DISCUSSION

Surface and cross-sectional SEM images of Si micro-cup substrates formed by 100 and 200 cycles of BOSCH process are shown in Figs. 1 and 2, respectively. As summarized in Table 1, one hundred cycles formed 223.1 μm × 312.2 μm square-shape trenches with depth of 38.1 μm, and two hundred cycles formed 255.0 μm × 346.9 μm square-shape trenches with depth of 95.3 μm. The former and latter trenches are abbreviated as shallow and deep trenches hereafter. Although over-etching of the resist pattern edge resulted in the inverted trapezoidal trench shape, two hundred cycles formed enough depth to embed the LED chip. Indeed, the LED chips are fully settled in the micro-cups as shown in Fig. 3. Emission patterns of micro-LEDs embedded in shallow and deep Si micro-cup substrates are comparatively shown in Fig. 4. Lateral spread of the LED emission lights up the neighbor LED edge for shallow micro-cup, but that is not the case for the deep micro-cup. To visualize the improvement, transverse line profiles of surface pictures for micro-LEDs embedded in shallow and deep Si micro-cup substrates are shown in Fig. 5. Obviously, lateral spread of emission is mostly suppressed by using the deep Si micro-cup substrate. The lateral spread of light is further evaluated by spatially integrating the light intensities, i.e., tophat line profiles are divided into a middle flat area and a halo area surrounding it. The flat middle area has a width of 200 μm, corresponding to the lateral width of the LED chip. The integrated intensity for the halo area is divided by that for the total area. As shown in Table 2, the value for the deep Si micro-cup substrate is smaller than that for the shallow one. The results demonstrate that the micro-LEDs embedded in the Si micro-cups work as vivid pixels.

4 CONCLUSIONS

A 16 × 16 array micro-LED display was fabricated by using Si micro-cup substrates. Emission patterns of LEDs mounted in shallow and deep Si micro-cup substrates were evaluated by analyzing the surface pictures. Lateral spread of emission was mostly suppressed by using the deep Si micro-cup substrate.

The results demonstrate that the micro-LEDs embedded in the Si micro-cups work as vivid pixels.

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REFERENCES

[1] J. Day *et al.,* Appl. Phys. Lett. **99**, 10 (2011). [2] J. Herrnsdorf *et al.,* IEEE Trans. Electron Devices **62**, 6 (2015). [3] R. Nawa *et al.*, in *LEDIA '18*, LEDIA4-2.

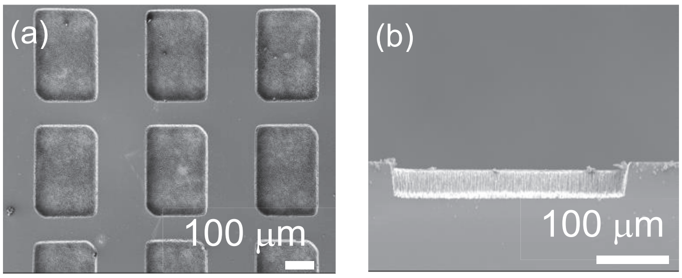

Fig. 1. (a) Surface and (b) longitudinal cross-sectional SEM images of Si micro-cup formed by 100 cycles of BOSCH process.

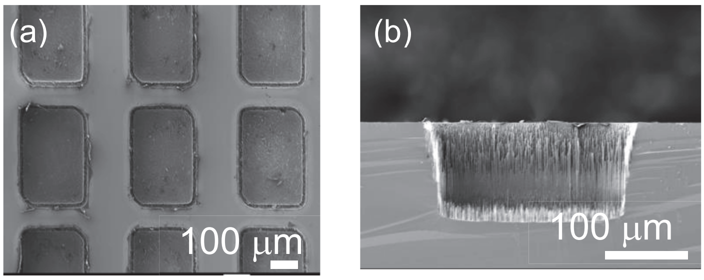

Fig. 2. (a) Surface and (b) transverse cross-sectional SEM images of Si micro-cup formed by 200 cycles of BOSCH process.

Table 1. Dimension of Si micro-cup formed by BOSCH process.

Number of etching cycles	Longitudinal width (μm)	Transverse Width (μm)	Depth (μm)
100	312.2	223.1	38.1
200	346.9	255.0	95.3

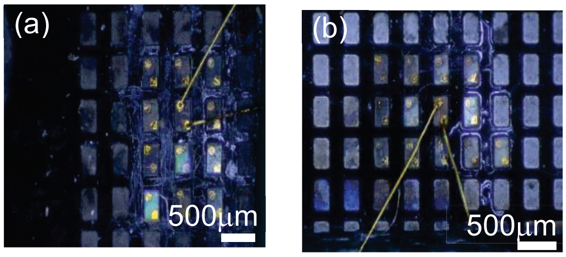

Fig. 3. Surface pictures of micro-LEDs embedded in (a) shallow and (b) deep Si micro-cup substrates.

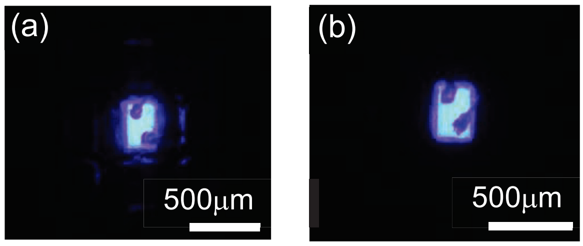

Fig. 4. Emission patterns of micro-LEDs embedded in (a) shallow and (b) deep Si micro-cup substrates.

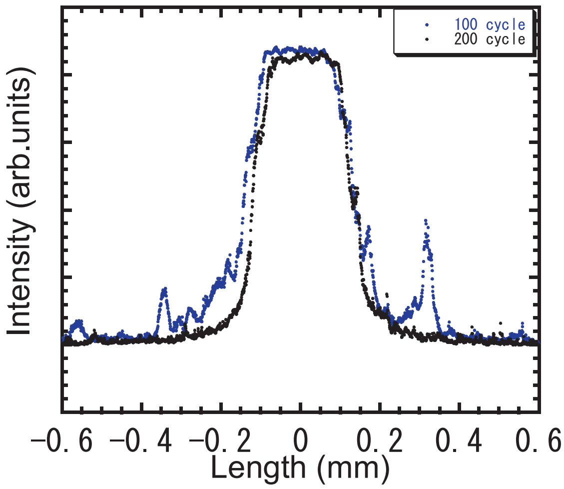

Fig. 5. Transverse line profiles of surface pictures for micro-LEDs embedded in shallow and deep Si micro-cup substrates.

Table 2. Ratio of spatially-integrated intensity for halo area to total area shown in Fig. 5.

Number of etching cycles	Ratio (%)
100	50.0
200	39.3