High Bandwidth Semipolar (20-21) µ-LED Serving as Photo-Receiver for Visible Light Communication

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Abstract *We propose and demonstrate a semipolar (20-21) green micro-light-emitting-diode (µ-LED) acting as high-speed photo-receiver for visible-light-communication (VLC). 300-Mbit/s green optical signal detection at free-space transmission distance of 125 cm is demonstrated using on-off-keying (OOK) format, fulfilling pre-forward error correction (FEC) threshold.*

Introduction

Recently, indium gallium nitride / gallium nitride (InGaN/GaN) based micro-light emitting diode (µ-LED) has received considerable attention in display technology due to the high efficiency, high brightness and high reliability over traditional display technologies. Besides, due to the low power consumption and long lifetime, LED is gradually replacing the traditional lighting devices for both indoor and outdoor applications. In addition, LED also allows the implementation of visible light communication (VLC), which can combine lighting and communication simultaneously [1, 2]. The license-free, electromagnetic interference (EMI) free and highly directional transmission merits also enable VLC to be an emerging complementary technology for future wireless communications. However, VLC system based on typical LED has difficulty to support Gbit/s transmission due to the low intrinsic modulation bandwidth of the LED. Several approaches, such as using digital equalizations, or spectral efficient modulation formats [3, 4] have been proposed to increase the transmission data rate. Apart from these approaches, increasing the intrinsic modulation bandwidth of the LED is important. This can be realized by reducing the chip size; hence smaller capacitance and higher current density can be achieved. Hence, µ-LED can be a potential candidate for high speed VLC. Recently, ~1 Gbit/s VLC system based on violet µ-LED array and on-off-keying (OOK) was demonstrated [5]. Moreover, 11.95 Gbit/s high speed VLC using GaN-based violet µ-LED with transmission distance of 27.5 cm was also reported [6]. Furthermore, 1.5 Gbit/s OOK VLC transmission based on InGaN/GaN semipolar (20-21) green µ-LED was also achieved [7].

Besides acting as an optical transmitter (Tx), it would be interesting to use the µ-LED as a photo-receiver (Rx). This comes up with a concept of smart µ-LED display, which can provide the functions of information display, VLC Tx and VLC receiver (Rx) simultaneously. The idea of using the µ-LEDs as Tx and Rx providing uplink and downlink transmission is illustrated in Fig. 1. In the literature, employing µ-LED as photo-Rx has been barely studied. The µ-LED acts as the VLC Tx, Rx or TRx using time-multiplexing can reduce the implementation cost of VLC and packaging complexity. Due to the different bandgaps of different color µ-LEDs, bandpass optical filter for wavelength multiplexing VLC is not necessary.

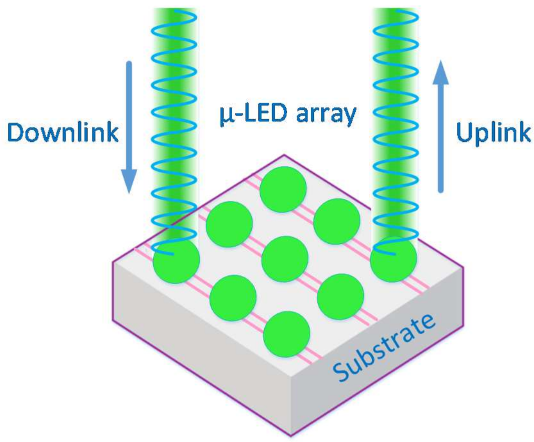

Fig. 1: Idea of using the µ-LEDs as Tx and Rx providing uplink and downlink transmission.

In this work, we propose and demonstrate for the first time up to the authors' knowledge, a semipolar (20-21) green µ-LED acting as high speed VLC photo-Rx. 300 Mbit/s green optical signal detection at a free-space transmission distance of 125 cm is demonstrated using OOK

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format, fulfilling the pre-forward error correction (FEC) limit (bit-error-ratio, BER = 3.8 × 10^{-3}). The result reported here offers much higher detection data rate than that reported in the literatures [8-10].

Device Architecture and Experiment

Fig. 2(a) shows the experiment of the proposed semipolar (20-21) green μ-LED as high speed VLC photo-Rx. An pulse pattern generator (PPG, Anritsu® MP1763C) was employed to generate the pseudorandom binary sequence (PRBS) data to drive a green LD (Thorlabs® PL520) via a bias-tee circuit. The LD has a peak wavelength of 522 nm and is modulated in OOK format. The optical signal is detected by the proposed semipolar green μ-LED photo-Rx after a 120 cm free-space transmission distance. A pair of lenses was used for focusing. The μ-LED photo-Rx is connected to a real-time oscilloscope (RTO, Tektronix® DPO7354C) via a radio-frequency (RF) amplifier (HP® 8447D) for signal amplification. Fig. 2(b) shows the photo of VLC experimental setup.

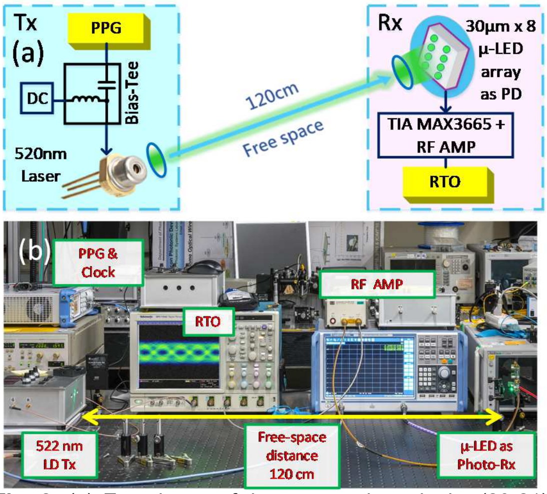

Fig. 2: (a) Experiment of the proposed semipolar (20-21) green μ-LED as high speed VLC photo-Rx. (b) Photo of VLC experimental setup.

Fig. 3(a) illustrates the structure of our developed semipolar green μ-LED photo-Rx. It is worth to mention that this device is optimized for light emitting as reported in our previous study [7], and here, we use the same device for photo-detection. The LED grown on nonpolar or semipolar orientations could offer higher modulation bandwidth due to a larger overlap of electron-hole wavefunction with shortened carrier lifetimes [7]. Besides, lower efficiency droop due to a higher percentage of radiative to Auger recombination will result [11]. In the proposed μ-LED, epitaxial growth of semipolar (20−21) GaN on a (22−43) pattern sapphire substrate (PSS) is carried out via low-pressure metal organic chemical vapor deposition (MOCVD). Here, the PSS is made by inductively coupled plasma reactive-ion etching (ICP-RIE). After this, semipolar (20−21) GaN is grown. An un-doped GaN is grown introducing in a bulk layer with thickness of 10 μm. It is then planarized by chemical-mechanical planarization to form a flat surface. As shown in Fig. 3(a), the device has a 1.5 μm n-type GaN, followed by an active region of three pairs of InGaN/GaN multiple quantum wells (MQWs), and a 100 nm p-type GaN layer. Then, an indium tin oxide (ITO) with thickness of 200 nm is deposited. HCl and ICP-RIE are used to etch the ITO film and a 1 μm depth mesa. Annealing at 450°C by rapid thermal process was performed to produce a p-type ohmic contact. Then, titanium/aluminum/titanium/gold (Ti/Al/Ti/Au) having 20/150/10/100 nm thickness are deposited as the electrodes. 30 nm aluminum oxide (Al_2O_3) passivation layer and 200 nm silicon dioxide (SiO_2) layer are grown. After this, titanium/aluminum/nickel/gold (Ti/Al/Ni/Au) is deposited as sidewall reflectors and metal pads. At last, at the back side of the device, a distributed Bragg reflector (DBR) is deposited. Figs. 3(b) and (c) show the photos of the μ-LED photo-Rx array mounted on a TO-package at different magnifications.

Results and Discussion

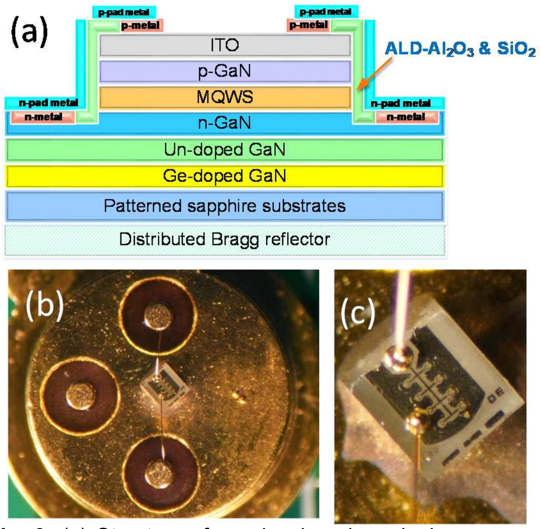

Fig. 3: (a) Structure of our developed semipolar green μ-LED photo-Rx. (b), (c) Photos of the μ-LED photo-Rx array mounted on a TO-package at different magnifications.

Fig. 4(a) shows the measured frequency responses of μ-LED photo-Rx at different biases. The frequency responses are measured by a vector network analyzer (VNA, Rohde & Schwarz® ZND). We can observe that the 3-dB bandwidth is 111 MHz and 170 MHz at bias voltage of 3.3 V and 5 V respectively.

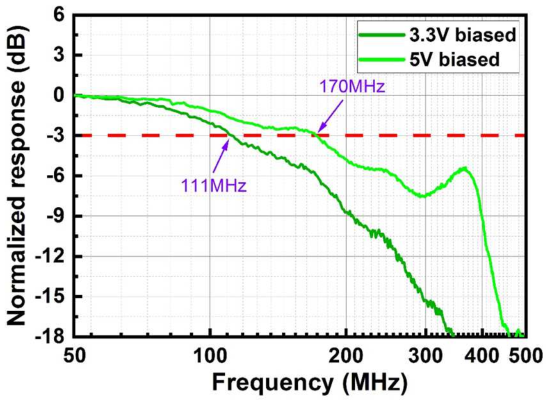

Fig. 4: Measured frequency responses of μ-LED photo-Rx at different biases.

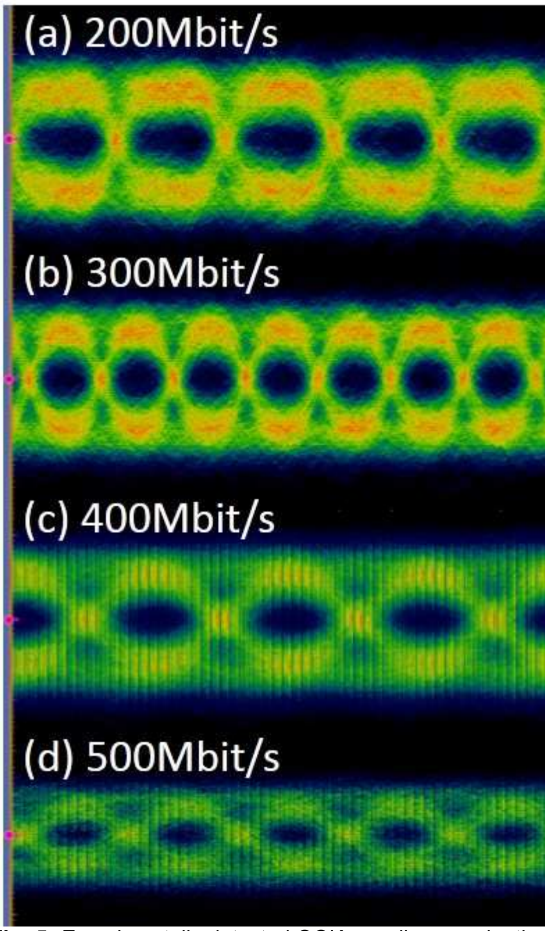

Fig. 5: Experimentally detected OOK eye-diagrams by the μ-LED photo-Rx at different data rates from (a)-(d) 200 Mbit/s to 500 Mbit/s.

Figs 5(a)-(d) show the experimentally detected OOK eye-diagrams by the μ-LED photo-Rx at different data rates from 200 Mbit/s to 500 Mbit/s. We can observe that clear OOK eye-diagrams can be observed at data rates of 200 Mbit/s and 300 Mbit/s with measured Q values of 3.375 and 3.333 respectively, corresponding to the BER of 3.97×10^{-4} and 4.63×10^{-4}), satisfying the 7% pre-FEC requirement. When the data rates are increased to 400 Mbit/s and 500 Mbit/s, the BERs are increased to 4.85×10^{-3} and 1.76×10^{-2}, respectively, and do not meet the FEC threshould. The BER measurement results of the μ-LED photo-Rx also agree with the frequency response measured by the VNA with the 3-dB bandwidth of 170 MHz.

Conclusions

We proposed and demonstrated a semipolar (20-21) green μ-LED acting as high speed VLC photo-Rx. 300 Mbit/s green optical signal detection at a free-space transmission distance of 125 cm was demonstrated using OOK format, satisfying the FEC requirement. The measured 3-dB bandwidth was 170 MHz at 5 V bias.

Acknowledgements

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