4 Gbit/s hybrid InP-SiGe photoreceiver for the user access network

L. Xu[1], M. van Heijningen[2], G. van der Bent[2], P.J. Urban[1], X.J.M. Leijtens[1],
E. Smalbrugge[1], T. de Vries[1], R. Nötzel[1], Y.S. Oei[1], H. de Waardt[1], M.K. Smit[1]

We present a low cost and polarization independent photoreceiver which is part of the optical network unit (ONU) of a fiber access network. It consists of a 30 μm long InP-photodetector with 35 GHz bandwidth, and a low cost SiGe amplifier with 3 GHz bandwidth. They are wire bonded together on a common substrate. This photoreceiver showed clear open eyes at 4 Gbit/s with Q factor higher than 11 when the input optical power is -12 dBm.

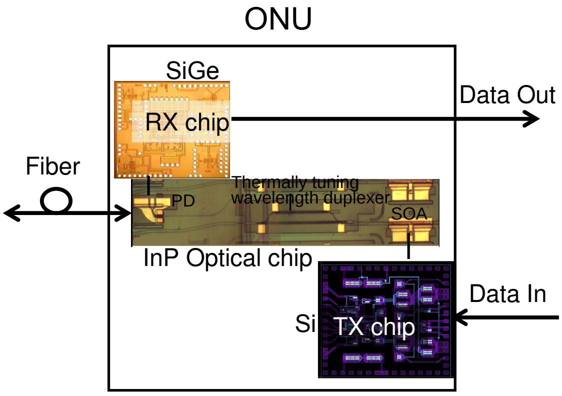
1 Introduction

Driven by the technology development and user demands on the huge bandwidth, the bit rate of optic fiber communication has been demonstrated up to 160 Gbit/s on-field based on optical time division multplexing (OTDM) [1] or Polarization-Division Multiplexed RZ-DQPSK [2]. Comparing with the demonstrated bit rate in the backbone network, however, currently the most commonly available bitrate of installed optical network units (ONU) at the user side is 156 Mbit/s for upstream data carried by a 1310 nm Fabry-Pérot laser, and 656 Mbit/s downstream data carried by 1550 nm in a TDM-BPON system in Japan [3]. The main limiting factor for the user access network is the cost, especially of the network operation and maintenance. One solution to decrease both the cost of the ONU and of the network operation is a colorless ONU, which was investigated in Dutch Broadband Photonics project (BBP) [4] aims for 10 Gigabit Ethernet user access network.

The ONU in BBP consists of three parts: a colorless monolithically integrated reflective transceiver [5] based on InP (optical part of ONU), an amplifier receiver chip based on SiGe and a transmitter burst mode driver chip based on Si, Fig. 1 (left).

In this paper, we will present the design and measurement results of the photoreceiver chip of the ONU which consits of one InP-photodetector, and an amplifier chip comprising a transimpedance amplifier (TIA) and a variable gain amplifier (VGA) which is a three stage amplifier with two tuning voltages, based on SiGe. The two chips are wire bonded together. The block functionality diagram and the photograph of the fabricated chip are shown in Fig. 1 (right). The photodetector was fabricated based on InP because the photodetector will be monolithically integrated with a semiconductor optical amplifier (SOA) acting as a reflective modulator at 1.55 μm. The electrical amplifier circuit is based on low cost SiGe. When the downstream data carried by the light is detected by the photodetector, the generated photocurrent will be pre-amplified and converted into a differential output voltage. The amplifier circuit also provides a DC bias voltage to the photodetector. The measured eye diagram of this photoreceiver shows clear open eye, and Q factor higher than 11 at 4 Gbit/s with -12 dBm input optical light before fiber-chip coupling.

[1]are with COBRA research institute, Technische Universiteit Eindhoven.
[2]are working in TNO Defence, Security and Safety, the Hague.



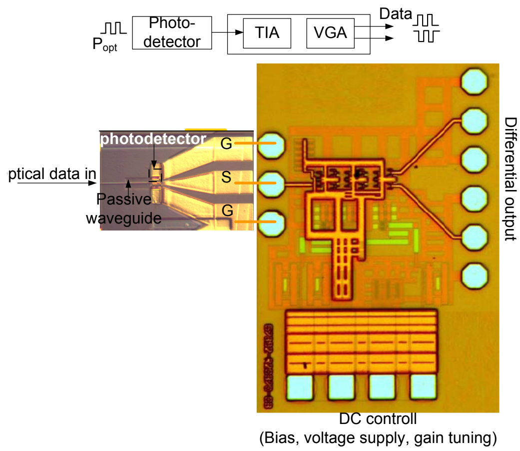


Figure 1: Left: Colorless ONU building blocks with three chips (sizes are not in scale). Right: Block functionality diagram of the photoreceiver and the photograph of the fabricated photoreceiver consisting of an InP-photodetector and a SiGe amplifier connected with bonding wires.

2 Fabrication

The InP photodetector is a ridge waveguide photodetector based on semi-insulating InP-substrate with lateral ground contacts. The photodetector is fabricated in the same run in which the full transceiver ciruict was realized. It has a 120 nm active layer (Q1.55 InGaAsP, $\lambda_{gap} = 1.55\,\mu$m) sandwiched between two 190 nm thick Q1.25 film layers. The photodetector is 1.5 μm wide and 30 μm long. The waveguide was deeply etched by reactive ion etching (RIE). Polyimide was spun for passivation and planarization. Before metallisation, firstly we etched back the polyimide in a barrel etcher to expose the p-InGaAs contact layer. To form the metal contact, Ti/Pt/Au were evaporated on the top p-InGaAs and the lateral grounds (n-InP) and patterned through lift-off. The access side of the finished photodetector is a cleaved facet with about 33% (26%) reflectivity for TE (TM) polarized light. The total fiber-chip coupling loss was estimated about 5 dB due to the reflection at the facet and the mode mismatch between the fiber and the input waveguide of the photodetector.

The amplifier circuit is implemented in the low cost AMS 0.35 μm-SiGe BiCMOS process that includes high-speed SiGe Heterojunction Bipolar Transistors. Finally, these two chips were bonded together through wires with 20 μm diameter.

3 Characterization

The bandwidth of the fabricated InP photodetector is about 35 GHz, and the external responsivity is about 0.25 A/W, shown in Fig. 2 (left). The measured polarization dependence in the responsivity is less than 0.27 dB. The measurement results on the amplifier circuit is shown in Fig. 2 (right), in which V1 and V2 are the tuning voltages. The purpose of the tuning voltage V1 is to vary the gain in the VGA depending on the input voltage swing. A second tuning voltage V2 is present to compensate for process variations. The VGA is designed to achieve a constant output voltage swing of 80~90 mV at the output. The bandwidth of this hybrid photoreceiver is mainly limited by the TIA which was measured with a transimpedance gain of approximately 1500 Ω and a bandwidth of 3 GHz.

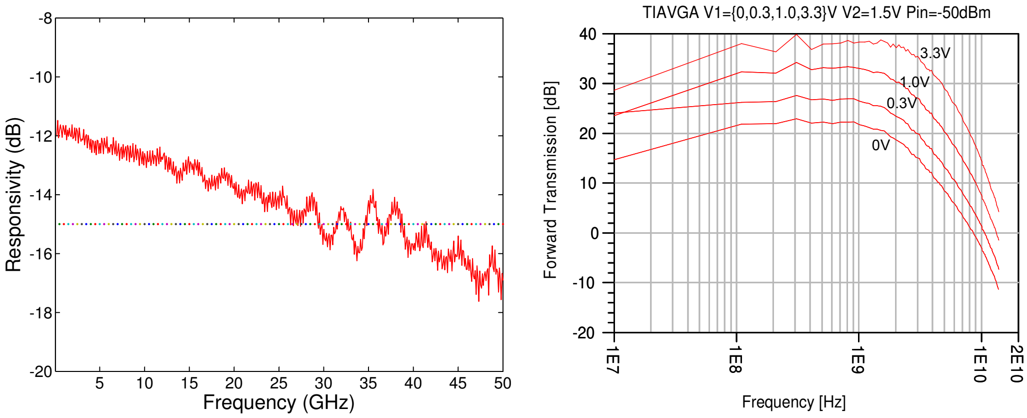


Figure 2: Left: Measured bandwidth and responsivity of 30 μm long InP based photodetector. Right: the measured bandwidth of SiGe amplifier at different gain control voltages.

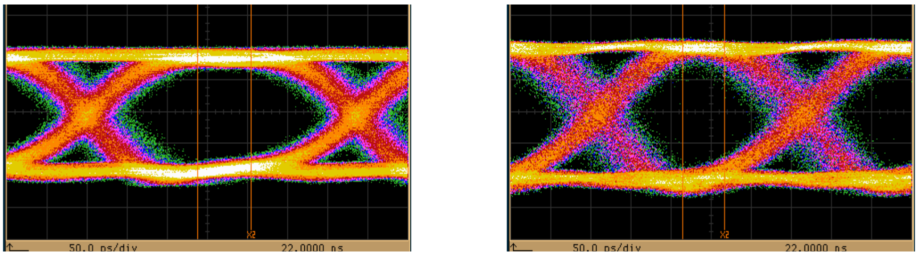


Figure 3: Eye diagrams for 3 Gbit/s (left) and 4 Git/s (right) with -12 dBm input optical power.

The equivalent input noise current is 4.5 pA/$\sqrt{\text{Hz}}$.

To measure the performance of the hybrid photoreceiver, we injected the light at 1545 nm from the tunable laser which was modulated by a 10 GHz commercial Mach Zehnder modulator driven by the pulse pattern generator (PPG) up to 10 GHz. The input optical power was monitored by an in-line power meter. The modulated light was coupled into the photoreceiver chip through a lensed fiber. The light was absorbed by the photodetector which was reversely biased at -3 V, and the generated photocurrent was converted into voltage and amplified by TIA and VGA. The output differential voltage from the photoreceiver was directly input to a digital communication analyzer without additional electrical amplification to record the eye diagram. The tuning voltage V1 was set at 1.5 V, corresponding to about 30 dB gain in Fig. 2. The recorded eye diagrams for PRBS with $2^{31}-1$ word length at 3 Gbit/s and 4 Gbit/s are shown in Fig. 3 for the average input optical power of -12 dBm before the fiber-chip coupling. The measured Q factors are more than 12.85 and 11. The BER measurement was not carried out because the output differential voltage from the amplifier is lower than the minimum required voltage of the error detector.

4 Conclusion and discussion

A low cost and polarization independent photoreceiver which consists of InP-photodetector and a SiGe amplifier developed for Gigabit Ethernet ONU has been presented. The eyes are clear open up to 4 Gbit/s with Q factor higher than 11. The further development on this receiver will include the phase detector and the clock recovery circuit.

This work is partly funded by the Dutch National Broadband Photonics Access project and the Dutch National Smartmix project Memphis.

References

[1] U. Feiste, R. Ludwig, C. Schubert, J. Berger, C. Schmidt, H. Weber, B. Schmauss, A. Munk, B. Buchold, D. Briggmann, F. Kueppers, and F. Rumpt, "160-Gbit/s transmission over 116 km field-installed fiber using 160-Gbit/s OTDM and 40 Gbit/s ETDM," in *Techn. Digest Opt. Fiber Comm. (OFC '01)*. San Diego, California, USA, Mar. 17 2001, p. ThF.

[2] M. Yagi, S. Satomi, and S. Ryu, "Field trial of 160-Gbit/s polarization division multiplexing rz-dqpsk transmission system using automatic polarization control," in *Techn. Digest Opt. Fiber Comm. (OFC '08)*. San Diego, California, USA, Feb. 20–25 2008, p. OThT.

[3] H. Shinohara, "Broadband access in Japan: rapidly growing FTTH market," *IEEE Comm. Magazine*, vol. 43, no. 9, pp. 72–78, Sep. 2005.

[4] P. Urban, E. Klein, L. Xu, E. Pluk, A. Koonen, G. Khoe, and H. de Waardt, "1.25-10 Gbit/s reconfigurable access network architecture," in *International Conference on Transparent Optical Networks (ICTON '07)*. Rome, Italy, July 1–5 2007, pp. 293–296.

[5] L. Xu, X. Leijtens, P. Urban, E. Smalbrugge, T. de Vries, Y. Oei, R. Nötzel, H. de Waardt, and M. Smit, "InP based monolithic integrated colorless reflective transceiver," in *Proc. 14th Eur. Conf. on Int. Opt. (ECIO '08), Post-deadline papers*, X. Leijtens, Ed. Eindhoven, the Netherlands, June 11–13 2008, pp. FrPD4, 13–16, ISBN 978-90-386-1318-5.