Compact filter structures in Silicon-on-Insulator for high-speed signal processing

Stefan Schwarz, Christian G. Schäffer
Helmut Schmidt University Hamburg, Department of High-Frequency Engineering and Optoelectronics

Abdul Rahim, Jürgen Bruns, Klaus Petermann
Berlin Institute of Technology, Hochfrequenztechnik-Photonics

11th July 2013
Agenda

- Approach of optical Serial-Parallel Filter Structures
- Realization in Silicon-on-Insulator
- Application Example I: OFDM Demultiplexing
- Application Example II: Dispersion Compensation
- Summary and Outlook

This project has been funded with the financial support of German Research Foundation
Agenda

• Approach of optical Serial-Parallel Filter Structures
• Realization in Silicon-on-Insulator
• Application Example I: OFDM Demultiplexing
• Application Example II: Dispersion Compensation
• Summary and Outlook
Approach of optical Serial-Parallel Filter Structures

shortening filter length

increasing MMI order
Agenda

• Approach of optical Serial-Parallel Filter Structures

• Realization in Silicon-on-Insulator

• Application Example I: OFDM Demultiplexing

• Application Example II: Dispersion Compensation

• Summary and Outlook
Realization in Silicon-on-Insulator

- Combination of MMI couplers, delay line regions and phase shifters

Input

MMI coupler

delay lines

Output

phase shifters

area consumption ≈ 6.7 cm²
Realization in Silicon-on-Insulator

- Fiber alignment using multi-axis stages
Realization in Silicon-on-Insulator

- Trenches and Substrate etching change the direction of heat flux
Realization in Silicon-on-Insulator

![Image with measurements]

- 24 μm
- 10 μm
- 4 μm
- >25 μm

**Parameters:**
- E Beam: 10.0 kV
- Spot: 3.0
- Magn: 2500x
- WD: 5.0
- Exp: 3

*Wet-Etch-cross-section*
Agenda

• Approach of optical Serial-Parallel Filter Structures
• Realization in Silicon-on-Insulator
• Application Example I: OFDM Demultiplexing
• Application Example II: Dispersion Compensation
• Summary and Outlook
Application Example I: OFDM Demultiplexing

- **WDM technique as typical approach for multi-channel transmission:**

  - Multi-Carrier Generator → Multiplier → Fiber → Demultiplexer → Receivers

- **Orthogonal frequency-division multiplexing (OFDM) approach for higher spectral efficiency:**

  - Multi-Carrier Generator → Multiplier → Fiber → Demultiplexer → Receivers
Application Example I: OFDM Demultiplexing

- Realization in 4 μm SOI:

- Filter Design:

- Filter Layout:

  - 2,2 cm x 1,9 cm
Application Example I: OFDM Demultiplexing

- Using VPI to emulate the splitting performance of the DFT-Demux

- 37 GBaud (QPSK)
- one polarization
- 3rd order 400 GHz gaussian noise filter
- varying laser linewidth (0 kHz, 100kHz, 1 MHz)
- varying OSNR
- varying Tx/Rx bandwidth (1st order bessel filter with 27 GHz … 75 GHz)
Application Example I: OFDM Demultiplexing

- BER vs. OSNR Plots (Tx/Rx bandwidth = 50 GHz, laser linewidth = 0 kHz)

- Ideal DFT filter response:

- Meas. DFT filter response:
Application Example I: OFDM Demultiplexing

- Realization in nano-photonic (manufactured @IHP, Frankfurt Oder):
  - 8×12.5 GBaud QPSK demultiplexer
  - small footprint of only 5 mm × 3 mm
  - one-dimensional grating coupler for in- and out-coupling
  - Insertion Loss ≈ 10 dB (3 dB/grating coupler, 4 dB waveguides and MMI couplers)
  - 28 mW for 360° phase shift
Agenda

• Approach of optical Serial-Parallel Filter Structures

• Realization in Silicon-on-Insulator

• Application Example I: OFDM Demultiplexing

• Application Example II: Dispersion Compensation

• Summary and Outlook
Application Example II: Dispersion Compensation

Distortion of transmitted signal due to chromatic dispersion

![Diagram of signal processing system with source, transmitter, channel, filter, receiver, and sink.]

1. Distortion of transmitted signal due to chromatic dispersion

\[ s_1(t) \]

\[ s_2(t) \]

\[ s_3(t) \]

\[ ...010110111001011... \]

\[ ...010110111001011... \]
Application Example II: Dispersion Compensation

- **Filter Design:**

  - Diagram showing a network of MMI (Multimode Interference Coupler) devices with tunable couplers.

- **Scalability:**

  - Graph showing scalability with 100 GHz bandwidth and conditions: \(|\tau_{\text{Ripple}}| < 3\) ps, RBWU = 0.4·FSR.

- **Measurements:**

  - Graphs showing normalized transmission in dB and group delay in ps over wavelengths from 1550 to 1551 nm.
Application Example II: Dispersion Compensation

- Using VPI to emulate the equalizing performance of the dispersion compensator

- 28 GBaud (QPSK)
- one polarization
- 3rd order gaussian noise filter (BW = 42 GHz)
- laser linewidth (100 kHz)
- varying OSNR
- Tx/Rx bandwidth (1st order bessel filter, BW = 28 GHz)
Application Example II: Dispersion Compensation

- BER vs. OSNR Plot
  - -100 ps/nm residual dispersion
  - filter curve „D“
  - Baud rate = 28 GHz
  - Tx/Rx bandwidth = 28 GHz
  - Laser linewidth = 100 kHz

- OSNR requirements (@BER = 1\cdot10^{-3}) for different residual dispersion values
Agenda

• Approach of optical Serial-Parallel Filter Structures

• Realization in Silicon-on-Insulator

• Application Example I: OFDM Demultiplexing

• Application Example II: Dispersion Compensation

• Summary and Outlook
Summary

- serial-parallel approach for compact FIR filter structure with low complexity
- realization in Silicon-on-Insulator (SOI)
- various applications are possible
  - OFDM demultiplexer
  - chromatic dispersion compensation
  - …
- results show good performance
  - separation of OFDM channels
  - equalization of distorted signals

Thank you for your attention!

Outlook

- selection of one good chip for packaging process
- real-time measurements
Attachment (Realization in Silicon-on-Insulator)

- Fiber alignment using multi-axis stages

4mm + 150mm travel
10nm resolution (closed loop)

4mm travel
5nm resolution (closed loop)

Planar filter
Attachment (Realization in Silicon-on-Insulator)

- **Optimization of fiber position using tracking system**

NanoTrack with 2-CH Piezo

2x

2-CH Stepper

2x
- OSNR requirements (@BER = 3.8·10⁻³) for different Tx/Rx bandwidths (laser linewidth = 0 kHz)

- Ideal DFT filter response:

By assuming a laser linewidth of 100 kHz and 1 MHz, the given OSNR values increase by approximately 0.1 dB and 0.7 dB, respectively.