Micro Sensor Array for Eye-Tracking Application based on Mini/Micro Light-Emitting Diodes

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ABSTRACT

The present study contributes to our recent efforts in the Human-machine interface based on mini/micro-LED technologies. By operating mini/micro-LED as light sensors, we demonstrate a sensor array type glass *capable of gaze sensing at a high rate. It has the potential enhancing experiences for HMD.*

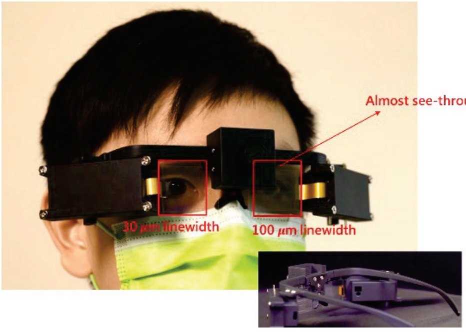
1 Introduction

Modern head mount displays (HMDs) commonly integrate various type of sensors in the system for providing better user experiences and immersive environment. These sensors detect user's body movement, head motion, head orientation and even bio-information, and they are regarded as the inner detectors for HMDs. With the improvement of compactness for HMD devices recently, the embedded sensors are also required to be more compact with efficient operation that can save power and speed up the HMD system. In fact, the 2019 XR industry survey reports that there are three major requirements for providing good user experiences in the HMD for the applications of augmented and virtual reality (AR/VR). They are HMD comfort, field of view (FOV) and eye-tracking technique. In other words, these requirements imply that the modern HMD needs to be slim with very good immersive experiences and one potential solution is to provide user's behavior detection by optical sensors for better Human machine interaction (HMI). In the present study, we demonstrate our recent progresses for HMI based on mini/micro LED technologies. By operating mini/micro LED as light sensors, a novel sensor array glass is built for the eye-tracking purpose. The ability to see through via a transparent glass make it suitable for AR/VR applications. Using gaze as an input modality is an intuitive and efficient way in HMDs, gaze information also makes the projected content of HMDs vivid and colorful, which can help to improve the user's feeling and experience with this device. To solve the notorious vergence-accommodation conflict (VAC) problem, our device must handle the information about the gaze depth and the eyes' vergence properly such that the subsequent image processing techniques like light-field can produce a correct projection. To achieve this, a good eye-tracking system must be implemented in our goggles.

Generally speaking, the non-invasive/contactless eye-tracking methodologies can be categorized into video-based method and optically sensor-based method. One can detect the eye-features by capturing the eye images in real-time through the cameras in video-based eye-tracking. The common eye-features include pupil center, corneal reflection or Purkinje images. The gaze line can be set up through eye-features by establishing 3D eye-ball model and the cameras are needed to be calibrated carefully for determining the intrinsic and extrinsic parameters. With the proper setting of cameras and illuminators, the video based eye-tracking method provides very good performance in the accuracy (finer than 1°) and precision [1]. However, the structural complexity and power consumption of the video-based eye-tracker increases the difficulty of integration on AR/VR HMD.

Instead of image capturing, some researchers also focus on optically sensor-based eye-tracking that utilizes a few optical sensors such as photodiodes (PDs) to obtain the eye-ball movement information. These optical sensors are set to closely surround the eye-balls at a centimeter distance to detect the reflected lights from the eyes. When the eye-ball movement occurs, the detected sensor signals change simultaneously. The spatial offset and time multiplexing between the optical sensors determine the eye-ball movement resolutions and the gaze point can be reconstructed by these signals through a robust algorithm such as mapping function or regression methods [2, 3]. This sensor-based eye-tracker provides another more straightforward platform for integrating eye-tracking and HMDs. Depending on the applications, the image-based and sensor-based eye-tracker have unique properties and advantages quite differently.

2 Micro sensor array glass



In the following section, we describe our proposed array glass, which should be suitable for eye-tracking application. As shown in Fig.1, the micro sensor array comprises several mini/micro LEDs on a transparent substrate, which act as illuminators and sensors simultaneously. One can transfer smaller LEDs from a wafer to a transparent circuit substrate through the micro-assembly technique. Depending on the dimension of LEDs, the flip-chip bonding or wire bonding can be applied for micro-LED, or mini LED devices, respectively. The glass circuit is designed as a passive circuit deployed by thin metal lines or ITO lines for increasing see-through capability. The optically non-sequential ray-tracing simulation is conducted for verification of the optical transparency of glass. The substrate could be a glass film or flexible material such as Polyimide for some particular applications.

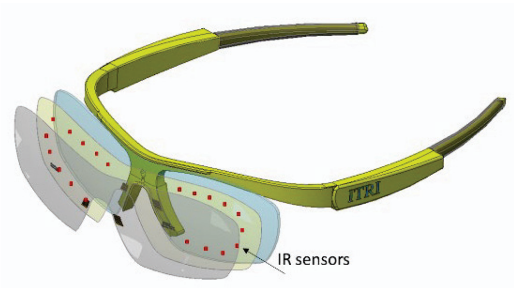


Fig. 2 shows the illustration of our proposed micro sensor array glass integrated into HMD applications. The micro sensor array can be attached to the target glasses with an integrated lens, waveguide combiner, or other optical components [4]. The mini/micro LEDs are periodically distributed on the glass substrate with proper allocation. The pitch of mini/micro LEDs is an important parameter to detect the reflected lights from different orientations and spatial positions for maintaining the signal spatial resolution. The sensor array film is visually 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 the infrared (IR) region. Because of this specific wavelength we adapted, one can avoid cross-talk by the strong ambient photons in visible range, and humans are also insensitive to IR illumination.

3 Infrared Micro LED

For our proposed micro sensor array glass, the mini/micro LED properties significantly influence the sensor system performance. In this section, we characterize our home-build IR micro-LED chips.

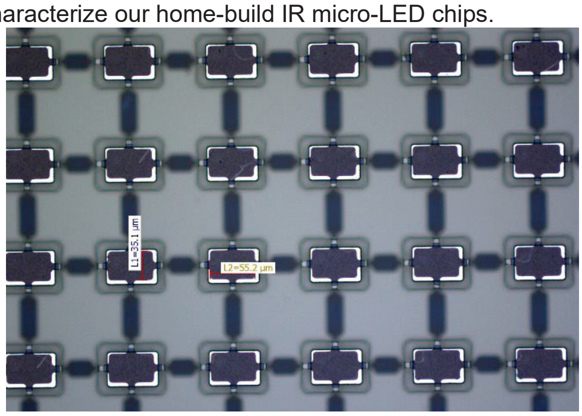
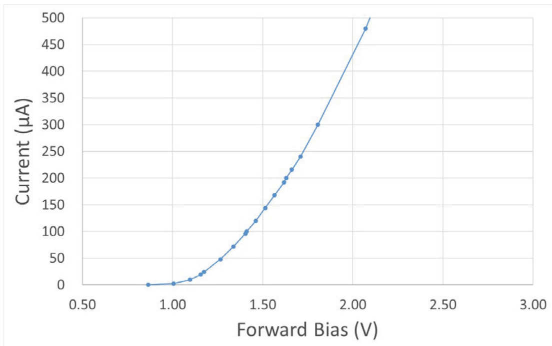
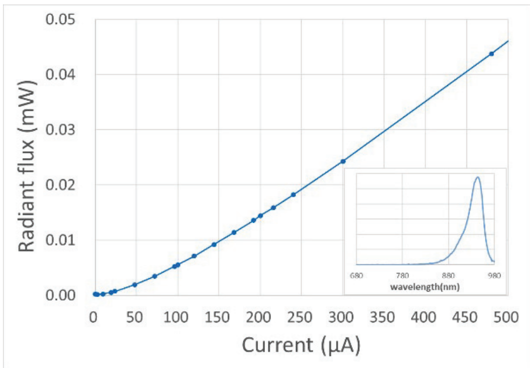
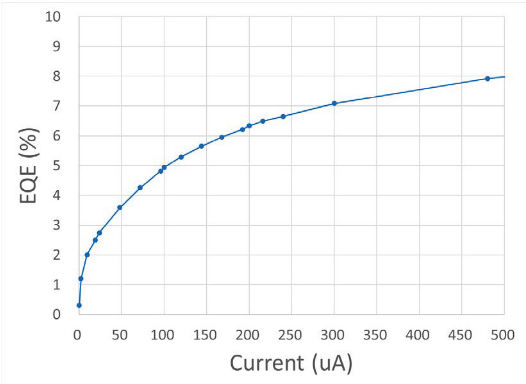


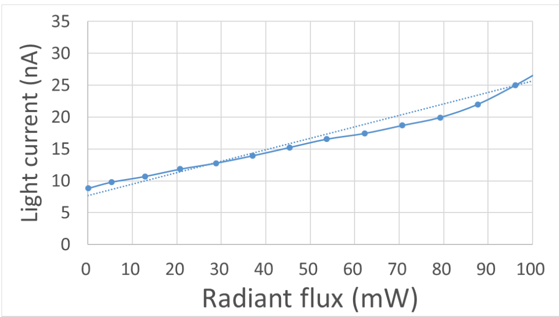
Fig. 3 indicates the optical microscopic image of our Micro-LED on the wafer after tether process. The micro-LED chip size is 60 x 40 μm^2 and are made of GaAs/AlGaAs based materials. To transfer these chips onto a different substrate, a semiconductor-based process called the “tether process” was developed in our lab to achieve this goal. After the tethering process is finished, the IR micro LEDs are first relocated on a temporary carrier and the chip is flipped on this carrier. Secondly, the IR micro LEDs are picked up and transferred to the test board for electrical and optical measurements. Fig. 4 is the measured I-V curve for the IR chip, and Fig. 5 shows the radiant flux. The inset of the Fig. 5 indicates the optical spectrum. The calculated external quantum efficiency (EQE) is plotted in Fig. 6.





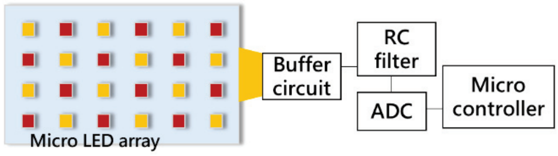


Next, we measure the properties of IR micro LEDs as light sensors. We directly illuminate the IR micro LEDs with IR light source and measure the generated light current under the zero-bias condition for designing the sensor circuit. Fig. 7 shows the photo-generated current measurement as a function of illuminated power. The estimated responsivity at near 940 nm wavelength is 0.12 nA/mW, which is small compared to the conventional PD because it is much smaller. In the following, we will demonstrate how our detection and eye-tracking system can deal with such a small signal.



4 Gaze sensing system

Fig. 8 indicates the system block diagram of a microsensor array eye-tracking module. The sensor data is collected from IR mini/micro LEDs via amplifier buffer and ADC circuits. Due to the tiny received signal, as shown in the Fig. 7, it is necessary to design the sensor buffer circuit and sensor channel very carefully to reduce the noise problems. Although the signal difference was minimal when the eye-ball was rolling in the eye-tracking experiments, the differences in light current levels could be visible so that the gaze reconstruction model could be set up. To enhance the agility of the detection system, the gaze reconstruction algorithm is a critical component for further optimization. We use Gaussian process regression to develop the gaze reconstruction and collect a large amount of training data under the fixed experimental environment with different gaze angles. Since the sensor array deals with fewer data than image capturing, the latency of the eye-tracker is much reduced when the real- time operation is free running.



5 Conclusions

We demonstrate our recent progress on micro sensor array glass. We utilize mini/micro LEDs as sensors and illuminators at the same time to successfully detect the ball movement. The Gaussian regression process is applied to train the collected sensor data to build a robust gaze-finding algorithm. The detailed IR micro-LED and system block diagram are characterized. We believe the current micro sensor array glass will be helpful for the applications of HMI wearable devices.

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