1.5-Gbit/s Filter-free Optical Communication Link based on Wavelength-selective Semipolar ($20\overline{2}\overline{1}$) InGaN/GaN Micro-photodetector

Chun Hong Kang,[1] Guangyu Liu,[1] Changmin Lee,[2] Omar Alkhazragi,[1] Jonathan M. Wagstaff,[1] Kuang-Hui Li,[1] Fatimah Alhawaj,[1] Tien Khee Ng,[1] James S. Speck,[2] Shuji Nakamura,[2] Steven P. DenBaars,[2] and Boon S. Ooi[1,*]

[1]Photonics Laboratory, King Abdullah University of Science and Technology (KAUST), Thuwal 21534, Kingdom of Saudi Arabia
[2]Materials Department, University of California Santa Barbara (UCSB), Santa Barbara, CA 93106, U.S.A.
**Email address: boon.ooi@kaust.edu.sa*

Abstract: We report on wavelength-selective semipolar ($20\overline{2}\overline{1}$) InGaN/GaN micro-photodetector with broad modulation bandwidth of 293.52 MHz, outperforming polar-based devices. A 1.5-Gbit/s data rate was achieved without the need of spectral-efficient modulation format.

1. Introduction

The unlicensed bandwidth of 400 to 790 THz optical wavelength is poised to relieve the saturated bandwidth in micro-and-millimeter communication [1]. The use of optical carriers offers a high data capacity and an electromagnetic-interference-free transmission suitable for various applications, e.g. indoor wireless communication, underwater wireless optical communication (UWOC), and vehicle-to-vehicle (V2V) communication. Following the trend of development, high-bit-rate optical transmitters based on compositionally-tunable group-III-nitride materials, e.g. laser diodes (LDs), light-emitting diodes (LEDs) and superluminescent diode (SLDs) could complement the value chain required in the optical wireless communication system. In particular, semipolar InGaN/GaN-based LED was reported to offer higher modulation bandwidth compared to that of polar devices [2]. Herein, we demonstrated for the first time, wavelength-selective semipolar InGaN/GaN micro-photodetector (µPD) grown on a ($20\overline{2}\overline{1}$) GaN substrate with low dark current of ~10^{-8} A/cm^2, peak responsivity of 0.17 A/W and large bandwidth of up to ~300 MHz, outperforming other reported polar GaN-based photodetectors [3]. A 1.5 Gbit/s optical-filter-free non-return-to-zero on-off-keying (NRZ-OOK) communication link was demonstrated based on a pseudorandom binary sequence (PRBS) of 2^{10}-1 data stream, which is transmitted over a 375-nm ultraviolet (UV) LD and received on the semipolar µPD.

2. Results and Discussions

Figure 1(a) shows the schematic diagram of the 80-µm diameter semipolar µPD, which consists of a semipolar ($20\overline{2}\overline{1}$) free-standing GaN substrate, a 1-µm-thick Si-doped *n*-GaN, multiple-quantum-well (MQW) region with 5 periods of $In_{0.15}Ga_{0.85}N$/GaN (3 nm/9.5 nm), a 350-nm Mg-doped *p*-GaN, a 15-nm Mg-doped p^+-GaN, and annealed Ni/ITO (10 nm/250 nm) transparent conducting layer. The *p*-and *n*-metal pads are Ti/Au of 20 nm/300 nm. The inset of Fig. 1(a) shows the transmission electron microscopy (TEM) image of the typical MQW layers in a semipolar ($20\overline{2}\overline{1}$) GaN device. The current density versus voltage of the fabricated device (see Fig. 1(b)) shows a low dark current density in the range of 10^{-8} A/cm^2. Under illumination with 370-nm light, over 3-orders of magnitude higher photocurrent, as compared to the dark current, was achieved. The sensitivity is only limited by the maximum achievable system light intensity. Figure 1(c) shows the responsivity curve, where the characteristics of wavelength-selectiveness was observed in the range of 370 nm to 410 nm. The band-pass characteristics of the semipolar µPD is due to the fact that the MQW region is transparent to wavelengths above 420 nm, while the reflectance of ITO increases gradually from 400 nm towards shorter wavelengths. Such modality, in which there is no need for an optical filter is highly advantageous in reducing stray noises at the receiver and for implementing a robust optical communication system.

The photogenerated current density of the semipolar µPD at different light intensities is shown in Fig. 2(a), in which the device demonstrated a linear response with no saturation observed across the system-allowable measurement range. The linear dynamic range (LDR) is estimated to be > 71.61 dB. Subsequently, the small-signal modulation performance of the semipolar µPD was measured over a 1-m-long optical communication link having a 375-nm UV LD and the semipolar µPD. The received signal from the semipolar µPD was pre-amplified using a linear amplifier (Mini-Circuits, ZHL-6A+). Both the transmitter and receiver ends were connected to the vector network analyzer

(Agilent, E5061B) which was calibrated before the measurement. Tested under different bias voltages, the modulation bandwidth gradually increased at higher reverse voltages and reached the saturation of around 293.52 MHz at -10 V (see Fig. 2(b)). The -3-dB modulation bandwidth demonstrated in this work surpasses the previously demonstrated *c*-plane InGaN/GaN µPD (i.e. 71.5 MHz) due to the reduced piezoelectric field and thus enhances the carrier transit time across the depletion region [3,4]. The performance of the semipolar µPD for high-speed communication links was tested using the simplest NRZ-OOK modulation scheme with a PRBS data stream of 2^{10}-1. In Fig. 2(c), a data rate of 1.5 Gbit/s at a bit error ratio (BER) of 1.03×10^{-3}, well below the forward-error correction (FEC) limit of 3.8×10^{-3}, was achieved. The inset of Fig. 2(c) shows the corresponding eye diagram at 1.5 Gbit/s.

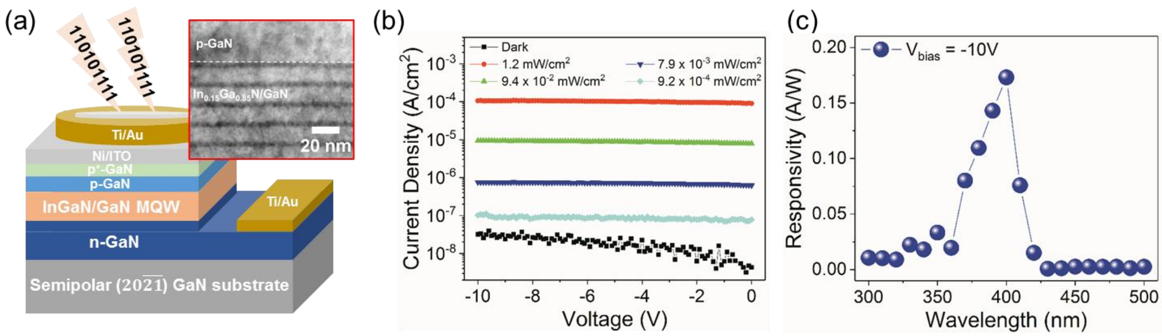

Fig. 1 (a) Schematic diagram of the device structure. The inset shows the TEM image of a typical MQW structure in a semipolar $(20\bar{2}\bar{1})$ GaN device. (b) Current density versus voltage characteristics under different light intensity values. (c) Responsivity curve measured under a reverse voltage of 10 V shows high wavelength-selectiveness ideal for filtered-free optical communication link.

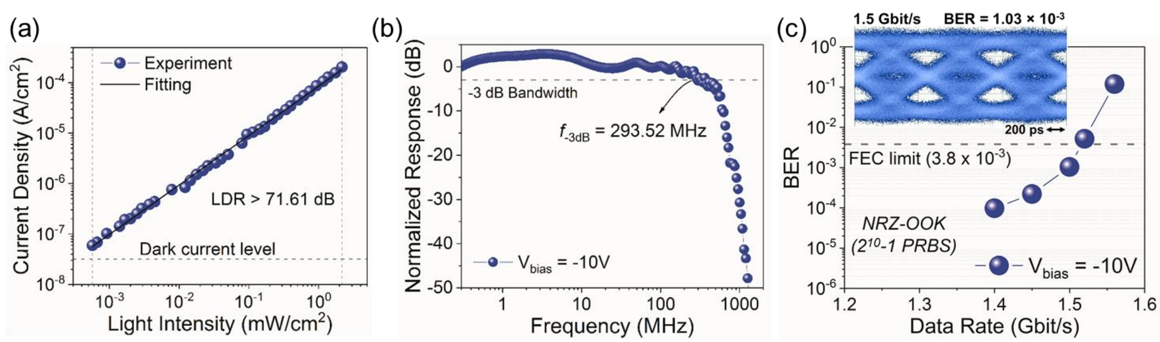

Fig. 2 (a) LDR of the semipolar InGaN/GaN µPDs measured by varying the light intensity at 370 nm with bias voltage of -10 V. (b) Normalized small-signal response measured at -10 V. (c) BER versus data rate achieved over a 1-m-long optical communication link using a 375-nm UV LD as the transmitter and a semipolar InGaN/GaN µPD as the receiver. The inset shows the eye diagram at 1.5 Gbit/s.

3. Conclusions

We demonstrated, for the first time, the surface-absorbing wavelength-selective semipolar $(20\bar{2}\bar{1})$ InGaN/GaN micro-photodetector with a low dark current density of ~10^{-8} A/cm^2, a peak responsivity of 0.17 A/W, and a broad modulation bandwidth of ~300 MHz, outperforming those of polar devices. A high data rate of up to 1.5 Gbit/s was achieved over a 1-m-long optical communication link without the need for a spectral-efficient modulation format.

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