Silicon CMOS photonics platform for enabling high-speed DQPSK transceivers

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Outline

- Introduction
- DQPSK receiver
- DQPSK transmitter
- Conclusions
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Introduction

The number of devices connected to Internet will be nearly three times as high as the global population by 2017

Source: CISCO VNI, 2013
Introduction

Annual global Internet traffic will pass the zettabyte threshold \((10^{21})\) by 2016

*Source: CISCO VNI, 2013*
Optical fiber communications

Source: CISCO VNI, 2013

LONG-HAUL, METRO
- From 100Gb/s to 1Tb/s
- PDM-QPSK + WDM
- Coherent detection
- High performance

ACCESS
- 10Gb/s (G.987 XG.PON)
- DQPSK
- Differential detection
- Low cost

Large Scale Photonic integration
Photonic integration

**Indium Phosphide (InP)**

- More mature technology
- High performance
- Monolithic integration with CMOS electronics
- Higher cost for high-volume
- Lack of silicon light source

**Silicon photonics (Si)**

- Cost-effective for high-volume

Infinera, CyOptics (Avago) vs Intel, IBM, Luxtera, Lightwire (CISCO), Kotura (Mellanox), Alcatel-Lucent
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Silicon DQPSK receiver

M. Aamer et al., to be published in IEEE Photon. Tech. Lett., 2013
Silicon DQPSK receiver

DQPSK signal → Mach-Zehnder Delay Interferometer (MZDI) → 2x4 90° hybrid → Balanced PD → I signal
DQPSK signal → Mach-Zehnder Delay Interferometer (MZDI) → 2x4 90° hybrid → Balanced PD → Q signal

FOOTPRINT ~1mm²

Fabrication at CEA-LETI CMOS foundry (Grenoble, France)
MZ delay interferometer

10 Gbit/s DQPSK

- 5 Gb/s - I
- 5 Gb/s - Q

T = 200 ps

ΔL = 18 mm

- Footprint → Compact spirals
- Bend losses → Adiabatic bends (R=5 µm)
- Propagation losses → Tunable splitter

Footprint

Compact spirals

Bend losses

Adiabatic bends (R=5 µm)

Propagation losses

Tunable splitter
Tunable power splitter

M. Aamer et al., Optics Express, vol. 20, pp. 14698, 2012

10Gb/s DPSK receiver
90° hybrid + BPD

- 10µm-long Ge BPD
- No bias $\rightarrow P_{DC}=0W$


$$i_l(t) \propto \cos(\Delta \Phi)$$

$$i_Q(t) \propto \sin(\Delta \Phi)$$
10Gb/s DQPSK receiver

10Gb/s operation
On-chip loss $\approx 15$ dB

DQPSK transmitted

DQPSK received

$P_R = -22$ dBm
BER = $4 \cdot 10^{-6}$

$P_R = -19$ dBm
BER = $10^{-15}$
20Gb/s DQPSK receiver

DQPSK transmitted

MZDI

DQPSK received

Reference constellation

$P_R=-12\text{dBm}$, $BER=1.7 \cdot 10^{-7}$
Polarization diversity

And polarization?

- Compact design (25µm-long)
- PCE > -0.85dB @ 30nm
- Insertion loss < 2.5dB

Experimental set-up

DQPSK transmitter

DQPSK receiver
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Silicon DQPSK transmitter

- Laser
- Mach-Zehnder Modulator (MZM)
- $\pi/2$-phase shift
- DPSK dual-drive MZM (push-pull operation)
- DQPSK signal
Silicon DQPSK transmitter

- Laser
- Mach-Zehnder Modulator (MZM)
- $\pi/2$-phase shift

Output: DQPSK signal

FOOTPRINT $\approx 3.8\text{mm}^2$

Dimensions:
- Width: 3mm
- Height: 0.8mm
- Length: 4.75mm
Silicon MZM

- Carrier depletion
- Self-aligned PN junction

\[ V_{\pi}L = 3.6 \text{ V} \cdot \text{cm} \]

On-chip loss = 10dB

Experimental set-up
Experimental set-up

- Silicon chip
- GSGSG RF probe
- 50Ω load
- Data
Measured results

Modulated eye diagram

Demodulated eye diagram

5Gb/s DPSK

10Gb/s DPSK
Measured results

- ~2dB power penalty
- No error floor

High modulation speed

- Not possible to demodulate due to DGD limitation
- Inter-symbol interference (ISI) is not observed
- High modulation speed feasible
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Conclusions and future work

- Silicon DQPSK receiver
  - Polarization diversity scheme + inverted taper
  - Integrate TIA and tuning circuitry
- Silicon DQPSK transmitter
  - Nested configuration
  - Reduce $V_\pi$ and insertion losses
  - Integrate MZM drivers and DC circuitry
- Full silicon DQPSK transceiver
  - Laser source
  - Packaging and assembling
Acknowledgements