Visible Light Communication

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Visible Light Communication (VLC) technology is an emerging technology using visible light modulation that, in the modern world, will mainly facilitate high-speed internet connectivity. VLC technology employs visible light for communication to facilitate high-speed internet connectivity exclusively in the indoor environment. This particular report will tell about some potential applications of VLC and the implementation of LEDs and some of the factors affecting the modulation bandwidth of LEDs for the VLC application.

Visible light communication   LEDs   modulation bandwidth   high-speed internet connectivity
Li-Fi   underwater communication   Quantum confined Stark Effect

1. Introduction

At its advent, wireless communication has motivated the need for increased connectivity and has been used since humans used smoke signals and birds for wireless communication. Robert Hooke subsequently discovered mobile panels in 1684 that coded the letters of the alphabet. The optical telegraph was built towards the end of the 18th century and over long distances can transmit coded words. Since then, several advances in telecommunications technology have progressed in response to consumer demands for quicker and more efficient connectivity. When it comes to radio communication, with the introduction of electromagnetic waves, wireless telegraphy, and the invention of the radio, wireless communication has gone through many paradigm shifts using coded information conveyed through electromagnetic (EM) waves [1][2]. In today's existence, EM waves have a wide range of applications that include various uses in cell phone communication, radio broadcasting, Wi-Fi, medical applications, etc., and EM waves can be classified into radio, infrared, visible, ultraviolet, etc. Among these, radio frequency (RF) is the portion of the EM spectrum that is commonly used for communication purposes, since RF transmission occurs at light speed, does not involve a travel medium, and can travel long distances. In addition, RF does not need a line of sight between the transmitter and the receiver, is not vulnerable to light source interference, and has low interference in the frequency band and wide area coverage [1]. However, RF communication faces many difficulties, such as interference, as the use of mobile phones in aircraft causes interference with communication and navigation systems; limitations of bandwidth, security problems, as they can easily penetrate through walls; limitations of transmitting power, as they can lead to risks to human safety; inefficiency of power; etc. [3][4][5][6]. To overcome these problems, it is therefore necessary to develop an alternative solution.

Visible Light Communication (VLC) is emerging to overcome the crowded radio spectrum as a solution for wireless communication networks. In VLC, data is transmitted by modulating the amplitude of an optical source that operates at a much faster rate within the visible range of the EM spectrum, making light-emitting diodes (LEDs) the most suitable light source for VLC due to their high switching rate. The EM spectrum ranging from 380 nm to 750 nm corresponding to the 430 THz to 790 THz frequency range is occupied by the VLC systems, and the availability of this broad bandwidth in the VLC has solved the problem of low bandwidth in RF communication. In VLC, security problems in RF communication can be solved, as optical source lights can not pass through opaque bodies and are confined in an intended area, nor does VLC cause any interference with RF signals resulting in improving VLC security [7]. It is a well-known fact that exposure to high-intensity RF signals can lead to burns and damage to body tissues, reducing the transmission capacity of the system itself thereby affecting the system performance [8]. VLC uses LEDs as a non-harmful optical source for the human body and can be used to reduce extra energy for illumination and communications [9]. VLC devices, however, cost substantially less than current RF modules and can also provide higher data rates [1]. In view of the above advantages, because of its high bandwidth, low power consumption, no health risks, and the fact that it is a more effective data transmission process, VLC is considered one of the promising candidates for wireless communication systems.

2. Potential Applications of VLCs

Some of the potential applications of VLCs include Light Fidelity (Li-Fi) [10], underwater communication [11][12], smart transport network [13][14], etc. Li-Fi is a new technology that uses the illumination principle as a method of transmitting data using visible light and is identical to Wi-Fi, which uses radio frequencies for communication. Li-Fi can reach a speed of up to 10 Gbps, which is 250 times higher than the speed of superfast broadband, and if there is concern about electromagnetic interference in airlines, hospitals, etc. where RF contact is prohibited, Li-Fi can also be a solution [6][10]. Nevertheless, since Li-Fi is a complementary technology that seeks to solve the challenges faced by the existing technology, one does not simply use a light bulb to transmit data to fast-moving objects or objects behind walls. VLC can also be used in underwater communication as an effective substitute for RF waves since RF signals can not spread well in seawater because of the salty, high conductivity, and high attenuation of seawater conditions [15][16]. Yet, when moving deep into the ocean, sound waves have a low propagation rate, restricted bandwidth, and high power demand, as well as being likely to communicate with marine animals, such as dolphins. VLC can effectively overcome these radio waves and sound waves limitations in underwater communication by allowing the use of visible light for data communication. The use of VLC for underwater communication, however, poses some concerns as the data transmission rate and the distance can be seriously impaired when the water loses its transparency due to the presence of suspended particles, i.e. turbidity [17]. VLC may be used to prevent accidents by communicating between vehicles with regard to pre-crash sensing, collision warning, lane shift warning, traffic signal violation warning, etc., as the risk of accidents in developing countries is growing [18]. Since these kinds of applications require reliable reachability and low latency, a high-speed visible light communication system like Li-Fi is needed. However, some problems will be met with VLC implementation, including interference with ambient light sources, interference with other VLC devices, and VLC integration with existing technologies such as Wi-Fi [6].

3. LEDs implementation in VLC

Due to its outstanding features, such as low cost, low power consumption, providing multiplexing options for wavelengths, and compatibility with existing solid-state lighting systems, LEDs have gained considerable interest in high-speed VLC applications [1]. However, conventional polar LEDs grown on the c-plane have limited bandwidth, especially in the green spectral region due to their inbuilt piezoelectric polarization [19]. This polarization in c-plane-oriented InGaN quantum wells separates electrons and holes, thus increasing the time of radiative recombination resulting in a strong Quantum Confined Stark Effect (QCSE) [20][21]. Not only can the QCSE cause a significant peak shift, but also a significant drop in luminous efficiency under high injection current, resulting in a significant deterioration of device performance along with Auger effects [20][22]. This polarization field can be reduced or removed by increasing the quantum wells in semipolar or nonpolar orientations. This allows better electron and hole overlapping and faster radiative recombination, especially in thicker quantum wells [23][24][25][26]. Thus, higher electro-optic bandwidths can be predicted for such crystal orientations along with potentially reduced Auger effects. Because of the luminous efficiency benefits offered by semipolar LEDs and stable light wavelengths, its functionality has been extended in applications such as high-resolution display, high-speed visible light communication, and researchers have therefore begun to devote their efforts to the production of semipolar GaN-based LEDs. Nevertheless, enhancing the modulation characteristics of the LED light source and the emission efficiency under high-speed modulation is part of a better VLC implementation. Several researchers have shown that the modulation characteristics of LEDs rely on the lifetime of carrier recombination, so semipolar LEDs with less QCSE can have faster radiative recombination and help to boost modulation characteristics for VLC applications [19]. However, compared with LEDs, micro-LEDs (μ-LEDs) have a better frequency response owing to their higher efficiency, low-power consumption, high brightness, and especially longer life [27]. Higher brightness for μ-LEDs corresponds to a faster transmission rate with a lower bit error rate (BER) for VLC applications. LEDs of micro-size can have a high modulation bandwidth by achieving a small carrier lifetime, as they can sustain higher injection current densities. In addition, having a small active region will lead to a decrease in geometric capacitance, thus reducing the RC time constant, which is a limiting factor of modulation bandwidth.

4. Conclusions

VLC technology has emerged as an alternative to RF communication because of the many advantages that VLC provides over RF. The factors affecting the modulation bandwidth in LEDs include QCSE, carrier localization effect, carrier lifetime, etc. The potential use of semipolar μ-LEDs for the purposes of the VLC has been well established and proposed by many researchers. Since the optical power of a single μ-LED is very low due to its limited light-emitting area, it is preferable to make μ-LED arrays to increase optical power; thus, its use for VLC applications is very significant. Another important application of VLC, which is communications underwater, is also a great interest. Numerous approaches have been developed by many researchers to greatly improve the modulation bandwidth of the VLC system, but there are still some challenges that need to be addressed in the near future. Despite having these issues, VLC will remain an innovation, and a breakthrough is expected in the coming years.

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