High responsivity III-V p-i-n photodetector array with wide wavelength range

Yunjie Yan,[1,2] Shaoshuai Han,[1] Chengpeng Kang,[1] Hasan Salmanian,[2] Mingxiang Yang,[1] Zhenlin Wu,[1] Yiying Gu,[1] Mingshan Zhao,[1*] and Geert Morthier[2]

[1] School of Optoelectronic Engineering and Instrumentation Science, Dalian University of Technology, Dalian 116024, China

[2] Photonics Research Group, INTEC Department, Ghent University, Technologiepark-Zwijnaarde, Gent 9052, Belgium

Radio over Free Space Optics (RoFSO) is an attractive optical wireless communication option in 5G and 6G networks. It has great potential for achieving a high data rate, compared to fiber communication. A drawback of the RoFSO systems is the lack of compactness and of a cost effective design due to the mechanical beam tracking and active alignment function. To overcome this drawback, we propose to use a photodetector array and here we report on a vertical backside-illuminated InP-based InGaAs PIN photodetector array. The pitch between neighbouring elements is 160 μm. The device exhibits average dark current densities of 0.63nA at -5V bias. The device achieves a highly linear optical response from 1510nm to 1575nm, with a corresponding maximum linear power of 0.8mW. Especially at 1.55 μm wavelength and -5V bias, the responsivity reaches up to 1.0A/W and the external quantum efficiency is 80%. Additionally, a 3dB bandwidth of 3.4 GHz is achieved at -5V bias.

1. Introduction

As 5G deployment rapidly advances, the global industry has already begun exploring the next generation of mobile communication technology 6G [1-2]. To support the 6G applications, which demand data traffic in wireless communications, high-data-rate transmission technologies in communication have been developed, such as radio over free space optical communication. However, in RoFSO systems, the free space beam should be aligned to a 10μm single mode fiber by using mechanical beam tracking and alignment functions [3-6]. It will limit compactness and prevent a cost effective design due to the mechanical beam tracking and active alignment function.

In this report, we demonstrate a newly developed InP-InGaAs based p-i-n photodetector array device as shown in Fig 1 and the 6-elements photodetector array performance is discussed. The distance between the elements, which have a diameter of 50 μm, is 160 μm. The lowest 3.4GHz frequency response in the PDA was obtained. The responsivity is up to 1A/W and the external quantum efficiency is over 80%.

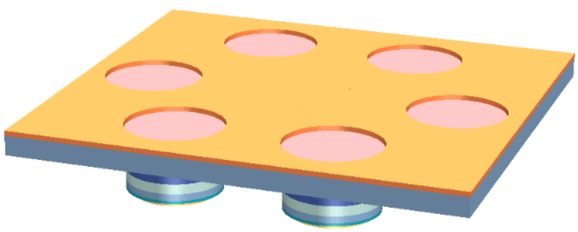

Fig 1. Schematic of the Ⅲ-Ⅴ p-i-n photodetector array

2. Measurement results and Discussion

The dark current of the photodetector array was measured using a Keithley 2400 semiconductor parameter analyzer at room temperature without illumination. The dark current I-V curve of the device with 50μm diameter at a bias voltage from -10 to 0.3 V is shown in Fig.2(a) for different elements. A low dark current density of 0.63nA at -5V bias is achieved for a packaged PDA with this large area device. It corresponds to a dark current density of about 3.20nA/μm^2. It can be clearly seen that the PDs exhibit typical rectifying characteristics, indicating an excellent quality of the PIN junction. These are acceptable values for optical receivers, and these low dark currents are very important to obtain a high signal-to-noise ratio for optical receivers The low dark current is an evidence of a high quality PDA, which indicates an excellent p-i-n junction and a superior-quality ohmic contact. There are several sources contributing to the dark current, including the imperfect surface passivation, diffusion current, generation recombination current, and tunneling current at high bias voltages. The packaging process may introduce mechanical stress into the semiconductor material, which can alter the lattice structure of the semiconductor, which can lead to changes in the local band structure and different dark current.

Fig 2(b) displays the spectral responsivity measured in the wavelength range of 1510 nm-1575nm. Here, the antireflection coating and the InGaAs thickness of the devices were optimized to obtain maximum responsivity for each wavelength measured. The spectral response measurements were carried out in the 1510–1575 nm wavelength range by using an SantecTSL510 tunable laser with a single-mode fiber pigtail as the light source. The devices were back illuminated vertically. The spectral response was measured under a 5V reverse bias. The responsivity of the 6-elements is over 1.0A/W in the chosen range and the external quantum efficiency is over 80%. The responsivity curve shows overall good absorption characteristics in a wide wavelength range of 1510nm-1575nm.

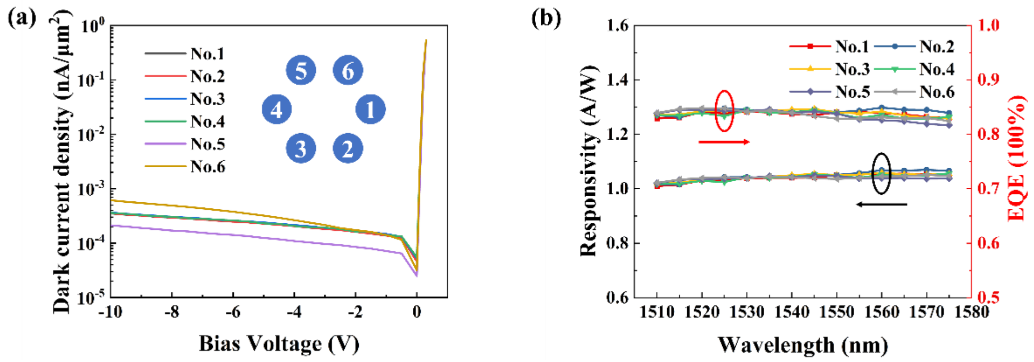

Fig 2.(a) Dark current density of the 6-elements photodetector array with 160μm center to center distance. (b) Measurement results of responsivity for all elements as high as 1.0A/W and external quantum efficiency up to 80%.

Measurement of the frequency response was made with a tunable laser and Rohde&Schwarz ZNB Vector Network Analyzer. The frequency response is calibrated using a commercial 25GHz photodetector. The device was contacted by a microwave cable of 50Ω characteristic impedance and biased through an internal bias tee. The measured frequency response (S21) is shown in Fig.3, where the 3-dB bandwidth of the InP-InGaAs PIN photodetector array is 3.4GHz, with a reverse bias of 5V and an optical input power of 60μW at 1550nm wavelength. The bandwidth is mainly limited by the

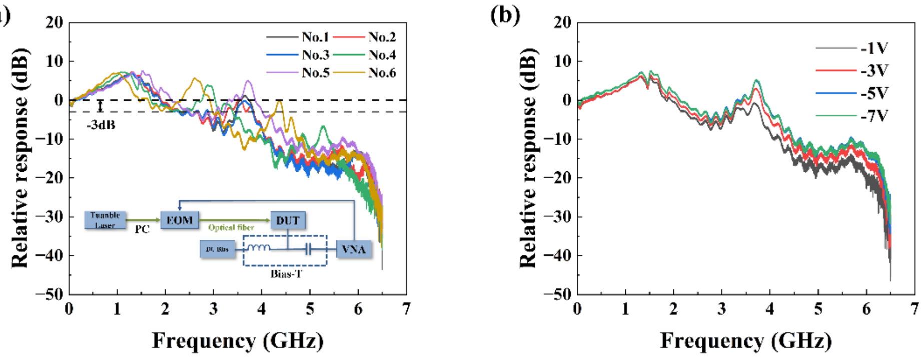

Fig 3.(a) Measured frequency response of 6-elements. The measurement set-up is also shown in the figure. The 3 dB bandwidth of the device is 3.4 GHz with a reverse bias of 5V and an optical input power of 60μW at 1550 nm wavelength. (b) Measured frequency responses of element 5 for a reverse voltage ranging from -7 to -1V.

transit time of the carriers and the RC time constant. Fig 3(b) shows the measured frequency responses of the element No.5 for various reverse bias voltages. The bandwidth increases with increasing bias voltage until it saturates at a reverse bias of 5V. The 3dB bandwidths upon −1 and −5V bias voltages are 3.8 and 4.0GHz, respectively. In the packaged PDA, wire bonding connects the chip to the PCB, which transmits the signal to the coaxial connector. The main sources of attenuation are the transitions from the PCB to the PDA and the coaxial connector to the PCB. The parasitic inductance from the gold wire bonding, solder and RF through-wall structure causes the resonance peaks around 1.5GHz and 3.4 GHz with different wire bond lengths causing different resonance frequencies.

3. Conclusion

We have developed and fabricated a 6-element photodetector array that delivers high quantum efficiency over a wide wavelength range. Each element achieves a quantum efficiency of over 80%. The device exhibits a responsivity over 1A/W in the 1510 nm to 1575 nm wavelength range, with a 3 dB bandwidth of 3.4 GHz. The device does not require an alignment system and is scalable to support more elements. This scalability helps to reduce the footprint of transceivers, enabling more compact designs, while also decreasing costs and power consumption in RoFSO communication networks.

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