# Self-assembled RGB micro-LEDs

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Display technology is ubiquitous in our digital society. Smartphones, laptops, televisions, and even watches and wristbands based on organic light-emitting diodes (OLEDs) and liquid crystal displays (LCD) are indispensable to us. Nowadays, newly emerging display technologies are blossoming including quantum dot LEDs (QD-LED), micro-LEDs, micro-OLEDs, electronic ink displays, and laser display technology.[1]

Among them, OLEDs, QD-LEDs, and Micro-LEDs represent the advancing forms of self-emissive display technology. OLEDs show big advantages in contrast ratio, response time, and view angle compared to backlit LCDs. However, the stability of organic materials is still unable to compete with inorganic emitters, especially under a high brightness of tens of thousands of nits. Quantum dots can be designed to emit any color of light across the

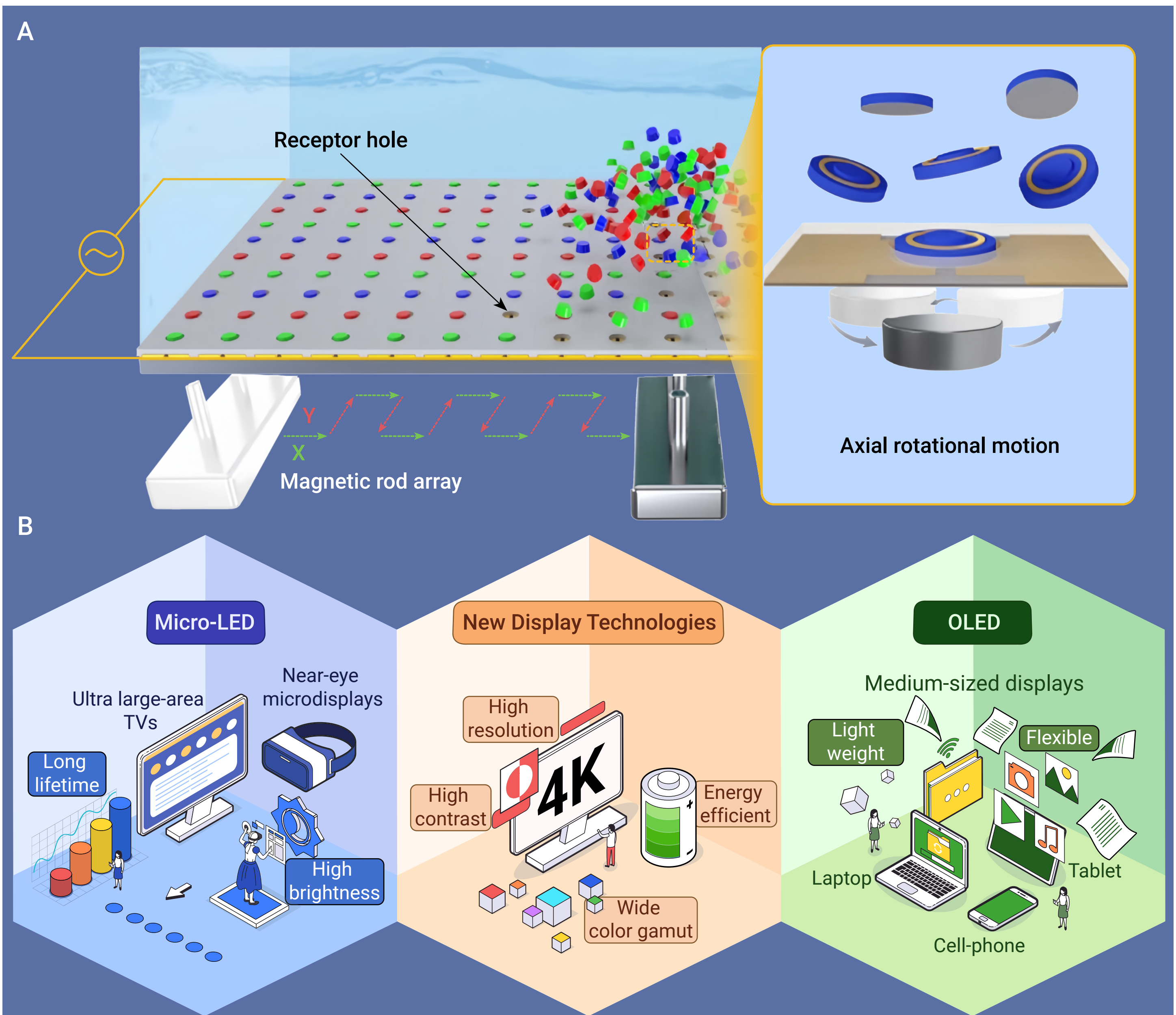


**Figure 1. Schematic diagram of MDSAT method and a comparison of Micro-LED and OLED technology** (A) Schematic of the fluidic system. An assembly substrate and the micro-LEDs are placed in a bath chamber and a cluster of micro-LEDs is formed by the axial rotational motions of magnets beneath the assembly substrate, as illustrated in the inset. The magnets move in the direction shown by the arrows while maintaining their axial rotational motions. Reproduced with permission from ref. 3, Springer Nature Ltd. (B) Requirements of new display technologies and the application scenarios of Micro-LED and OLED technology in the near future.

entire visible spectrum; thus QD-LEDs are capable of displaying a wider color gamut with higher brightness and they also have a low cost to manufacture by solution process. However, similar to OLEDs, the stability of quantum dot emitters must be solved before their market launch.

Micro-LEDs provide benefits in terms of extremely high brightness, wide color gamut, high resolution, and superb stability. Additionally, the small size of individual micro-LED emitters and the compact pixel pitches open up exciting possibilities for unique display applications such as near-to-eye technologies and sensor-integrated displays.[2] Apple, one of the leading developers of micro-LEDs, considered this next-generation display technology suitable for its various products and starts R&D projects in 2014. The commercialization of micro-LED technology is underway, while active research and development efforts are also being conducted for various applications, including large displays, virtual/augmented reality (VR/AR) devices, and body-worn smart displays. However, the cost of micro-LED displays is the decisive factor for commercialization due to the complicated production, especially mass transfer.

Mass transfer is the main approach to manufacturing large-scale micro-LED displays, which means a large amount of tiny LED chips must be transferred from the wafer to a substrate or backplane and assembled in a specific arrangement. Significant challenges persist in this technology, specifically about achieving high throughput, high yield, and scalable production up to Generation 10+ glass sizes measuring 2,940 × 3,370 mm.

One of the common approaches to realize mass transfer is fluidic self-assembly (FSA), which suffers from low transfer yield for large-scale displays and the lack of a solution for selective FSA of assembling LEDs with three primary colors (RGB). Overcoming these hurdles is crucial for micro-LED to penetrate the mainstream product markets and establish itself as a formidable competitor to LCDs and OLEDs.

Chang et al. from LG Electronics recently proposed the magnetic-force-assisted dielectrophoretic self-assembly technology (MDSAT) method, which simultaneously transfers RGB LEDs onto a large-area substrate at high speeds.[3] As shown in Figure 1A, the RGB LEDs are moved to receptor sites in a fluid by the magnetic force, and they are trapped and self-aligned within receptor sites by the dielectrophoresis (DEP) force, resulting in a promoted transfer yield than that of the previous FSA method.

Additionally, MDSAT is a scalable method that can accommodate different substrate sizes in the fabrication of displays. The magnet array will still cover the glass in the same amount of time even if its size is increased to equal that of the glass. As a result, neither the transfer area nor the number of receptor sites within the glass will have an impact on the assembly time. This starkly contrasts the stamp transfer method, where the processing time increases linearly with the transfer area. Specifically, the LED chips were transferred by embedding magnet-controllable nickel in it and applying a localized DEP force centered on the receptor site, so the micro-LED can be effectively grabbed and assembled at the receptor site. In addition, the simultaneous assembly of micro-LEDs with RGB primary colors was successfully realized by shape matching between micro-LEDs and receptors. A transfer yield of 99.99% was reached for RGB LEDs by improving the assembly condition, receptor design, and shape matching, which is sufficient to enable defect-free 4K-resolution displays when utilized in conjunction with redundancy pixel architecture. As a result, we believe MDSAT is an excellent micro-LED transfer method for the mass production of next-generation commercial devices.

In the foreseeable future, micro-LED displays may show potential advantages in small micro-displays such as smart watches, head-up displays (HUD), and AR devices, where high brightness and resolution are critical for visual performance in tiny places, near to the eye, or under fluctuating ambient lighting conditions (Figure 1B). Furthermore, due to their high brightness and small chip size, micro-LEDs exhibit a small aperture ratio, which means empty space in the display can be used to embed different sensors, greatly expanding the application range.

However, micro-LED still faces fierce competition from OLED technology. For example, the newly reported phosphor-assisted thermally activated delayed fluorophore (TADF)-sensitized fluorescence (p-TSF) can also realize ultrahigh brightness with excellent operational lifetime, unlocking the full potential of OLEDs.[4] The color purity and stability of OLEDs have been significantly improved with the development of TADF-sensitized fluorescence, known as hyperfluorescence. Until now, OLEDs also show great dominance in flexibility, a desirable feature for bendable, rollable, and foldable display applications, although the small-aperture micro-LED is theoretically the best candidate.

Bluntly, micro-LED adoption is doubtful in the near future in smartphone/tablet screens and television, the two biggest display markets. Both of them are commonly available in ultra-high-definition (UHD) resolutions based on LCD or OLED displays with high yields and technological maturity. In a word, these applications gain the least from the advantages that micro-LEDs provide. Televisions are often viewed indoors in controlled and lower-ambient lighting conditions, which are ideal for moderate LCD and OLED performance. Similarly, tablets and smartphones would only benefit modestly from micro-LED performance when used outside. Micro-LED manufacturing costs will need to plummet in both segments to compete with LCD and OLED panels, even for flagship products.

We believe that, with the improving device manufacturing technology represented by MDSAT, micro-LED displays will begin to service new industries and create new display formats for our daily life. Creating new demands beyond our imagination is the most exciting thing that micro-LEDs may provide.

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## DECLARATION OF INTERESTS

The authors declare no competing interests.