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100 Gb/s Photoreceivers for Coherent and Direct Detection

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Abstract: Photoreceivers for coherent and direct detection of 100 Gb/s data rates, consisting either of 90° optical hybrids integrated with pairs of balanced detectors forming coherent QPSK photoreceiver OEICs, or pin-diodes with travelling-wave amplifiers, are presented.

OCIS codes: (250.3140) Integrated optoelectronic circuits; (040.5160) Photodetectors; (060.2360) Fiber optic links, subsystems

1. Introduction

The realization and standardization of next generation 100 G Ethernet relies on transmission schemes employing advanced modulation formats (D)QPSK in conjunction with polarization switching, e.g. 4x28 Gb/s, which improves spectral efficiency, helps in managing fiber impairments over larger distances, and being compatible with the 50 GHz grid of the existing fiber base [1]. Components for coherent transmission schemes for a single polarization were developed within the frame of 100GET [2, 3] and will be ongoing evolved in just started programmes, like FP7 MIRTHE for dual polarization employment. For short range communications, e.g. optical cable interconnections in datacenter applications, transmission over a single-wavelength, serial 100 G OOK (on-off keying), applying ETDM transmitter and receivers, gains interest when components will be available at affordable prices. 107/112 Gb/s 1:2 demultiplexing photoreceivers are key components, which are on the way from applying optimized analog frontends followed by digital demuxing modules migrating to co-packaged photoreceivers comprising pin/pinTWA and DEMUX in a single housing [4, 5]. Within the European projects GIBON and HECTO InP-based components for 100 G serial transmission were developed [6]. This work focuses on the receiver parts in those projects.

2. Monolithic InP-based coherent 90° hybrid photoreceiver OEICs

In a coherent receiver, the modulated phase information is decoded by 90° optical hybrid six-port devices, which are key components for DP-QPSK 100 GbE transmission concepts, elaborated at several sites worldwide [7-9] .

This contribution focuses on the 2x4 MMI-based version [2], monolithically integrated with four separate indentical photodiodes (dual-type), which allow a direct chip-to-chip interconnection to transimpedance amplifiers (TIA) with differential inputs. Comprehensive investigations on the output imbalance dependence on MMI fabrication tolerances, the PDL, and initial investigations of the thermal behaviour of the 90° hybrid receiver OEICs were undertaken and described.

Fig. 1a shows the principal OEIC structure applying tapered input access waveguides, a 2x4 MMI which equally distributes the intensity to four output ports, a standard waveguide network with appropriate crossings of low insertion loss and low crosstalk, and the dual photodiodes. Phase shifters are used only for test purposes.

a)

b)

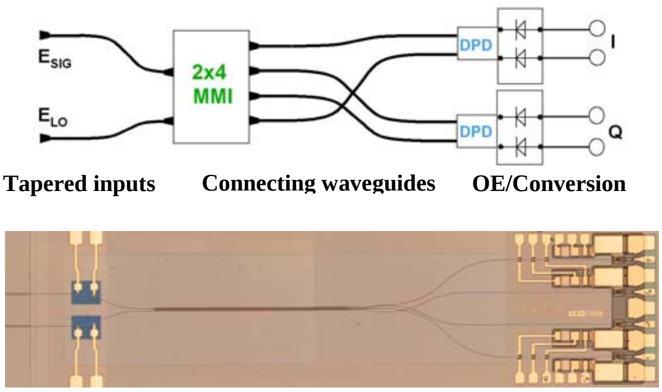

Fig 1. a) Principal design of the monolithic 90° optical hybrid receiver with one 2x4 MMI and a pair of dual photodiodes,
b) photomicrograph of the 90°-hybrid OEIC chip.

Fig. 1b exhibits the realized AR-coated OEIC according to Fig. 1a. The semi-insulating epitaxial sheet package was compatible with earlier published ultra-high speed photodiode MOVPE-grown stack [2, 7], but with slightly increased GaInAs absorber thickness to enhance responsivity of the 5x30 µm² sized p-i-n diodes at 60 GHz frequencies. The bandwidth of the implemented photodiodes (PD) was measured using the established heterodyne method. The dual PDs and even balanced PDs with different active areas showed bandwidths exceeding 60 GHz, see Figure 2. The exploitable RF responsivity is 6 dB higher compared to the 50 Ω terminated balanced detectors reported earlier [7].

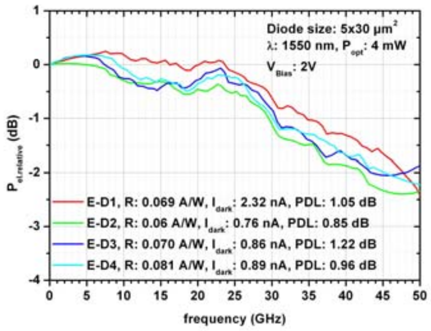

Fig. 2 Conversion gain characteristics of the 4 dual pin photodiodes, measured behind the 90°-hybrid waveguide network.

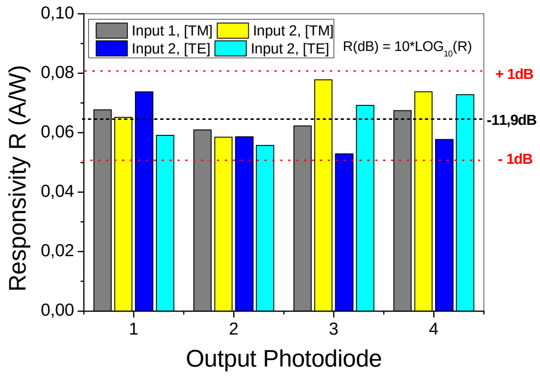

Fig. 3 Responsivity at the four outputs for coupling into both inputs at TM- and TE-polarization at 1550 nm and a temperature of 20 °C.

Guiding layer thickness and etching depth have to be well controlled by the epitaxy (3%) and dry etching (20nm). A typical and representative data collection with good uniformity is displayed in Fig. 3. Reference detectors with identical technology on the same wafer show a responsivity up to 0.7 A/W. In Fig. 4, a plot of the imbalance of the output intensities as function of the MMI-width deviation from the design value is shown. Data are shown both for TE and for TM polarization. We observe that the imbalance increases drastically for smaller MMIs, conform with simulations.

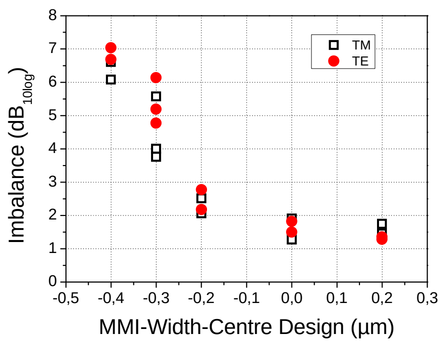

Fig. 4. Imbalance of the four output signals from both inputs as function of the difference from the designed MMI width at λ=1550nm.

A very low temperature sensitivity of the responsivities was assured by measurements in the range of 15° to 35°C, showing a nearly athermal behavior of the 90° hybrid photoreceiver OEICs.
Novel coherent receiver modules have been fabricated by our industry partner u2t Photonics AG, comprising two of these optical 90° hybrids. The full functionality of the modules was shown in characterization measurements and system tests up to 160 Gb/s DP-QPSK, including transmission over 610 km SMF with no optical dispersion compensation [1].

3. Copackaged 107 Gb/s photoreceiver comprising InP-based pinTWA and DEMUX

The pinTWA photoreceiver OEIC co-integrates a waveguide-integrated photodetector with a travelling-wave amplifier [5]. This saves one 100 GHz electrical interconnection, in order to both avoid wire bonding or costly 1mm-connectors and to avoid transition loss. Additionally, in short range communications its on-chip-gain may spare an otherwise needed expensive EDFA. The photodiode with an active area of 4 x 10 µm^2 and a InGaAsP/InGaAs heterostructure absorption layer stack is located on top of a semi-insulating (5*10^7 Ωcm) optical waveguide stack. The HEMTs forming the TWA are integrated by MBE over-growth after mesa-structuring the PD areas. The circuit is given in Fig. 5. The advantage of applying the pinTWA concept is demonstrated in Figure 6, which exhibits a comparison of gain and bandwidth properties of single high-power photodiodes and pinTWA OEICs, comprising differently optimized travelling-wave-amplifiers.

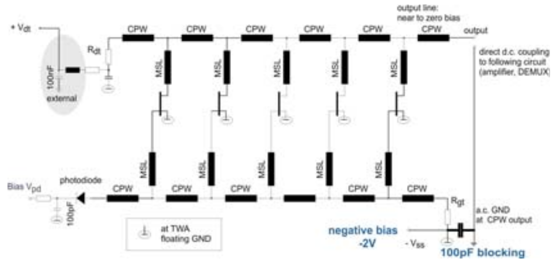

Fig. 5 Circuit of the 100 Gbit/s pinTWA photo-receiver comprising a pin diode and a 5-stage travelling-wave amplifier.

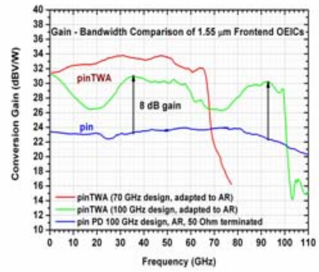

Fig. 6 Conversion gain comparison between pin photodiode chips and pinTWA OEICs, designed for different bandwidths, suitable for 100GE operation.

The pinTWA and a 1:2 InP HBT-based DEMUX IC from ATL [5, 10] were co-packaged into a module, shown in Figure 7 (with an inset of inside view), and a 107 Gb/s back-to-back system experiment was successfully performed. The system experimental setup was based on an RZ-OOK transmitter with optical time-division multiplexing to generate a 107 Gb/s optical data signal. The average optical power to the pinTWA-DEMUX module as well as the clock rf-power was +8 dBm. The demultiplexed 53.5 Gb/s electrical signals at the two data outputs (Q and QB) of the pinTWA-DEMUX are shown in Figure 8, for a word length of 2^{31}-1 (PRBS31).

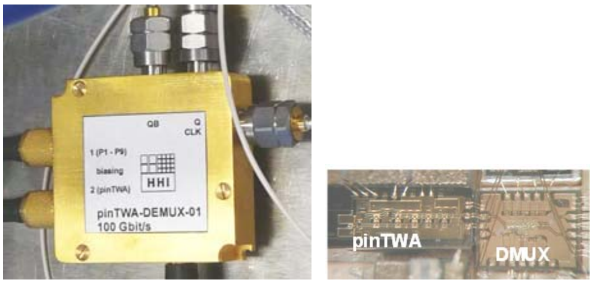

Fig. 7 Copackaged pinTWA-DEMUX module; pinTWA-DEMUX chips.

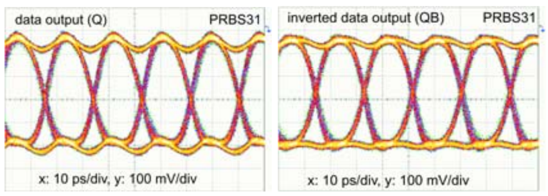

Fig. 8 Data outputs (Q and QB) at 53.5 Gb/s for 107 Gb/s RZ-OOK optical input at +8 dBm.

For 100GE DP-QPSK transmission systems we presented a nearly athermal 2x4 MMI-based monolithically integrated InP 90° hybrid QPSK receiver OEIC operating at 50 Gbit/s for a single polarization, which exhibits good performance with respect to low output imbalances within ±1 dB and low PDL <1dB. These OEICs for at least 56 Gbaud data rates enable ultra-compact low-cost coherent receiver modules for 100 GbE applications and support even data rates of up to 224 Gbit/s (DP-QPSK).

For 100GE ETDM transmission systems we showed 107 Gbit/s capable pinTWA OEICs, delivering electrical post-amplification gain values up to 10 dB. Demultiplexing of an 107 Gb/s data stream into 53 Gb/s data rate demonstrated at PRBS31.

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