The European Galactico Project: Coherent Terabit Ethernet Systems Using 4 µm Rib Waveguide Silicon-on-Insulator Technology and GaAs Electro-optic Modulators

L. Zimmermann (1), K. Voigt (2), K. Vyrsokinos (3), L. Stampoulidis (3), P. Bakopoulos (4), I. Lazarou (4), S. Dris (4), H. Avramopoulos (4), Y. Zhou (5), S. Clements (5), J. Heaton (5), M. Kroh (6), Y. Yamamoto (1), D. Micusik (1), J. C. Sheytt (1), M. Llopis (7), G. B Preve (7), R. Nogueira (8), P. Monteiro (8) A. Chiado' Piat (9) and D. Roccato (9)
(1) IHP Microelectronics, Im Technologiepark 25, 15232 Frankfurt (Oder), Germany
(2) TU Berlin, HFT4, Joint Lab Silicon Photonics, Einsteinufer 25, 10587, Berlin, Germany
(3) Constelex Technology Enablers, Corallia Microelectronics Innovation Center, 12 Sorou Str., Marousi 15125 Athens, Greece
(4) Photonics Communications Research Laboratory, National Technical University of Athens, Zografou 15773 Athens, Greece
(5) u2t Photonics UK Ltd, NETPark Incubator, Thomas Wright Way, Sedgefield, TS21 3FD, Uk
(6) u2t Photonics AG Reuchlinstrasse 10/11. Berlin 10553 Germany
(7) Nanophotonics Technology Center, Universitat Politècnica de València, Camino de Vera s/n, 46022 Valencia, Spain
(8) Nokia Siemens Networks Portugal, S.A. Rua Irmãos Siemens, 1 - 1A Ed. 1, Piso 0, R 2720-093 Amadora Portugal
(9) Telecom Italia, Transport and OPB Innovation Department, Torino 10141, Italy

Abstract

We report R&D efforts of the GALACTICO project. New coherent Terabit Ethernet systems will be integrated using silicon-on-insulator rib waveguide and GaAs modulator technology. We report technology basics and first prototype components.

Introduction

100 Gb/s optical transport is now a commercial reality. Everything is set; the first standard was chosen and commercial products are hitting the market. Now the focus is on photonic integration that will guarantee an efficient migration to 100G in terms of system size, cost, volume production and power consumption. On the transmitter side, InP and LiNbO3 have been used for modulator development [1, 2]. InP offers compactness, but achieving high yield on the small 2-inch wafers is always challenging. LiNbO3 modulators are fabricated on 4-inch wafers and the assembly with passive optical chips is feasible, but modules tend to be bulky. On the receiver side, there is already a turn towards the silicon solution. Silicon-on-insulator (SOI) nanowire platforms have been utilized for monolithic integration of 90^{o}-optical hybrids and photodetectors [3]. The disadvantage is the high insertion loss due to the coupling to the nanowires, so integration in silicon has to be adapted to become mature and meet performance requirements.

In this paper we present two alternative approaches for the integration of coherent Terabit Ethernet systems. We propose the use of a 4µm SOI rib waveguide platform for the hybrid or monolithic integration of coherent receivers. The platform exhibits a low insertion and waveguide loss and mode-size can be matched to enable on-chip coupling of III-V components. In addition, we propose GaAs for the fabrication of electro-optic modulators exploiting standard 6-inch silicon fabrication facilities. This work is done within the GALACTICO project that has officially started on October 2011. Here we present some of the first project results; the fabrication of a 90^{o}-optical hybrid using SOI 4x4 MMIs and DPSK modulation and demodulation using a single drive GaAs modulator and a SOI-DI demodulator.

SOI MMI-based 90^{o} optical hybrid

Coherent receivers rely on integrated optics with defined quadrature phase relations, most prominently the 90°-optical hybrid. SOI nanowire technology could be established as a platform for integrated optics, showing high performance in many applications. However, this technology still shows some drawbacks for PSK receivers such as high insertion loss, high polarization dependence and high sensitivity to fabrication errors.These issues can be avoided with a larger SOI waveguide cross-section. Our approach deploys 4 µm thick SOI, with rib-waveguide dimensions as shown in Figure 1. These dimensions result in a spot-size of approximately 2.5-3 µm, making it well adapted to the mode-size of devices in InP or GaAs.

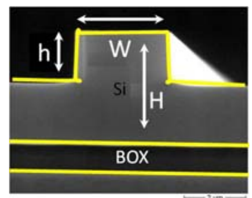

Figure 1 Typical dimensions of intermediate SOI SM rib-waveguides: H = 4µm, h = 2µm, W = 3µm

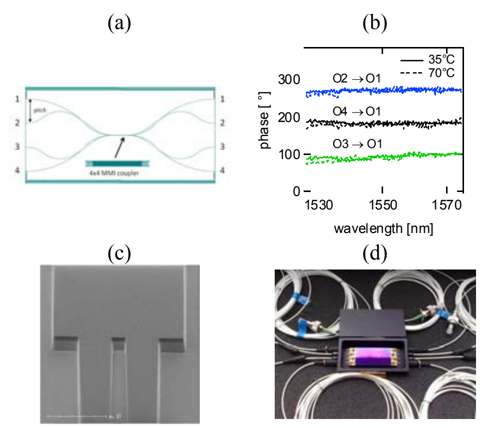

Figure 2. a) 90^{0}-hybrid layout, b) phase performance, c) SEM image of MMI splitter and d) packaged device.

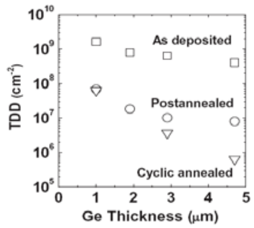

Figure 3. Threading dislocation density of RPCVD grown Ge on Silicon.

Using intermediate SOI rib-waveguide technology we realized fully passive optical 90°-hybrids with low insertion loss and low polarization dependence. The quadrature phase relations are implemented by 4x4 MMIs with high performance accross the C-band. Figure 2 shows the phase stability of passive 90°-hybrids. Figure 2d) illustrates a packaged module. The packaging was done by Optocap Ltd based on a configurable bathtub package.

Germanium photodetectors (Ge-PDs)

The key to the development of such Ge-PDs is high-quality Ge hetero-epitaxy on Silicon. In Galactico, IHP has a long standing in SiGe-technology, mostly applied to their high-speed SiGe:C bipolar devices that range among the fastest in the world. In recent years, considerable effort went into the development of CVD-based epitaxy of pure Germanium. The results are promising (Figure 3). RPCVD grown Ge showed threading-dislocation densities as low as $7x10^7 cm^{-2}$ and an rms surface roughness of 0.4 nm. Presently, we are investigating process integration schemes for Ge waveguide PDs. First electric tests show dark currents levels comparable to state-of-the-art.

40 Gb/s DPSK modulation-demodulation

To validate the GALACTICO technology concept, a GaAs Mach-Zehnder modulator (MZM) was combined with a SOI-DI demodulator in a 40 Gb/s DPSK system. The MZM was based on the commercially available technology of U2t. The transmitter consisted of a DFB laser externally modulated in the GaAs MZM. To generate the DPSK data stream, the MZM was biased at its null point and was driven by a 40 Gb/s single-ended

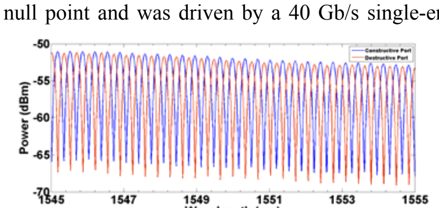

Figure 4: Filter response at DI constructive (blue) and destructive (red) ports.

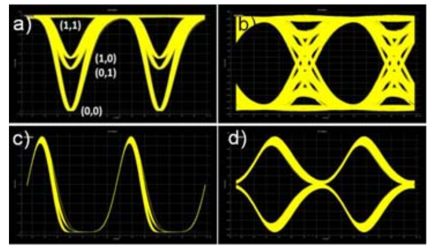

Figure 6. 56 Gb/s NRZ and RZ QPSK modeling results

electrical signal, carrying a 2^7-1 PRBS. The NRZ-DPSK signal was launched in the DPSK receiver, comprising a 25-ps SOI-DI chip for decoding and a 33 GHz single-ended InP photoreceiver. Eye diagrams and pulse traces were recorded at each stage of the setup using a 70 GHz photodetector and an 80 GHz sampling oscilloscope. Figure 5 (a) shows the electrical driving signal at the input of the GaAs MZM. The device was first biased at quadrature to generate a 40 Gb/s OOK data stream (Fig. 5(b)). Subsequent biasing at the MZM null point revealed a DPSK modulated signal (Fig 5 (c)). The DPSK signal was decoded at the SOI DI chip. The two complementary data streams at the DI outputs are shown in Fig. 5(d) and (e). The amplitude variations are due to the fact that the specific MZM was not originally designed for 40 Gb/s DPSK operation, but still error free performance at 1E-11 BER was obtained. Finally, the ability of the GaAs modulator to generate 56 Gb/s QPSK was investigated through simulations. The MZM model incorporated measured electro-optic and phase response from commercial GaAs devices. The setup incorporated two nested GaAs MZM modulators driven by a pair of differential SiGe CMOS drivers. An additional MZM was used as pulse carver for RZ modulation. The driving signals were 28 Gb/s 2^15-1 PRBS (Vpi=3V) for the IQ and 14 GHz sine wave for the carver. Figure 6 shows the results that reveal the feasibility of 56 Gb/s QPSK signal generation using GaAs MZM and SiGe driver IC setup.

Conclusion

We report first R&D efforts of the GALACTICO project. The project aims to provide coherent TbE devices using SOI rib waveguide and GaAs modulator technology.

Acknowledgement

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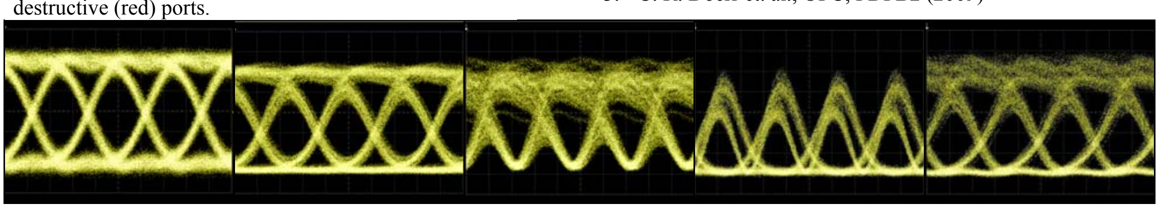

Figure 5. (a) Electrical driving signal at modulator input, (b) 40 Gb/s OOK eye, (c) 40 Gb/s DPSK eye, (d) decoded signal at destructive port and (e) decoded signal at constructive port of the SOI DI.