Optical Wireless Communication Empowered by Photonic Integrated Circuits for 6G

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Abstract: *Optical wireless communication (OWC) is expected to play a major role in next generation wireless communication systems such as 6G. Photonic integrated circuits (PICs) are critical in order to realize compact, practical, and cost efficient devices for OWC. In this paper, we report on one of our PIC activities at TNO. We present results from the initial phase of our work towards achieving a broadband integrated OWC receiver with large optical aperture and wide field-of-view (FoV). Our ultimate goal is a data rate of >10Gb/s, a detector aperture of >1cm x1cm and full-width-half-maxima FoV of ~60 degree.*

Introduction

Security, energy/spectral efficiency, latency, data density and peak data rates of up to 1 Tbps are some of the key performance indicators (KPIs) of 6G that are difficult to achieve with current radio frequency based technologies due to fundamental spectrum limitations. Optical wireless communication (OWC) is a powerful alternative to cope with such astronomical demands. Despite key benefits such as high unlicensed wireless capacity, high security and low power consumption, etc., it is mainly deployed in niche markets such as defense and satcom at the moment. This is because a stable high-speed OWC link under practical conditions require accurate beam steering at the transmitter and a large optical aperture and wide field-of-view (FoV) at the receiver. Moreover, challenges associated with size, power consumption and cost have to be overcome before it can successfully penetrate the wireless communication market.

Integrated photonics technology is critical in realizing compact, energy efficient and cost-effective transceivers. It enables development of miniaturization and micro-packaging/assembly options, allowing a cost-down roadmap, and eventually facilitating OWC adoption in consumer markets. In this paper, we report on the initial phase of one part of the activities that we are pursuing at TNO towards realizing an OWC system powered by integrated photonics. We concentrate on photodetector arrays, the first part of our OWC program, here. We present on-off keyed (OOK) data transmission speeds of up to 2.5Gb/s using an 8x8 array of photodetectors (PDs) realized by flip-chip bonding of individual PDs on a glass submount. The overall aperture of the PD array structure is 2.45mm×2.05mm with expected full-width-half-maxima (FWHM) FoV ~40deg. The goal of the OWC program at Holst Centre is to develop new photonic integration and assembly solutions in order to realize compact and energy/cost efficient OWC transceivers.

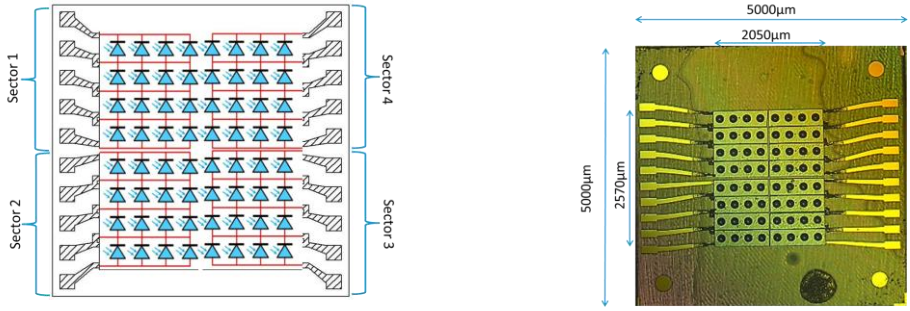

Fig. 1. PD array architecture and realization on glass carrier

PD array design and PoC realization

One of the main challenges in OWC is to realize a broadband receiver with a large aperture and wide FoV to capture the beam, with a sufficiently large link budget for a high data rate, without the user being required to precisely align the receiver to the transmitter. Several approaches have been reported to increase the effective aperture and/or FoV of the OWC receiver [1-4]. However, these solutions still present either limited bandwidth, aperture and/or FoV, or increased complexity and noise.

An OWC receiver using a novel arrangement of multiple PDs which still achieves the high bandwidth of a single photodiode is presented in [5]. It requires only a single trans-impedance amplifier (TIA) which simplifies the opto-electronic integration. In this work, we use a similar arrangement of PDs to realize a sectorized array of PD arrays as shown in Fig. 1. We added the number of pre-amplifiers of the overall receiver to increase the sensitivity and data rate further. As a proof-of-concept (PoC) we realized an 8×8 sectorized PD array; each sector consists of a 4×4 PD array with the series/parallel PD interconnection presented in [5], followed by one TIA. The PoC PD array was realized by flip-chip bonding commerial PDs of diameter 120µm onto a glass submount. The effective aperture of the array was 2.45mm×2.05mm (diameter of ~3.3mm) with a fill-factor of ~9%, corresponding to an optical loss of 11dB. The expected bandwidth of the PD array (without TIA) is ~3GHz, whereas that of an equivalent area single PD would be ~4MHz, with a fill-factor of 100%. Our next objective is to improve the fill-factor of the array to reduce the optical loss with improved array design and monolithic fabrication.

First experimental results

Before performing charaterization and experiments using the stup shown in Fig. 2b, the glass submount where the PDs are flip-chip mounted is wirebonded to the PCB for connection with the TIAs (see Fig. 2a). Shunt resistors and current buffers are inserted between the PD arrays and the TIAs in order to minimize reverse-bias imbalance across the PDs and capacitance fluctuations at the input of the TIAs, respectively.

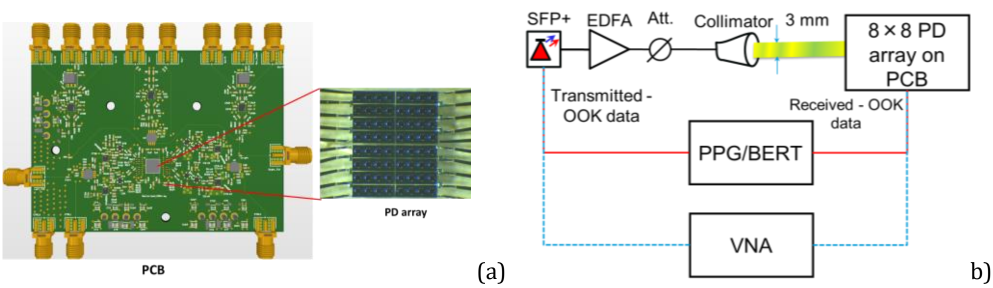

Fig. 2. a) OWC receiver: PD array on glass submount on PCB; b) Experimental setup

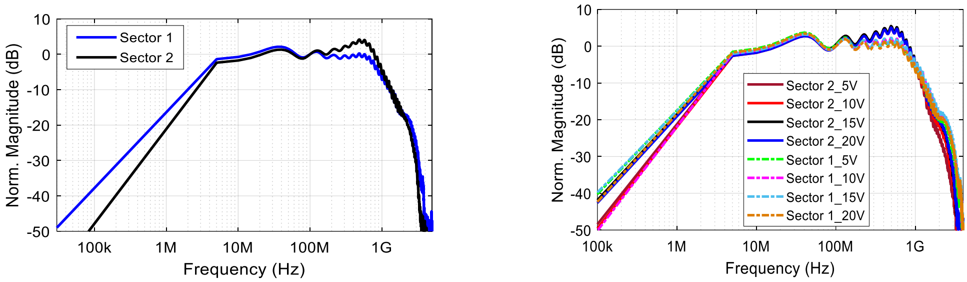

Fig. 3. Frequency response measurements for varied reverse bias voltages

Figure 3 illustrates the bandwidth measurement results for two of the sectors (sectors 1&2). A bandwidth of ~840MHz and ~930 MHz have been measured for the two sectors, respectively. The sunt resistors are used to balance the bias voltage across detector elements that are connected in series, and were 100Ω and 500Ω, respectively for the two sectors. We believe that this is the reason why we observed slightly different bandwidth for the two sectors. The bandwidth measurement results in Fig. 3b also tell us that the performance is not highly dependent on the applied reverse bias voltages. This is attributable to the fact that the current buffers mask the PD capacitance fluctuations at the input of the TIAs resulting from variations of the bias voltages.

We also performed BER tests for OOK signals of 1 – 2.5 Gb/s data rates. We see that data transmission speeds of up to 2.5Gb/s are feasible at BER values <10^{-3}. The sensitivity of the receiver at BER = 10^{-9} was -1dBm for 1Gb/s and +0.5dBm for 2Gb/s. These sensitivity values can be improved by incorporating TIAs with higher gains. The trans-impedance gain of this particular receiver structure was 4kΩ which is much lower than what is available currently commercially. Our next objective is to use TIAs with high gain, in addition to lowering the 11dB optical fill-factor loss by designing the PD array in a better way, and employing monolithic integration.

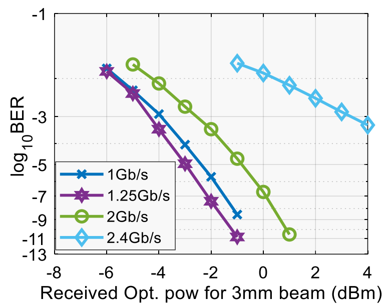

Fig. 4. BER measurements

Conclusion

At the moment OWC it is restricted to niche application areas such as defense and satellite communication. In order to unleash its full potential to mass consumer markets such as 6G, cost, power consumption and practicality need to be improved in addition to performance. This is where PICs play a critical role. Here, we presented our ongoing work on PIC based broadband receiver with wide FoV. Our goal is to realize a compact OWC receiver with FWHM FoV of >60 deg, aperture area of ~1cm^2 and data rate of >10Gb/s for practical applications in datacenters and 6G. It is part of a program that also includes activities towards integrated beam-steering, and transmitter-receiver co-assembly.

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