Ge on Si p-i-n Photodiodes for a Bit Rate of up to 25 Gbit/s

S. Klinger[(1)], M. Grözing[(1)], W. Sfar Zaoui[(1)], M. Berroth[(1)], M. Kaschel[(2)], M. Oehme[(2)], E. Kasper[(2)], J. Schulze[(2)]

[(1)] Institute of Electrical and Optical Communications Engineering (INT), University of Stuttgart, sandra.klinger@int.uni-stuttgart.de

[(2)] Institute for Semiconductor Engineering (IHT), University of Stuttgart

Abstract *Ge on Si p-i-n photodiodes are characterized on wafer in the time domain at a wavelength of 1550 nm. The photodiode output signal is sampled by a flip flop. At a bit rate of 25 Gbit/s and a Pseudo Random Bit Sequence (PRBS) length of 2^7-1, the Bit Error Ratio (BER) is smaller than 10^{-12}.*

Introduction

Research on Ge photodiodes has been strongly pushed forward in recent years. Their feasibility to be integrated in Si and CMOS processes makes them an ideal candidate for fast optical links in the Near Infrared Range (NIR) where even 100 Gbit/s Ethernet is an aspired goal. The achievable photodiode bandwidth is often presented to demonstrate the performance of a photodetector technology. For optical links, however, the maximum achievable bit rate for operation with PRBS is the most important parameter. Ge on Si p-i-n vertical photodiodes are thus examined in the time domain in this paper. A flip flop is used for sampling the output signal of the photodiode.

Device Structure of the Photodiode

The photodiode is fabricated at the IHT in a 2 mesa Molecular Beam Epitaxy (MBE) process[1]. A thin Ge buffer is used at the interface between the Si substrate and the Ge p-i-n structure. This is necessary due to the lattice mismatch between the two materials. The intrinsic Ge region has a thickness of about 300 nm. The thickness of the whole photodiode stack stays below 1 µm. The diameter of the device under test is 10 µm. A lensed single mode fiber (SMF) with a beam waist diameter of 2.5 µm is used for coupling the light into the photodiode.

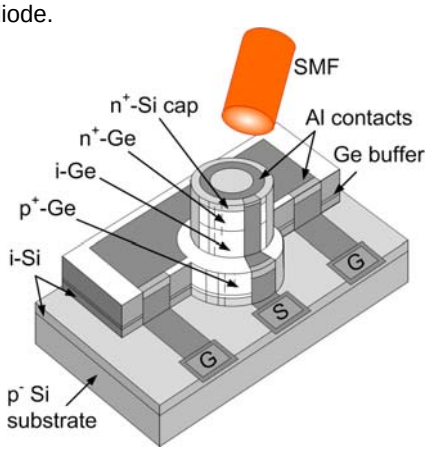

Fig. 1: Device structure of the photodiode.

Characteristics of the Flip Flop

A flip flop is designed at the INT in a 90 nm CMOS technology as an ADC building block. The flip flop in use differs from the flip flop formerly presented[2] in terms of additional inductive peaking. It works up until an input bit rate of 50 Gbit/s. The output differential voltage swing is ±300 mV. The flip flop is designed for differential input and output but also works with the single-ended signal from the photodiode.

Time Domain Measurement Setup

The measurement setup shown in Fig. 2 is used to determine the eye diagram and the BER of the photodiode output signal. The available Bit Pattern Generator (BPG) works up to 12.5 Gbit/s. To provide a bit rate of the input signal of up to 50 Gbit/s, a 4:1 multiplexer (MUX) is used: The inverted and non-inverted output signal of the BPG is split into four data streams by power splitters and the four data streams are de-correlated by transmission lines of different lengths. Thus a Pseudo PRBS data stream with bit rates up to 50 Gbit/s can be generated.The clock signal for the 4:1 MUX is provided by a frequency generator working up to 50 GHz. The according frequency is set to half of the desired data rate. The bit pattern generator provides the clock signal for the oscilloscope and the flip flop. At the flip flop, the clock signal is one fourth of the data rate. The wavelength of the laser is 1550 nm. The optical output signal of the intensity modulator is amplified by an Erbium Doped Fiber Amplifier (EDFA). The optical power at the fiber tip is about 40 mW which provides a current of approximately 5 mA at a bias voltage of -2 V. The flip flop is connected to the RF port of the bias tee. It samples each fourth bit of the incoming data stream. One of the differential outputs of the flip flop is connected to the sample oscilloscope, the other one to a bit error rate tester (BERT).

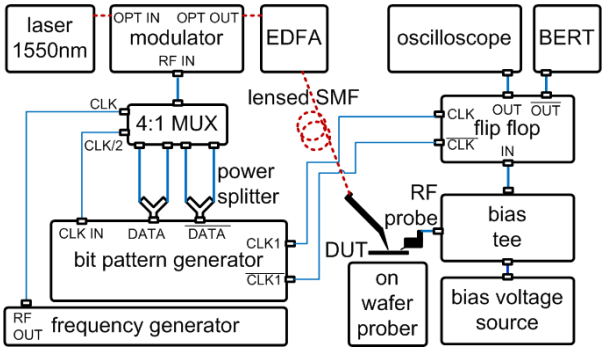

Fig. 2: Setup for time domain measurements.

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Measurement Results

Measurements are done at different data rates. For a photodiode without flip flop, the eye diagram is shown in Fig. 3 for a bit rate of 10 Gbit/s and 20 Gbit/s. The results with flip flop are presented in Fig. 4 for data rates of 20 Gbit/s and 25 Gbit/s. The according PRBS length and the BER are listed in table 1. All measurements are done at a wavelength of 1550 nm and a bias voltage of -2 V.

In the following, these results are shortly compared with other publications[3,4]. High data rates of up to 19 Gbit/s at a bias voltage of -1.8 V across the photodiode are achieved at a wavelength of 850 nm[3]. The lateral Ge on Si photodiode is bonded to a CMOS amplifier stage. At 1550 nm[4], a monolithic optical receiver in 130 nm CMOS integrating a Ge waveguide photodiode obtains 10 Gbit/s. The PRBS length is 2^7-1 and the BER < 10^{-12} in both cases. In this work, the optical signal is amplified rather than the electrical signal. With an appropriate amplifier stage for the photo current suitable for a large frequency range, the EDFA could be replaced.

Tab. 1: Data rate, PRBS length and BER achieved with photodiode and flip flop at 1550 nm.

wavelength	bit rate	PRBS length	BER
1550 nm	10 Gbit/s	2^{31}-1	<10^{-12}
1550 nm	20 Gbit/s	2^7-1	<10^{-12}
1550 nm	20 Gbit/s	2^{31}-1	<10^{-10}
1550 nm	25 Gbit/s	2^7-1	<10^{-12}

Tab. 2: Results of other publications.

850 nm[3]	19 Gbit/s	2^7-1	<10^{-12}
1550 nm[4]	10 Gbit/s	2^7-1	<10^{-12}

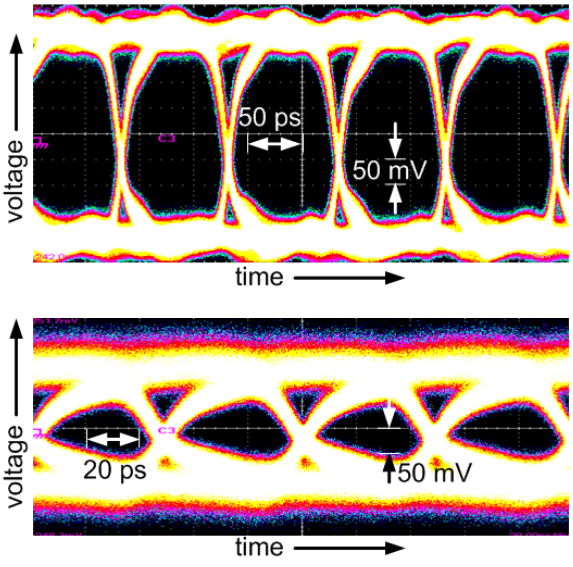

Fig. 3: Eye diagram of photodiode, PRBS length = 2^7-1, bit rate = 10 Gbit/s (top) and 20 Gbit/s (bottom).

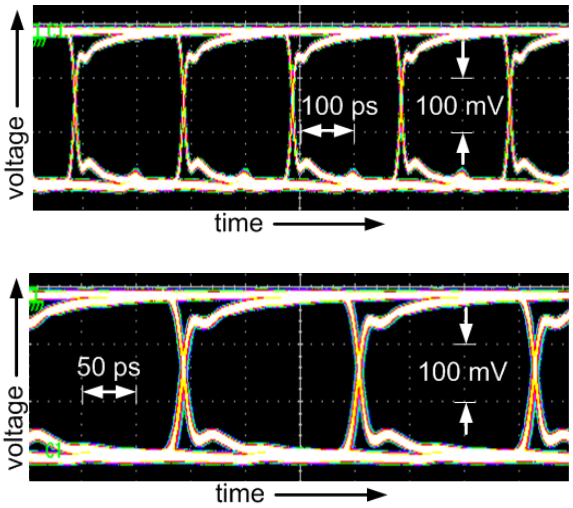

Fig. 4: Eye diagram after the flip flop, PRBS length = 2^7-1, bit rate at the photodiode = 20 Gbit/s (top) and 25 Gbit/s (bottom).

No de-embedding is done, so the frequency response of all passive electrical elements involved deteriorates the overall frequency response. These are the cables from the bias tee to the photodiode, the bias tee itself and the cables and adapters from the bias tee to the flip flop. For example, the 50 GHz cables in use have a loss of above 1.5 dB at 10 GHz. Thus, even higher bit rates are expected for an optimized setup where signal paths are kept as short as possible. This can be done by mounting the photodiode and the amplifier or flip flop on the same RF substrate and connecting them with short bond wires. The assumption is supported by measurements in the frequency domain where 3 dB bandwidth values up to 49 GHz are achieved[5].

Conclusions

Ge on Si p-i-n photodiodes in combination with a CMOS flip flop have been characterized in the time domain. At a bit rate of 25 Gbit/s and a PRBS length of 2^7-1, a BER smaller than 10^{-12} can be achieved. This is to the authors' best knowledge the fastest PRBS transmission experiment with SiGe photodiodes. In order to reduce the optical input power, a transimpedance amplifier stage suited for operation up to 50 Gbit/s is currently developed at the INT in a bipolar SiGe technology.

References

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