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ABSTRACT

As the next-generation display technology, microscale light-emitting diode (μ -LED) displays have attracted significant attention recently. For applying μ -LEDs as direct emissive pixels in everyday display applications, many chips in a relatively small-sized wafer must be relocated and distributed quickly over a wide screen area via so-called transfer technology. After a brief review of current conventional transfer technologies for placing μ -LEDs on a wide screen, for perspective, a new and versatile delivery technique for μ -LEDs is presented, in which an LED chip is converted to a ball shape in order to facilitate handling and processing of μ -LEDs for practical applications. Plausible procedures including the formation, arrangement, and removal of the plastic ball are discussed to envision potential impacts of the technology.

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INTRODUCTION

Light-emitting diodes (LEDs) fabricated from inorganic crystalline semiconductors are the most efficient, brightest, and longest-living light emitters available for displays.^{1,2} Inorganic LEDs are currently used as backlights for liquid crystal displays (LCDs)³ and as compact color pixels within large outdoor video displays.⁴ Interest in LED chips as direct light emitters in pixels of everyday displays, such as televisions (TVs), monitors, and even smartphones, is increasing, forecasting these devices as the next-generation display technology following LCDs and organic LED (OLED) displays.^{2,5} Along with the development of micro-LEDs (μ -LEDs, LED chips of dimensions one order of magnitude smaller than those of typical LED chips), inorganic LED-emissive TVs are expected to perform better than the current dominant display technologies. μ -LED panels using arrays of individual red/green/blue (R/G/B) devices of less than 100 μm in size can achieve resolutions of >2000 ppi with reduced power consumption and higher brightness and contrast.^{5,6} As examples, Samsung unveiled a 34-foot-wide cinema LED display in July 2017 and a 150-inch μ -LED TV called “The Wall” at the Consumer Electronics Show (CES) 2018 in Las Vegas,⁷ as shown in Figure 1. These demonstrated the Samsung’s focus on the future display

technologies after LED-backlit and quantum-dot LCD TVs. However, to realize a true LED TV (using inorganic LEDs as active emitting pixels, rather than as backlights), above all things, the manufacturing processes need to be refined to permit separation of the epitaxial layers of R/G/B LEDs from their substrates and the accurate en-masse transfer of them onto a receiver substrate (e.g., glass or flexible polymers) at speeds that can compete with existing LCD display processing. Methods to achieve such separation and relocation are called “transfer technology”.^{2,5,6} Although some notable transfer technologies have been developed for this purpose,^{8–10} their efficiency and performance remain in question relative to those of state-of-the-art LCD and OLED technologies. Here, the current technologies are briefly summarized with their pros and cons; as the perspective view, a new technology called “delivery technology” is proposed, which may provide a new display platform to facilitate the dominance of LED-based displays in the near future.

ABOUT THE TRANSFER TECHNOLOGY

First, μ -LED displays can be divided into two categories. The first are small-size screens for targeted virtual-reality (VR) and augmented-reality (AR) display applications.⁵ In this case, the screen

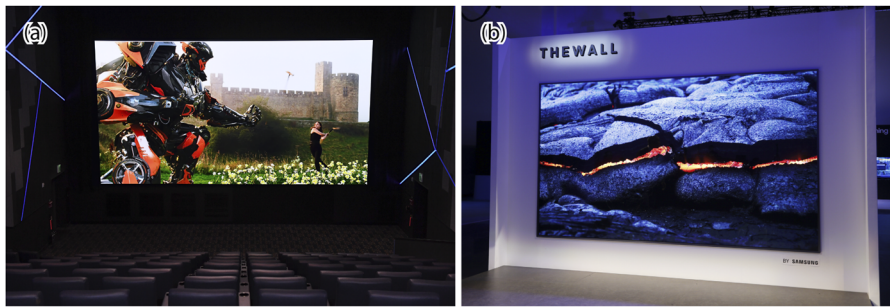


FIG. 1. (a) A 34-foot-wide cinema LED display by Samsung. (b) A 150-inch μ -LED TV, reproduced with permission from Samsung unveils “The Wall,” presented at the Consumer Electronics Show (CES) 2018 in Las Vegas. Copyright 2018 Samsung.

is located near the human eyes, equipped using glasses and head-mount devices. The arrayed LED chips fabricated on a wafer can be used as-is or simply transferred with the same dimensions to another substrate. Uniformity in performance among the LEDs on the wafer is the most important factor for these applications to avoid bad pixels in the display.^{5,6}

The other category, the focus of this article, is displays applicable to smartphone, monitor, and TV applications; they have larger screen surfaces than VR and AR displays. In these μ -LED displays, many chips in a relatively small-size wafer must be relocated and distributed over a wide screen area. Considering the size difference between a typical semiconductor wafer (2–6 inches in diameter) necessary for LED chip growth and fabrication and a typical TV screen (55 inches diagonally), an expansion of $>10\times$ in size is necessary to cover the whole screen; methods for achieving this are termed expansion transfer technology. However, expansion transfer is neither easy nor simple to achieve using current transfer technologies; above all, it is extremely time-consuming.

A simple and intuitive way to achieve this expansion transfer is known as a “pick-and-place” method, wherein a small vacuum chuck pulls a tiny chip, moves it to the desired position, and drops it by releasing the force on the chip.¹¹ This process works well and can be used to produce even a TV-sized display. However, the major inevitable disadvantage of this technology is the processing time required for display production. Considering the number of chips required for a display (approximately more than six million for full HD resolution), this is unlikely to be appropriate for the mass production of μ -LED TVs.

Another approach to speeding up the transfer process is to use transfer printing technology with elastomer stamps.^{8,12} During the transfer printing process, a glass stamp with a viscoelastic elastomer serves as a carrier to transfer arrays of chips from their native substrate onto the non-native destination substrates. The process exploits the rate-dependent and switchable adhesion between the device and elastomer to pick up and print arrays of μ -LED devices. In this technology, the relief structure on the stamp surface enables the deterministic dispersion of devices from dense arrays on the native substrate to sparse arrays on the destination substrates. Similarly, electrostatic stamps have been proposed for transfer, as shown in Figure 2.¹⁰ The process time of these technologies is faster than that with the pick-and-place method because multiple chips can be transferred simultaneously. However, they remain time-consuming, because the native substrate does not have the same dimensions as

the destination substrate (i.e., the display screen); a solution to this problem needs to be found.

ABOUT THE DELIVERY TECHNOLOGY

As mentioned previously, the technical difficulties of existing transfer technologies mainly arise from the poor processing capacity of very tiny slab-form LED chips. Previous techniques have simply transferred chips from a wafer to another substrate one-by-one or moved multiple chips at a time using chip grabbers. However, let us consider a similar process performed with spherical balls. More versatile and efficient methods for placing the balls in certain locations would become available. Once a small slab-shape LED chip is converted to a ball shape (termed “LED ball”), as illustrated in Figure 3, it can be easily stored in a bottle, dispersed in a solute before use in practical applications, and delivered to a substrate via spreading, distributing, and even printing. Furthermore, in this method, LED chips can be sorted and binned based on certain criteria before use; this method may therefore provide more reliable and uniform results than the pick-and-place and other methods, because these have very limited selectivity for bad LED chips during the transfer process. Next, we discuss how delivery technology incorporating LED ball formation can be realized for practical use.

First, the conversion of an LED chip to a plastic ball with a centered LED chip can be prepared by the dispersion

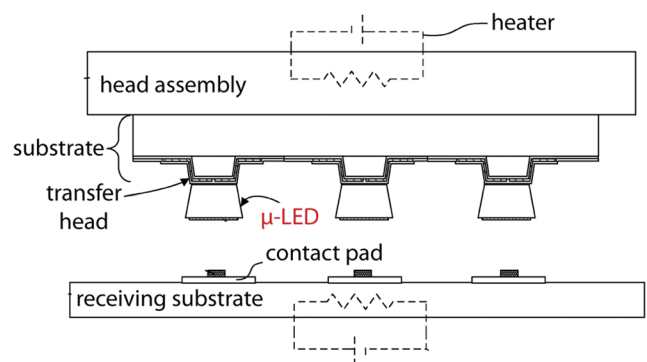


FIG. 2. LuxVue has developed a transfer technology that uses electrostatic forces to pick up μ -LEDs (adapted from Ref. 10).

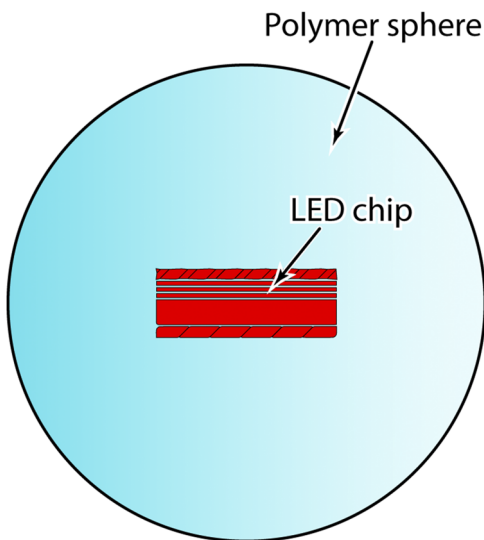


FIG. 3. A schematic of the polymer LED ball with an LED chip in the center.

polymerization process. Dispersion polymerization has been widely employed to prepare polymer spheres of regular size at the micro scale for various applications, such as toners, optical devices, and coatings.^{13,14} Furthermore, polymerization with a core of inorganic semiconductor material has been studied, showing the combination of organic and inorganic materials systems.^{15,16} Briefly, in the dispersion polymerization process for the LED balls, ternary systems comprising chips, monomers, and water are considered, where the μ -LED chip is encapsulated by monomers. Locating μ -LED chips in the center of the monomer droplets (e.g., acrylic monomers with a different polarity) during dispersion polymerization can be achieved by precisely manipulating the interfacial energies of the system;¹⁵ inappropriate size distributions can be minimized by optimizing the polymerization equipment and the processing variables such as baffles and agitators in the reactor. As an alternative method for ball formation, the polymer materials can be dispensed on spatially distributed LED chips. The optimization of the polymer's viscosity and the difference of surface energies between materials at the surface would allow the polymer drops to form a specific shape, such as a sphere. After a curing process for hardening, polymer balls with surface-located LEDs would be formed. Unlike the dispersion polymerization method, the LED chips would be located at the edge of the ball.

Secondly, for the arrangement of the LED ball dispersion, a sieving (printing) method can be considered as a potential method.¹⁷ The sieve (template) has holes at the required screen locations for the LED balls, and the LED balls easily roll to these locations, as schematically shown in Figure 4. The sieving is used to position the LED balls in the correct locations by applying the sieves. A dispersion can be formulated with additives in order to prevent the formation of voids, agglomeration, and thermal degradation on the screen surface. This arrangement process can be repeated for different R/G/B pixels using three different sieves. After the arrangement of the LED balls, the plastic balls fabricated during

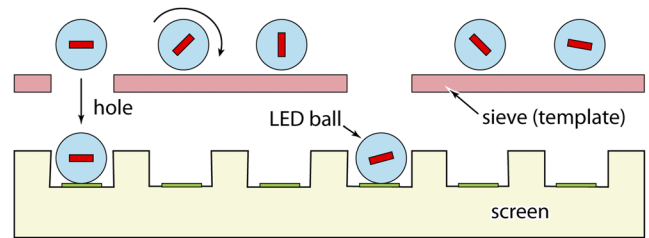


FIG. 4. The arrangement of the LED ball dispersion by a sieving (printing) method. The sieve has holes at the required screen locations for the LED balls, which easily roll to these locations.

the dispersion polymerization process can be removed completely. One potential removal process is depolymerization: the balls containing the polymer can be dissociated at moderate temperatures. For example, acrylic polymers are easily removed by depolymerization and decomposition into monomers at moderate temperatures such as below 300 °C; LED devices are not affected by thermal energy in this regime. Monomers with relatively low boiling points would be preferred for this process and acrylic copolymers are expected to have satisfactory depolymerization properties with no residues.¹⁸ Once the plastic polymer comprising the body of the LED balls is dissociated, only the LED chips positioned at the target locations of the screen would remain, as shown in Figure 5.

Finally, the electrode formation process is needed to allow LED operation by current injection. For vertical-type LEDs, row and column electrodes need to be prepared. First, a web-shaped row electrode could be formed on the screen substrate before the arrangement step described above. After arranging the LED balls and removing the polymers as aforementioned, only the LEDs would remain on the screen substrate at the designed intervals. After a proper electrical passivation process, a similar web-shaped column electrode could be formed on the LEDs using a conventional semiconductor process, thus providing top and bottom contacts for the operation of the vertical LEDs. With lateral-type LEDs, more consideration is necessary for the electrode design. An electrode structure that allows the cathode and anode of the LED chip to be connected in two different electrodes in each pixel can be considered. This description includes potential and plausible examples for the LED ball process; however, further modifications, replacements, and upgrades for the practical realization are necessary.

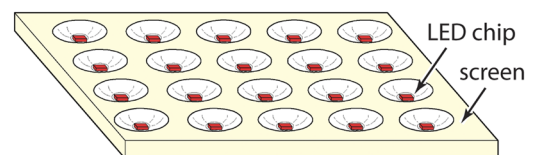


FIG. 5. LED chips positioned at the target locations of the screen remain after depolymerization.

CONCLUSION

As a perspective view, we proposed a versatile and efficient technique for placing μ -LEDs on a wide screen. Present state-of-the-art transfer technologies were briefly reviewed regarding their strengths and weaknesses. Alternatively, a delivery technology was proposed, in which the μ -LED chips could be converted to balls using plastic polymerization, enabling μ -LEDs to be easily stored in a bottle, dispersed in a solute before use, spread, distributed, and even printed onto a substrate. Unlike the conventional transfer technology, this delivery technology is expected to provide a faster and more productive method for producing LED displays. This approach is immature at this moment, but it is new, has not been tried, and potentially provides a platform for industrial fabrication. This technology may not only benefit display technology, but also further encourage new innovations in many other applications requiring the placement of LED chips.

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REFERENCES

- ¹J. Cho, J. H. Park, J. K. Kim, and E. F. Schubert, *Laser Photonics Rev.* **11**, 1600147 (2017).
- ²H. X. Jiang and J. Y. Lin, *Opt. Express* **21**, A475 (2013).
- ³M. Anandan, *J. Soc. Inf. Disp.* **16**, 287 (2008).
- ⁴H. Morkoç and S. N. Mohammad, *Science* **267**, 51 (1995).
- ⁵V. W. Lee, N. Twu, and I. Kyymissis, *Inf. Disp.* **32**(6), 16 (2016).
- ⁶T. Wu, C.-W. Sher, Y. Lin, C.-F. Lee, S. Liang, Y. Lu, S.-W. Huang Chen, W. Guo, H.-C. Kuo, and Z. Chen, *Appl. Sci.* **8**, 1557 (2018).
- ⁷Samsung unveils “The Wall” the world’s first modular micro LED 146-inch TV, Samsung Newsroom, 08 January 2018.
- ⁸M. A. Meitl, Z.-T. Zhu, V. Kumar, K. J. Lee, X. Feng, Y. Y. Huang, I. Adesida, R. G. Nuzzo, and J. A. Rogers, *Nat. Mater.* **5**, 33 (2006).
- ⁹S. H. Ahn and L. J. Guo, *ACS Nano* **3**, 2304 (2009).
- ¹⁰A. Bibl, J. A. Higginson, H.-H. Hu, and H.-F. S. Law, US Patent No. 9,773,750, 26 September 2017.
- ¹¹J. Kahler, N. Heuck, A. Stranz, A. Waag, and E. Peiner, *Compon. Packag. Manuf. Technol.* **2**, 199 (2012).
- ¹²A. Carlson, S. Wang, P. Elvikis, P. M. Ferreira, Y. Huang, and J. A. Rogers, *Adv. Funct. Mater.* **22**, 4476 (2012).
- ¹³R. Arshady, *Colloid Polym. Sci.* **270**, 717 (1992).
- ¹⁴S. Kawaguchi and K. Ito, *Adv. Polym. Sci.* **175**, 299 (2005).
- ¹⁵Z. Zhang, H. Shao, X. Zhou, L. Zhao, H. Liu, X. Ji, and H. Liu, *Mater. Chem. Phys.* **195**, 105 (2017).
- ¹⁶J.-C. Daigle and J. P. Claverie, *J. Nanomater.* **2008**, 1.
- ¹⁷T. Kraus, L. Malaquin, H. Schmid, W. Riess, N. D. Spencer, and H. Wolf, *Nat. Nanotechnol.* **2**, 570 (2007).
- ¹⁸C. Y. K. Lung and B. W. Darvell, *Dent. Mater.* **21**, 1119 (2005).