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A Novel Approach for Underwater Optical Wireless Communication Using Micro LEDs

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Abstract

Underwater wireless communication has many fold applications including oceanography, seashore oil well exploration, researches in sea water living organs and so on. In this paper we have proposed a high-speed underwater optical wireless communication (UOWC) using 80 μm blue-emitting GaN-based micro-LEDs. We have obtained 100 Mb/s data communication speed with areceived light output power of -- 40 dBm and a BER of 1.9 × 10−3, suggesting that UOWCwith extended distance can be achieved. Our experimental results illustrated that a 200 Mb/s data rate with aBER of 3.0 × 10−6 at an underwater distance of 5.4 m.

Keywords: *UOWC, Wireless communication, micro LEDs, Visible Light Communications (VLC)*

1. Introduction

Nowadays an increased thrust for higher bandwidth wireless communication, that facilitates faster and secure data transmission. Telecommunication industry presently relies on Radio Frequency (RF) for data transmission. However, the RF spectrum has certain limitations: Capacity, Efficiency, Availability and Security. So, we need find an alternate solution and one such solution is based on Light Emitting Diodes (LEDs) that offers in the transmission of data much faster and reliable than the data that can be transmitted through Wi-Fi. In Li-Fi communication system visible light is used as a carrier signal instead of conventional RF [1]. Underwater communication can be considered to be a vital tool for Oceanography investigations, sea floor monitoring, oil exploration inside sea require high speed data communication, especially for real-time video communication. Optical communication has high bandwidth but is strongly affected by the water absorption and suspended particles scattering. However, the water dilution is relatively small in the blue-green spectrum region, thus making blue emitting GaN-based LEDs or lasers will be suitable optical data communication forunderwater optical wireless communication (UOWC) [2–7].The exterior quantum efficiencies of blue gallium nitride GaN-based LEDs have improved very much in the past two decades and widely used in general lighting [8], which make the recent development of visible light communication (VLC) , also known as LiFi [9–

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11].Researchers found that micro-LEDs with pixel sizes of tens of μms had high modulation bandwidth up to severalhundreds of MHz [10,11],An added advantage of VLC is that VLC systems can provide secure data communication over short distances than RF or microwave communications devices whose signals can be easily detected by the intruders.In this paper we propose a technique using blue emitting micro LEDs for under water communication. We demonstrated the performance of this work using a prototype model.

2. Literature Review

Wireless communication is playing a vital role in the recent developments. Modern inventions and sophisticated applications have been enabled by various forms of wireless communication standards. In [12] the authors explained the use of wireless communication in the UOWC. In [13] the authors have demonstrated a 2.5 Gbps communication system based on a 450 nm laser over 60m underwater transmission distance at the BER level of 3.5×10-3 by using NRZ-OOK modulation and digital nonlinear equalization technology. The authors in [14] have proposed a low-power 520 nm green laser diode (LD) based UOWC system and provedthe maximal communication capacity of up to 2.70 Gbps data rate over a 34.5 m underwater transmission distance by conducting various experiments.

In [15] the authors have compared, discussed, and analyzed DCO-, ACO-, and U-OFDM in underwater optical communication systems. Distortions caused by the peak power is considered because the peak transmitted power is limited. The authors have optimized the modulation index and compromise the clipping effects and SNR. In [16] the authors have compared the performance of UOWC and underwater acoustic communication UAC systems in terms of data rate and energy efficiency.

3. Proposed System

Visible Light Communication (VLC) has increased great interest during the last decade due to the quick developments in Light Emitting Diodes (LEDs) fabrication. The basic components of a VLC system are the transmitter (LEDs), receivers (photo detectors), modulation of data to optics and the optical communication channel as shown in Figure 1. A blue laser LED array can be used for long distance communication and high modulation bandwidth for high speed communication with a high data rate of up to 4.8 Gb/s. However, laser is costlier than LEDs, as well as lasers may damage human eyes. Due to these disadvantages, we can use the improved LED modulation bandwidth for the high speed and long-distance communication for under water communication. In this work, we used a packaged 80 μm × 80 μm blue-emitting micro-LED with a maximum modulation bandwidth of ~160 MHz.

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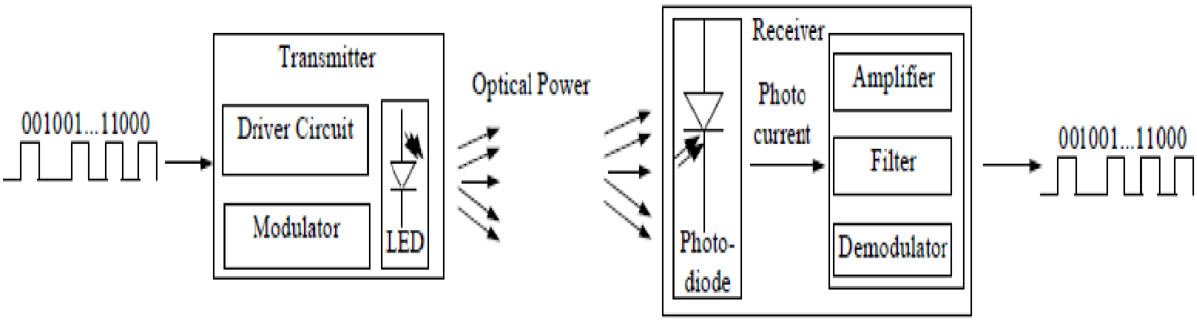
The micro-LED fabrication technology is well-suited with traditional LED fabrication processes [9, 10] and cost of the traditional LED fabrication is greatly reduced due to its wide applications in solid-state lighting, and hence the cost of micro-LED can be much lower than that of laser. There are many potential advantages of using a micro-LED array which include the applications in both underwater micro-display and communication [17], and parallel data communication using multiple micro-LED pixels to further increase the data rate [18].

Figure 1. Block Diagram of VLC Architecture



In this work we have used a blue GaN-based micro-LED array fabricated on a sapphire substrate was used forunderwater optical wireless communication (UOWC). The LED structure consists of an *n*-GaN layer, an InGaN/GaN multiple quantum well (MQW), an AlGaN electron blocking layer, and a *p*-GaN layer, grownby MOCVD. The metal layers of Ni/Au (10nm/25nm) were deposited on top of the *p*-GaN, after which dry etching was used to etch away the Ni/Au layers and the GaN layers down to the *n*-GaN layer. The *p*-contact is formed by Rapid thermal annealing at 500 °C. SiO2 was deposited as the isolation layer and then apertures were formed on the micro-LED mesas and in the *n*-contact areas. Ti/Au(50nm/200nm) metal layers were deposited as the *p*- and *n*-padsto individually address each pixel. A PCB with light extracted from the sapphire side used to bond the micro-LED array. There are micro-LED arrays with variety of sizes ranging from 20 μm × 20 μm to 80 μm × 80 μm. In this research work, we have used an 80 μm micro-LED for UOWC. It is very important to have high modulation bandwidth and high light output power to enable the high-speed communication [11,12].

The current versus voltage (*I-V*) characteristics were measured by feeding a DC current. After passing the light emission of the micro-LED by a non-spherical lens, the light transmitted through a water tank and the characteristics of output power versus current (*P-I*) is measured at a point 1 m from the micro-LED. An Ocean Optics USB4000 Spectrometer is used to collect electroluminescence (EL) spectra.

Figure 2. shows the schematic setup of UOWC. The micro-LED is driven by combining a DCcurrent source and the signal generated bya pulse pattern generator module (0.1-14 Gb/s) and BER was analyzed by an error detectormodule (0.1-14 Gb/s) from an Anritsu MP1800 signal quality analyzer.

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Pulse patterngenerator generated pseudo-random binary sequences (PRBS) with a standard pattern lengthof 2^7-1 bits and a peak-to-peak voltage swing of 2 V. The light emitted by the micro-LED is collimated and transmitted through a water tank filled with tap water. High-reflectivity mirrors are used to reflect the light within the water tank for UOWC application with extended distance. The distance of the light propagates in the water can be extended by increasing the reflection times of the light beam inside the water. The distance between the micro-LED and the receiver is 1 m and the length of the water tankis 0.6 m. On the receiver side, we have the Femto PIN photo-detector with 0.4 mm photosensitive diameter on which the light was focused. The received optical signal was converted to electrical signal by the PIN photo-detector and further sent to the error detector to test the BER. The high-speed photo-detector was employed to test the highest achievable data communication speed.

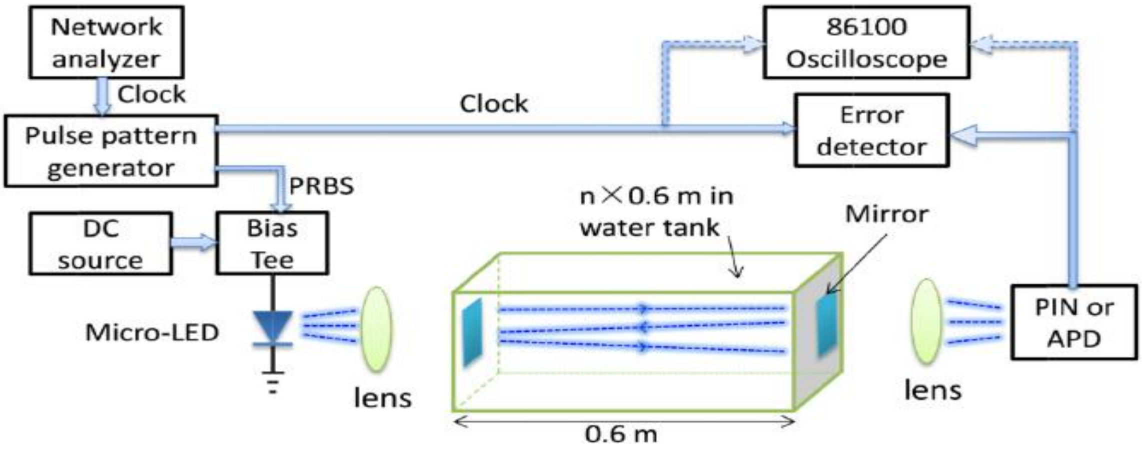

Figure 2. Schematic setup of UOWC

(*n*represents the reflection times of the light beam)

4. Results

In this section we describe the experiment results conducted with prototype. Figure 3(a) shows the *I*-*V* and *P*-*I* characteristics are. We can obtain light output power versus voltage (*P*-*V*) characteristics from the *I*-*V* and *P*-*I* characteristics, and then good linear modulation characteristics for the micro-LED device. In order to exactly determine the water attenuation of light output power, we have considered the light output power with a fixed distance of 1 m from the micro-LED in three setups: (i) In free space (without tank and water), (ii) with tank, and (iii) with water in the tank. The light output attenuations by the tank and the 0.6 m water were 17% and 13%, respectively. Water attenuation ~1 dB/m can be extracted from Figure.3(a). In Figure 3(b), the EL peaks show blue shift from ~446 nm at 0.8 mA to ~439 nm at 61 mA and then keepconstant until 88 mA. The blue shift was caused by carrier screening effect and band fillingeffect, and self-heating affected the EL spectra of the micro-LED at higher currents [19]. Thehigh junction temperature induced by self-heating can degrade the micro-LED’s aging

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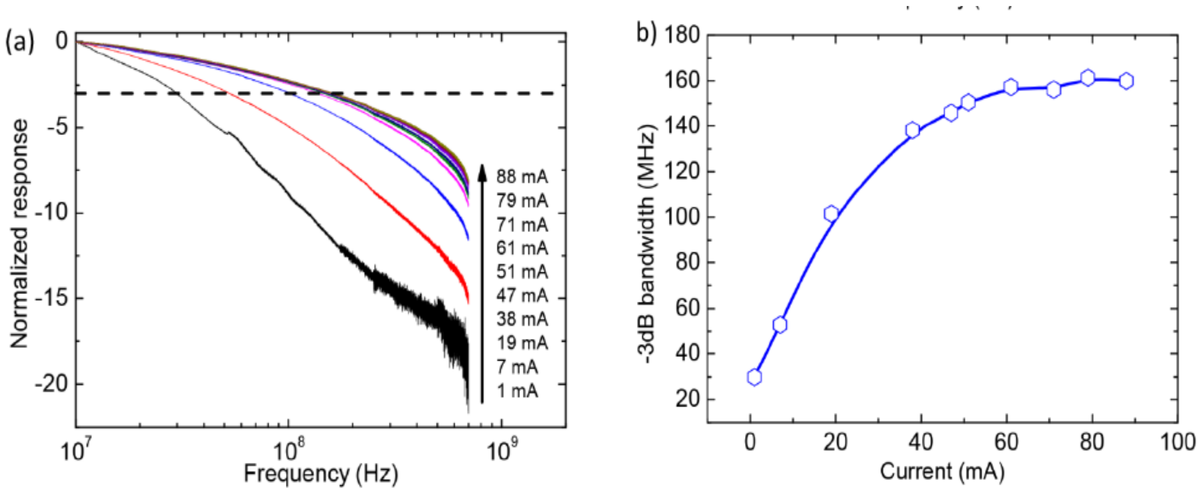
andreliability characteristics significantly [20], as well as the modulation bandwidth [21], somoderate driving current should be chosen to achieve both high light output power and good device reliability.

Figure. 3. (a) The *I-V* And *P-I* Characteristics; (b) The EL Spectra of The Micro-LED Under Different Injection Currents



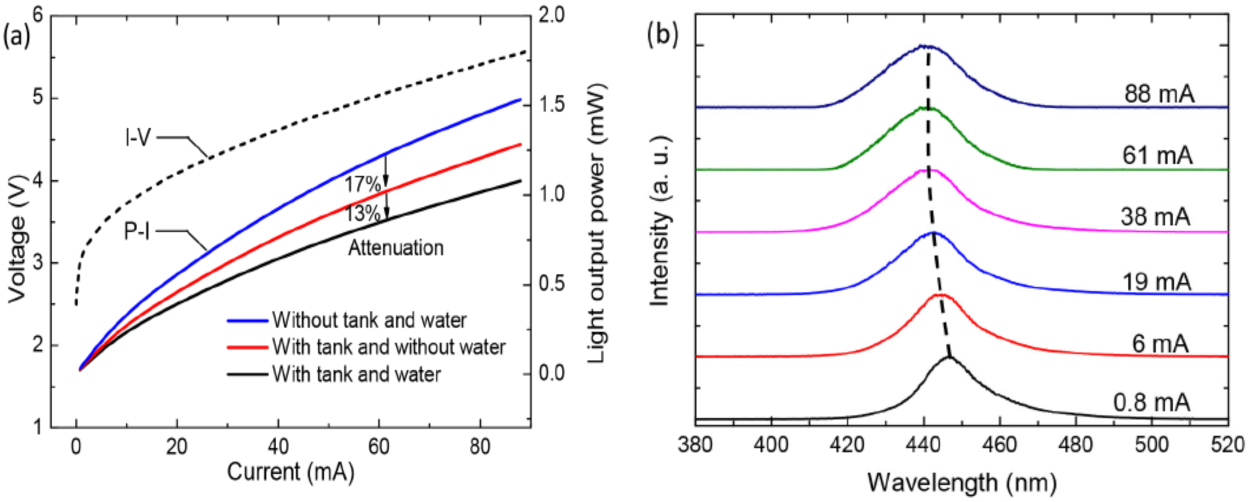


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Figure. 4. (a) Frequency response of the micro-LED at injection currents from 1 mA to 88 mA, and (b) the extracted −3dB modulation bandwidth versus current characteristics

The normalized electrical-to-optical frequency response of the micro-LED from 1 mA to 88 mA is demonstrated in the Figure. 4(a), and the characteristics of extracted -3dB modulation bandwidth versus current are summarized in Figure. 3(b). As current increases, the bandwidth increases to ~160 MHz at 61 mA and then it will be kept constant.

5. Conclusion

Wireless communication using LEDs have been used for decades in the form fiber optic communication. However recent application scenario requires a lot of improvements and underwater communication is one such important application in variety of domains. In this paper we have proposed a new approach by using a high bandwidth micro-LED with a size of 80 μm and a peak mission wavelengthof ~440 nm to achieve high-speed UOWC. The underwater attenuation was estimated to be 1dB/m after collimating the micro-LED light emission beam. The experimental results show that our proposed method addresses the challenges in UOWC and succeeded with comparable performance. In futuredifferent water types, such as coast ocean and turbid harbor cab be demonstrated for the UOWC.

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