Multi Format High Speed linear Preamplified Receiver Operating at 100 Gbit/s NRZ-OOK

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Abstract *We demonstrate a monolithically integrated preamplified receiver with >70 A/W responsivity, 60 GHz bandwidth which demonstrate detection of very low power 100 Gbit/s NRZ-OOK signal and compatible with PAM4 detection.*

Introduction

The explosion of internet traffic lead to the need of very high speed (50 Gbit/s and more) photoreceivers for short reach connection in various application field: future high speed PON (passive optical network) network which are under study at 50 Gbit/s[1], intra datacenter link of few 100s meter to few km and mobile xhaul. For such short distances, direct detection is preferred to coherent technology due to lower cost and power consumption. Several modulation format are under investigation: 50 Gbit/s NRZ-OOK for high speed PON, 50 Gbit/s PAM4 (4-levels Pulse Amplitude Modulation used for 50G FR/LR, 400G DR8/LR8) or 100 Gbit/s PAM4 (100G DR/400G DR4).

For next generation 100 Gbit/s links, one possible choice is a single 100 Gbit/s NRZ-OOK channel due to its low complexity (single laser&photodiode, no DAC…). However, the increase of the baud rate leads to a limitation of the optical power budget required to achieve the transmission. High-speed receiver associating a photodiode with a travelling wave amplifier was demonstrated with a sensitivity of 1 dBm for a BER of 10^{-3} [2] which is not compatible with present transmitter output power. Therefore a high sensitivi ty receiver is mandatory and the integration of an optical preamplifier is a promising solution as demonstrated in the past at 40 and 64 Gbit/s[3],[4]. We recently demonstrated a high speed SOA-UTC receiver with a very large bandwidth of 95 GHz and 95 A/W responsivity which is very promising for high speed OOK applications[5].

For some applications, PAM4 is more interesting than NRZ modulation format as it halves the required bandwidth. Furthermore, from an operator point of view, multiformat receiver is interesting as it allows using the same component for different applications but also an adaptation of the modulation format to the need. However, PAM4 requires highly linear components, which question the compatibility of preamplified receiver with this modulation format as SOA is known to induce patterning effect. A SOA-PIN with no patterning effect was demonstrated[6] but only in NRZ modulation format.

In this paper, we demonstrate a linear SOA-UTC receiver module with >70A/W responsivity, >-9 dBm saturation input power, and 60 GHz 3-dB bandwidth. This receiver was able to detect 100 Gbit/s NRZ signal with <-10 dBm input power and, to our knowledge, demonstrate for the first time for a preamplified receiver the capability of error-free PAM4 detection without equalization.

SOA-UTC design and technology

Fig. 1 shows the SOA-UTC receiver module which is made of a SOA-UTC chip coupled to a lensed fiber and a GPPO connector or the HF output. A Peltier cooler is used for temperature regulation. The SOA-UTC chip is represented in Fig. 1 and is made of a buried heterostructure SOA and a deep ridge UTC photodiode. The SOA is 700 µm long and the photodiode area is 5×25 µm². The component is made on a semi-insulating InP substrate and involve mainly GSMBE growth for the SOA, the passive waveguide and the photodiode, and dry etching[5]. Decoupling capacitor and matching resistor was integrated on-chip as shown in the photography of the chip to improve the photoreceiver response and HF signal integrity.

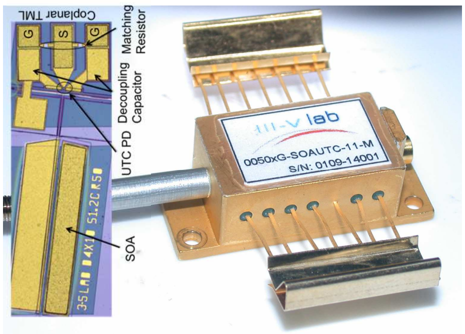

Fig. 1: SOA-UTC receiver module (inset: SOA-UTC chip)

Result and discussion

Fig. 2 shows the ASE optical spectrum of the

SOA-UTC module under 180 mA bias current. The gain peak is at 1540 nm (1550 nm at 140 mA) and the 3-dB optical bandwidth is 73 nm.

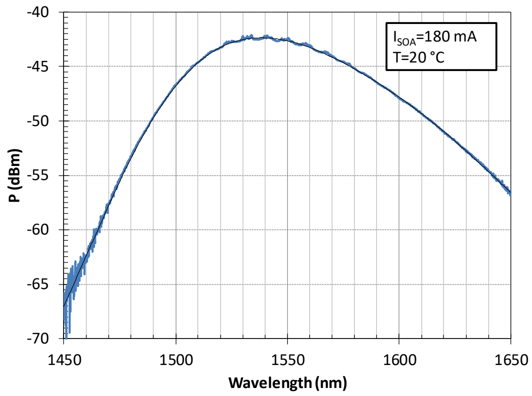

Fig. 2: ASE spectrum of the SOA-UTC module

Fig. 3 shows the receiver module responsivity and polarization dependence loss (PDL) versus SOA drive current and versus the input power at a regulated temperature of 20°C and for an input signal at 1.55 µm. For an input power of -20 dBm, the receiver demonstrates a responsivity of 36 A/W for 120 mA SOA drive current and 70 A/W for 180 mA SOA drive current. This represents a high gain of 56 compared to an ideal photodiode with 1.25 A/W responsivity. The PDL is around 2 dB for all SOA drive current.

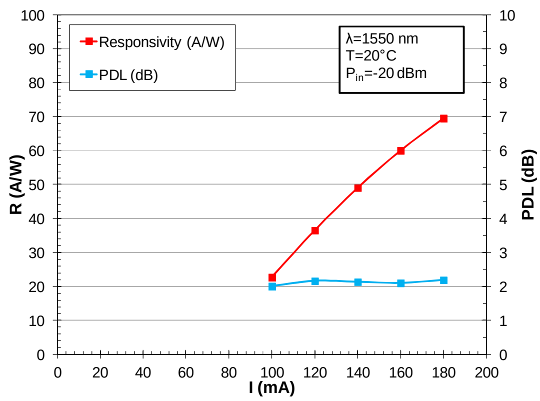

Fig. 3: Responsivity and PDL of the SOA-UTC module

Fig. 4 shows the variation of the responsivity at 1.55 µm as a function of the input optical power. For a SOA drive current of 180 mA, the

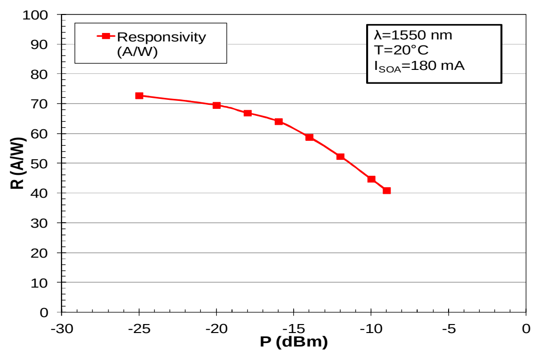

Fig. 4: Responsivity versus input power of the receiver

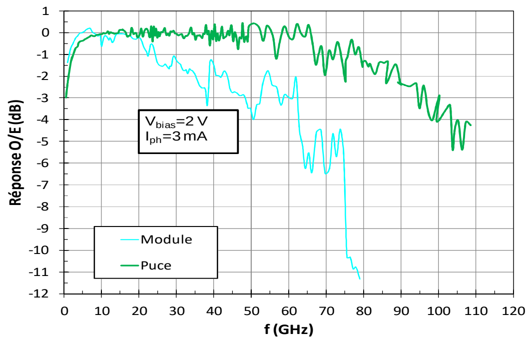

Fig. 5: Frequency response of the SOA-UTC chip and the SOA-UTC module

responsivity is 73 A/W for a very low input power of -20 dBm and the 3-dB saturation input power is above -9 dBm.

We then measured the frequency response of the receiver module using a heterodyne setup for a diode photocurrent of 3 mA. The preamplified receiver module presents a large 3-dB bandwidth of 60 GHz and a 6-dB bandwidth of 75 GHz as shown in Fig. 3. The bandwidth is lower than the SOA-UTC chip mainly because of the bonding between the chip and the HF ceramics and due to the limited bandwidth of the GPPO connector. Because of the integration of the 50Ω matching resistor on chip, the chip present a very large bandwidth of 95 GHz and the module response is not affected by inductive peaking. The roll-off observed below 3 GHz is due to the high pass filter behavior of saturated SOA and by the low frequency cut-off of the decoupling circuit[5]. As in the module we add a 100 nF capacitor to the 5 pF on chip capacitors, the low frequency roll off is reduced compared to the chip and is mainly due to the SOA frequency response.

We then provide 100 Gbit/s NRZ-OOK optical signal into the module. A 2.3-Vpp 100-Gbit/s electrical signal generated by a high speed InP selector feeds a high speed transmitter module comprising a DFB laser and an electroabsorption modulator delivering −11.4 dBm optical output power[7]. The signal is then injected into the SOA-UTC module and recorded on a high-speed sampling oscilloscope with a 70 GHz sampling head for different optical input powers (Fig. 6). For a very low input power of −16 dBm, the SOA-UTC receiver module demonstrates an open eye with a Q factor of 3.3, even if we can observe some noise in the eye. When the optical input power is increased to −10 dBm, it delivers a clear eye opening with a Q factor of 3.5 and the eye is now noiseless. The BER is estimated below 10^{-3} which is compatible with forward error correction code. To our knowledge, this is the first time a 100 Gbit/s NRZ signal is detected with such a low input power which is compatible with the output power of state-of-the-art transmitter. As the Q

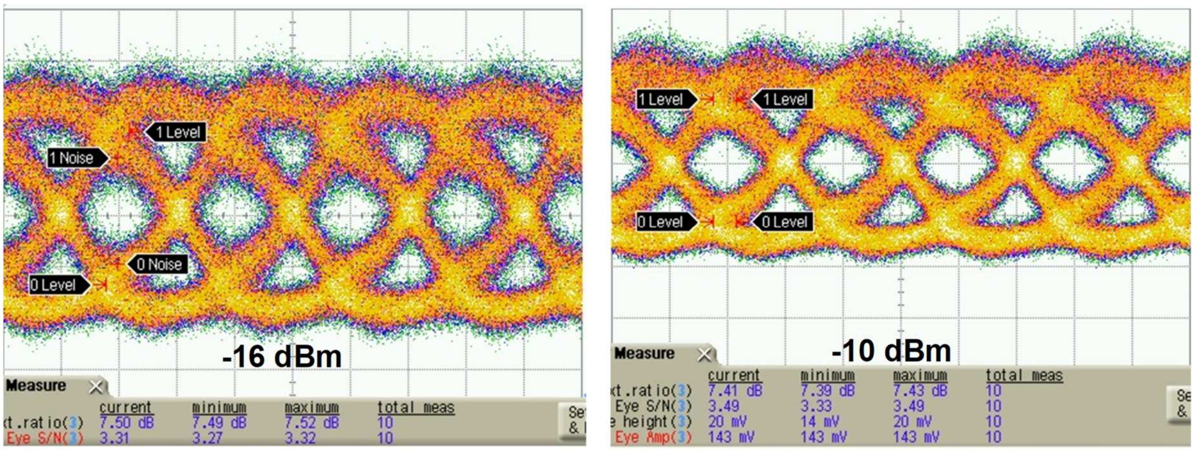

Fig. 6: 100 Gbit/s eye diagram (left: -16 dBm input power; right -10 dBm input power)

factor was 6 at 64 Gbit/s for an input power of only -17.5 dBm, we can deduce that the performance at 100 Gbit/s is mainly bandwidth-limited. Reception performance of SOA-UTC modules can be improved by mitigating bandwidth limitation on electrical interfaces: first by replacing GPPO® connector by a 1 mm connector and secondly by improving the bonding between the chip and the connector.

We then measure SOA-UTC with 20 Gbaud PAM4 signal to demonstrate receiver linearity. The signal is generated by two time-decorrelated outputs of a PRBS generator which are multiplexed and used to drive a Mach-Zehnder modulator. The resulting optical signal is then passed through an optical attenuator, injected into the SOA-UTC receiver module, and subsequently acquired with a 16 GHz real-time oscilloscope sampling at 80 GSa/s. For BER couting, 41 MSa-long data trace (the largest possible with the available oscilloscope memory) was acquired. The input optical power was adjusted to 1 mA average photocurrent in order to ensure sufficient signal-to-noise ratio in the oscilloscope. Due to the limited bandwidth of the

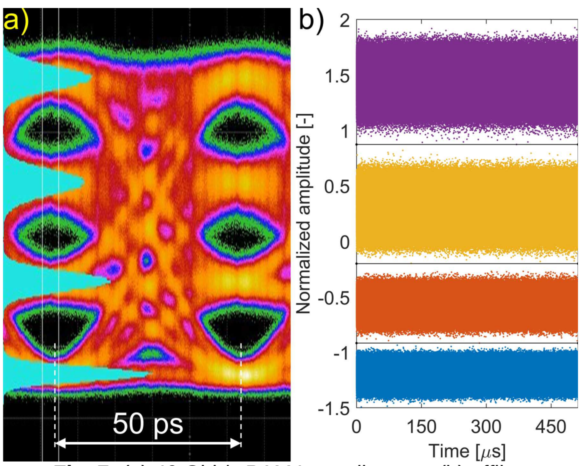

Fig. 7: (a) 40 Gbit/s PAM4 eye diagram, (b) offline demodulation result of 21 million bits.

real-time oscilloscope, the symbol rate is limited to 20 GBd (40 Gbit/s) and corresponding eye is shown in Fig. 7(a). By using offline processing with a digital zero-crossing clock-and-data recovery, no equalization, and optimized fixed decision thresholds (Fig. 7(b)), we find no errors in the the received signal block. Due to no errors being observed, we statistically estimate that the actual BER of the received signal is below 7.3×10^{-7} with a 99% confidence level.

Conclusions

In this paper, we demonstrated a high speed preamplified receiver module comprising a chip, which monolithically integrates a semiconductor optical amplifier and a UTC photodiode. The receiver exhibits a very high responsivity of 70 A/W, a low PDL of 2 dB and a large bandwidth of 60 GHz. A clear eye opening with 100 Gbit/s NRZ-OOK signal for a very low input power of -10 dBm, and compatibility with PAM4 is demonstrated. Therefore, this component paves the way for future high-speed short reach interconnect at 100 and 400 Gbit/ as well as next-generation PON at rates exceeding 50 Gbit/s.

Acknowledgements

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