Micro LED Technologies for AR/VR Glasses: Display and Sensing

Yen-Hsiang Fang [1,*], **Cheng-Jhih Luo**[1], **Kai-Ling Liang**[1], **Chia-Hsin Chao**[1], **Chien-chung Lin**[1,2]

*email: YHFang@itri.org.tw
[1]Industrial Technology Research Institute, Hsinchu, Taiwan.
[2]Graduate Institute of Photonics and Optoelectronics, National Taiwan University, Taipei, Taiwan

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ABSTRACT

The present study contributes our efforts in the micro LED technologies for AR/VR applications. We demonstrate our recent achievement on full-color micro display and sensor array for eye-tracking based on micro LEDs. By combining these sub-systems, it has potential for enhancing the experiences in the usage of AR/VR glasses.

1 Introduction

It has been known that micro light-emitting diode (μLED) is considered as the crucial technology for augmented reality/virtual reality (AR/VR) applications because of its fine-pitch and high emission efficiency that are beneficial for high PPI and brightness operations. According to the XR industry survey report in 2019, there are three major requirements or functions for establishing good user experiences in the AR/VR head mounted display (HMD), which respectively are HMD comfort, field of view (FOV) and eye-tracking technique. In other words, these requirements imply that the future HMD needs to be slim with wide FOV and eye-tracking interaction features. Generally speaking, one can consider a HMD system as the combination of several sub-systems as shown in Fig. 1, and the integration complexity between these sub-systems plays an important role for the form factor of the HMD, which can affect the user comfort as described above.

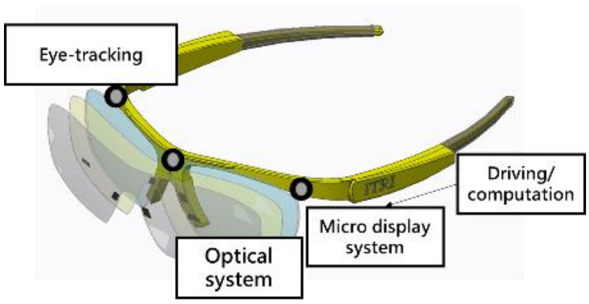

Fig. 1 The illustration of hardware system structure for AR/VR HMD.

In the micro display system, the high pixel per inch (PPI) and brightness are important factors for fulfilling the wide FOV projection, and one promising solution is to construct the micro display by μ LED with color conversion method. Different from the direct mass-transfer of red, green and blue LED chips to the designated display, the color converted technique requires a layer of color absorption and re-emission substances and using a single color array of μLEDs (usually blue color) to pump this layer. Through the absorption and re-emission process, it is possible to realize full-color demonstration without mass transfer and thus we can overcome the difficulties of moving small chips in the other method. Colloidal quantum dots (CQDs) are often considered as the suitable candidate for this role because of their wide range of color emission and narrow linewidth of emission spectrum, which can provide purer colors. With this capability, one can concentrate on the processes of monochromatic micro LED array using advanced semiconductor fabrication technologies and higher PPI can be realized with much fine-pitch for the micro display system [1, 2].

For the eye-tracking system in the AR/VR goggles, there have been plenty of studies by image capturing. Based on this scheme, one can detects the eye-features by capturing the eye images in real-time through the cameras. The common eye-features include pupil center, corneal reflection or Purkinje images. The gaze reconstruction algorithm can be set up through these eye-features such as establishing 3D eye-ball model or regression approaches [3, 4]. The image based eye-tracking method provides very good performance in the accuracy (up to < 1°,) however, the structure complexity and power consumption of the image-based eye-tracker increases the difficulty of integration on AR/VR HMD. Instead of image capturing, some researchers also focus on sensor type eye-tracking that simply utilizes a few sensors such as photodiode (PD) or electrical capacitors to obtain the eye-ball movement information. And the gaze point can be reconstructed by these sensor signals through a robust algorithm [5]. This sensor-based eye-tracker provides another simpler platform for the integration between eye-tracking and AR/VR HMD. Dependent on the applications, the image-based and sensor-based eye-tracker own unique properties and advantages quite differently.

In the present study, we report our recent progresses on the AR/VR HMD systems through μLEDs. A full-color micro display with quantum dot (QD) color conversion is demonstrated for the micro display system and a visual transparent micro LED sensor array for the eye-tracking purpose is described in detail. A novel conceptual integration method for these sub-HMD systems is proposed based on μ LEDs, the integration concept exhibits great potential for reducing the complexity of HMD hardware.

2 Full-color micro display for AR/VR

The demand of micro LED technology for the next generation AR/VR display is due to its high brightness, high power efficiency and high reliability. Compare to OLED now with 35,000 nits as the highest brightness, the green micro-LED arrays of 5000 ppi and 5 μm pixel size can reach 3,000,000 nits of brightness. These properties bring a clear view to outdoor or transparent devices as well as power saving.

To manufacture a high resolution full-color micro display for AR/VR HMD, the display with a sub-pixel size smaller than 5 μm is expected, and as mentioned before, the color conversion method is a popular technique [6] due to the difficulties in the process of mass transfer. As shown in Fig. 2, the color conversion layer method can greatly simplify the mass-transfer step and use the pre-formed QD arrays that can provide red and green colors for further integration. With this structure, the decreasing efficiency and dropping yield problems of small size red micro-LED under 5 μm can be solved. Also, the long processing time and position shifting of mass transfer can be avoided. A result of full-color μ LED display fabricated with color conversion method is show in Fig.3 with 992 PPI, sub-pixel pitch of 12.7 μm and size of 10 μm.

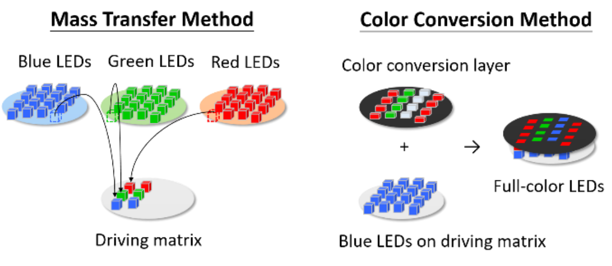

Fig. 2 Full-color micro-LED fabrication: mass transfer and color conversion method

Here we demonstrate a full-color μLED display with color conversion method, as shown in Fig.3. Each pixel size of QD pattern is 12.7 μm of pitch and 10 μm of size. The QD patterns were fabricated with QD photoresist through photolithography process. Since the color conversion performance is now limit by QD material and the thickness of QD photoresist pattern, a layer of color filter photoresist was applied to sieve the excess blue emitting light and increase the color purity of the panel.

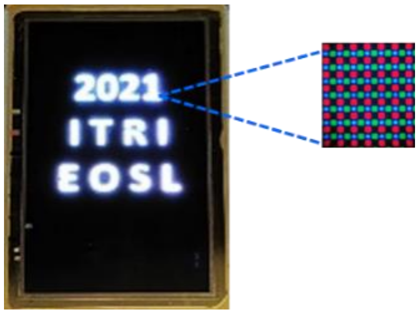

Fig. 3 The demonstration of a full-color micro-LED display

3 Micro sensor array for near-eye detection

In the following section, we qualitatively describe our proposed scheme for a novel eye-tracking method based on the micro sensor array. The micro sensor array is composed of dense μLEDs on a transparent substrate, which act as illuminators and sensors. By the micro-assembly technique, one can transfer μLEDs from wafer to transparent circuit substrate. The substrate could be a glass film or flexible material such as Polyimide for some particular applications. Fig. 4 shows the illustration of our proposed micro sensor array for AR/VR HMD applications. The sensor array glass film can finely attached on the lens, waveguide combiner, glasses or others optical system with proper anti-reflection coating and precisely lamination [7]. The μLEDs are periodically distributed on the glass substrate with proper allocation. Basically, the micro sensor array film is set to be visual transparent in the near eye. The dimension of the sensor array glass is set to cover all the eye-box and the illumination/sensing wavelength is around 950 nm, which is in infrared (IR) region. One can avoid cross-talk with others light that in the visible region and the humans are also insensitive to IR illumination.

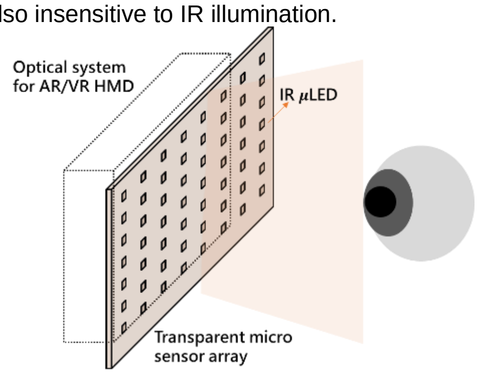

Fig. 4 The illustration of micro LED sensor array.

On the substrate, the μ LEDs are acting as both illuminators and sensors by manipulating the driving circuit. It is already well-known that LEDs can be emitters under forward bias and be photodetectors with reversed-bias through configuring LEDs as variable electrical capacitors. As shown in Fig. 5, by controlling the time sequence of the circuit, one can sense the reflected IR light from the eye that illuminated. If the reflected light is weak or LED size is further reduced, the longer exposure time is needed for integrating sensor signals. Consequently, we optimize the circuit parameters and design for the lowest latency and best detection sensitivity due to the signals detected from micro LEDs are usually very small.

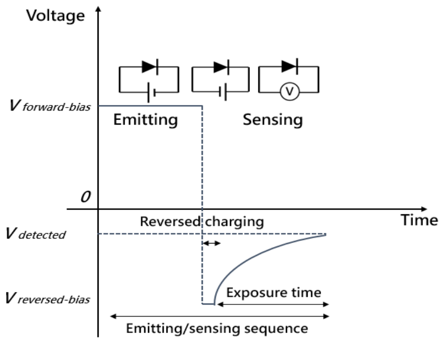

Fig. 5 The illustration of time sequence for manipulating micro LED as sensor

In addition to the electrical properties, the optical properties of micro LEDs also affect the sensing performance and the integration on AR/VR HMD. In general, μLEDs emit lights with Lambertian distribution without secondary optics, which is relatively large angle. Same as the sensing mode, the large sensing angle causes the spatial cross-talk between micro LEDs and decreases the spatial resolution of the sensor array. To prevent this, it is better for optimizing the allocation of the sensors and even considering the secondary optics for the micro LED in the package process. The major reason for choosing micro LED as sensor is that the size of micro LED is small enough for maintaining the transparency of the sensor array, which is important for fulfilling practical applications and hard to be implemented by conventional sensors. Utilizing small size micro LED as sensor also avoids the additional light scattering that destroy the precisely optical engine of AR/VR system in near-eye applications. Fig. 6 shows the transparency of the sensor film as a function of micro LED size with 0.1 mm sensor pitch.

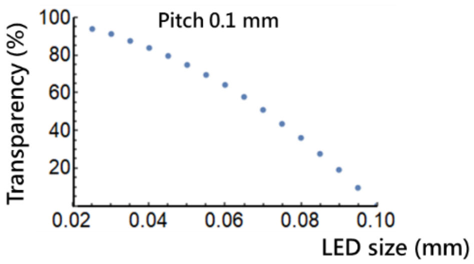

Fig. 6 The transparency versus to micro LED size of sensor array film with 0.1 mm sensor pitch.

The Fig. 7 shows the work flow of the micro sensor array-based eye-tracking system. Since sensor array deals with fewer data compare with images, the latency of the eye-tracker is much reduced. For our prototype, the latency can be smaller than 5 ms. We believe the proposed simple eye-tracking system could be useful in AR/VR HMD with much stronger gaze-finding algorithm. The proper choices include Gaussian process regression (GPR), support-vector machine (SVM), convolutional- neural network (CNN) or others machine learning- based computation [8].

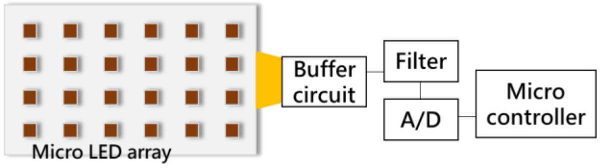

Fig. 7 The illustration of eye-tracking system by micro sensor array. A/D: analog-digital convertor

4 Conclusions

In the present study, the recent progresses of our full-color micro display with quantum dot color conversion is demonstrated and a visual transparent micro sensor array for eye-tracking purpose is described in detail. A QD based full color micro display is demonstrated with 992 PPI, sub-pixel pitch of 12.7 μm and size of 10 μm. The novel method for implementation of eye-tracking system is implemented by μLEDs as sensors in IR wavelength band. The proposed micro sensor array provides good transparency for the vision. Moreover, the latency and power consumption is much lower for the eye-tracking purpose compare with conventional video - based eye-tracker. It should be useful for reducing the structure complexity of AR/VR HMD as well as to enhancing the user experiences in these HMDs.

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