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Towards Glass-based μ-LED Displays Fabricated with Advanced Transfer Technology

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ABSTRACT

This paper reports our works on implementation of the concept of highly integrated semiconductor information display (HISID). Micro light-emitting diodes (μ-LEDs) within dimensions of 15 μm × 25 μm were transferred onto glass-based display panels with a mass transfer method. A thick Cr/Al/Ti/Pt/Au interconnection metal was deposited on the glass substrate to form the passive matrix driving structure. This approach has the potential to mass-produce high performance novel display device.

1 INTRODUCTION

With the rapid development and growing consumer market, information display technologies are facing new opportunities and challenges. In recent years, micro light -emitting diodes (μ-LEDs or micro LEDs) have gained favors from both industry and academia due to its fascinating superiority of efficiency, stability, response speed and so on [1-4]. Comparing with current mainstream technology such as liquid crystal display (LCD) and organic light-emitting diodes (OLED), μ-LEDs are not only of greater performance, but also of better compatibility and utilization to advanced semiconductor manufacturing processes. By means of well-developed lithography and etching technology, the light-emitting area of single device of μ-LEDs could be rather small (less than 50 μm in diameter), which enables integration of more complicated and varied structures and devices in one single panel. Here we define this concept as highly integrated semiconductor information display (HISID) and we believe that μ-LEDs are the key enabling technology and it could help us to realize many fancy ideas and devices including augmented reality (AR), virtual reality (VR), 3D holographic display, etc.

Despite all the mentioned advantages, μ-LEDs are still facing quite a few difficulties and challenges. First and considered as the greatest barriers hinder realizing the industrialization are the technique issue known as mass transfer. Unlike the previous display technologies, μ-LEDs is tiny inorganic device fabricated from epitaxial wafers usually grown by metal organic chemical vapor deposition (MOCVD). In this case, to make the most of utilization ratio of the epitaxial wafer and to achieve high resolution in any size, it is inevitable to transfer millions of tiny devices from processed wafer to the target panel [5-6]. In this pick and place process, transfer speed and alignment accuracy are of the greatest concern. In addition, the full-color solution is the other popular issue since most epitaxy technology could only afford monochromatic LED wafer. Blue and green devices could be easily attained from the GaN-based epitaxial wafer while red devices are mainly made from GaAs-based epitaxial wafer which uses a different material as the substrate. Furthermore, researchers found that green LEDs have only half the efficiency of blue LEDs at room temperature, which is known as the “green gap” [7].

In this pater, we bring about our works on μ-LEDs by utilizing mass transfer methodology to integrate micro emitting chips with glass substrate based display panel. Since Si-based monocrystalline silicon and glass-based amorphous silicon are well promising for the driving of μ-LEDs, traditional Bismaleimide Triazine (BT) printed circuit board (PCB) are not the first choice. Here, glass-based panel with passive matrix (PM) driving structures were designed and fabricated. Flip-Chip GaN based micro LED chips with dimensions of 15 μm × 25 μm were transferred onto the panel. Anisotropic conductive films (ACF) were utilized as the electrical connection and adhesive medium between μ-LED chips and the glass panel while PDMS stamps with specific patterns were used to implement the pick and place process. Finally, passive matrix (PM) micro display devices with pixel pith of less than 130 μm and resolution of 80 × 120 were produced. After ACF bonding of the driver IC and been connected to the peripheral circuit, the screen was lit up. This is the early achievement of our research and development in mass transfer and glass-based μ-LED display, which is a good start and it did show great promise of the concept of HISID we mentioned above.

2 EXPERIMENT

2.1 μ-LED chips

Inverted μ-LED chips within dimensions of 15 μm × 25 μm produced by San'an Optoelectronics CO., LTD were used in this work. All three primary colors (RGB) are available to obtained by lighting the diode chips growing on different substrates. Here blue flip chip bonded μ-LEDs were utilized as the emitting units, which is of great research significance since blue lights can be converted to other colors via a variety of ways.

2.2 Glass-based display panel

4 inch glass wafer were used to fabricate the display panel. As shown in Fig.1, three steps of lithography were utilized to accomplish the PM structure. In the 1st step lithography, patterns of column lines of the electrodes were transfer onto the glass wafer and electrode metals (Cr/Al/Ti/Pt/Au total 2.2 μm) were deposited by E-beam evaporation with a lift-off process. Then, in the 2nd step lithography, a SiO_2 dielectric layers were deposited by plasma enhanced chemical vapor deposition (PECVD) with a wet etching process, which avoids short circuits between the column line electrodes prepared in the 1st step lithography and the row column line electrodes to be prepared in the next third step and provides open vias for electricity connections between the panels and the micro diodes. Finally, in the 3rd step lithography, patterns of row lines of the electrodes and pads were transfer onto the wafer. Metals with the same formula mentioned in the first step were deposited by E-beam evaporation with a lift-off process. With this, glass based display panel with a passive matrix driving structure are successfully produced. It should be noted that the pixel pitch of display panel is an integer multiple of the device pitch of micro diode wafer. Here, display panels with a resolution of 80 × 120 and pixel pitch of 126.6 μm were carried out as shown in Fig. 2. All pixels in the same columns share the common anode, while all pixels in the same rows share the common cathode.

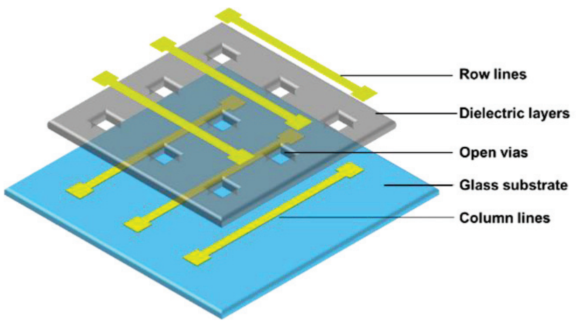

Fig. 1 Structural diagram of the glass-based display panel.

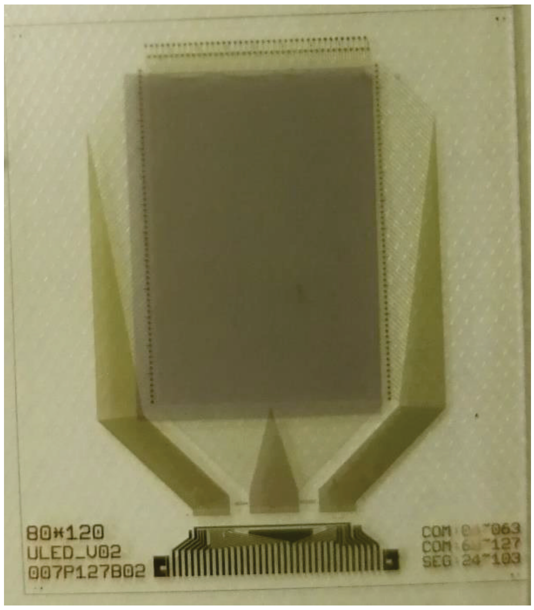

Fig. 2 Photographs of finished glass-based display panel.

2.3 Mass transfer

In this experiment, stamp technology using polymer material was utilized as solution of the issue of high accuracy pick and place process. PDMS stamps within specific protrusion pitch were used to grab micro diodes from the LED wafer within Van der Waals' force. Here the protrusion pitch of the stamp is the same as the pixel pitch of desired display panel which is an integer multiple of the device pitch of micro diode wafer. In addition, ACF bonding was used not only for driver IC but also for helping accomplish fixation and electricity connection between the transferred diodes and the target panel.

3 RESULTS & DISCUSSION

After finishing the preparation of the display panel and the mass transfer process, driver IC SSD1327 produced by Solomon Systech Limited was bonding onto the display panel and then the display panel was connected to a well-designed peripheral circuit module. As shown in Fig. 3, the display panel was lit up with a bad/dead pixel rate of nearly 20%, which should be considered due to process instability of the fabrication of the display panel and the process of mass transfer. The average value of the total serious resistance of each row line is 8 Ω, while the average value of the total serious resistance of each column line is 17.5 Ω, which did affect the uniformity of the screen. And as shown in Fig. 2, the transparency of the display panel has gotten lower because of the large-area residual ACF on the display panel which needs additional processing in the future.

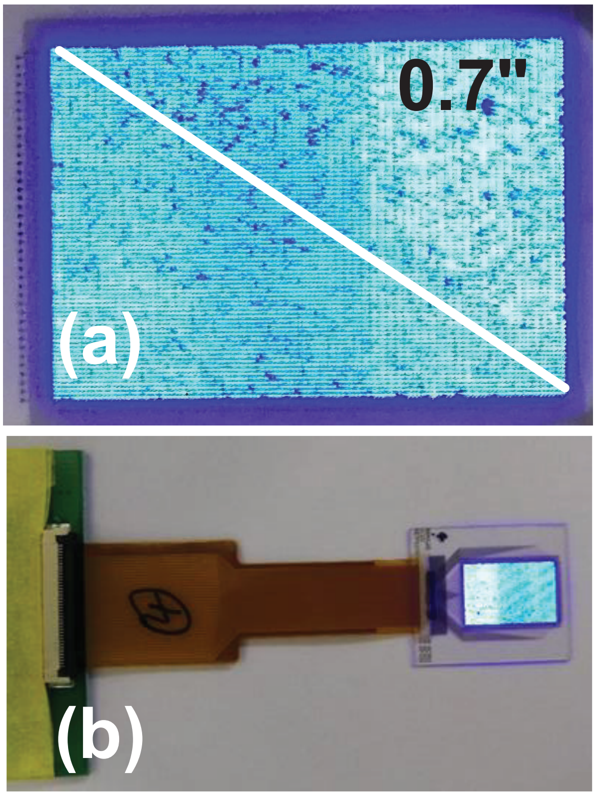

Fig. 3 Photographs of finished display device. (a) Working blue μ-LED display screen. (b) Working blue μ-LED displays connected to the peripheral circuit module.

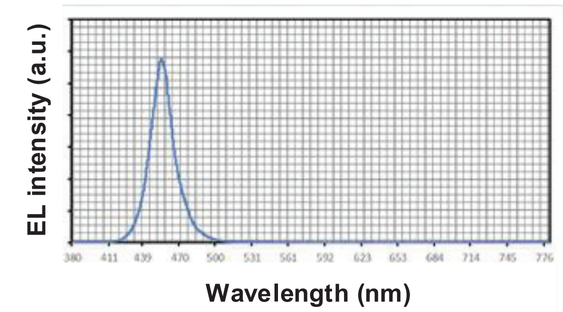

Fig. 4 EL spectrum measured from the fabricated device.

Fig. 4 shows the electroluminescence (EL) spectrum measured by focusing on the center of the screen within lighting up all of the workable pixels with a driving current of 300 μA. EL peaks can be find on the spectrum, where full width half maximum (FWHM) is 21.1 nm at 455 nm. In addition, luminance measured under this situation reached 131.1 cd/m^2.

4 CONCLUSIONS

We present some of our initial results of our research and development of glass-based μ-LED display using the mass transfer methodology in this paper. Prototype monochromatic blue passive matrix μ-LED displays based on glass substrates within a resolution of 80 × 120 were prepared. Micro diodes within a dimension of 15μm × 25μm were transferred onto the desired panel which was well prepared by using conventional semiconductor process on a glass substrate wafer. PDMS stamps combining with ACF bonding were utilized to accomplish the pick and place process. Although much remains to be improved, including the dead pixel rates, the transfer speed and accuracy, the transparency of the final device, etc, the approach in this paper provides feasibility of the new concept of HISID.

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