Silicon Photonics in Optical Communications

Lars Zimmermann, IHP, Frankfurt (Oder), Germany
Outline

• IHP – who we are
• Silicon photonics
• Photonic-electronic integration
• IHP photonic technology
• Conclusions
IHP in East Brandenburg

1hr east of Berlin.

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IHP at a Glance

Institute of the Leibniz Association
- 300 people from 22 countries, including 130 scientists
- Founded in 1983
- Owner is the State of Brandenburg

Main Activities
- R & D for wireless and broadband communication, health, security, space and industrial automation with silicon based systems, RF circuits and technologies

Core Competencies
- Design of wireless systems and RF circuits
- Development of modular BiCMOS including RF MEMS and Si Photonics
- New device concepts and materials in technology
- Preparation of prototypes and small series in own pilot line

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0.25/0.13μm BiCMOS

200mm technology

• regular MPW service
• 24/7 operation
• mixed signal design kit support

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<th>Year</th>
<th>SG13S</th>
<th>npn13P</th>
<th>npn13V</th>
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<td>Gate Delay (ps)</td>
<td>2.0ps</td>
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<td>fT (GHz)</td>
<td>200/200</td>
<td>300/350</td>
<td>300/300</td>
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<td>fmax (GHz)</td>
<td>70/100</td>
<td>120/140</td>
<td>2.5ps</td>
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<th>C-Doped SiGe base</th>
<th>Profile optimization</th>
<th>Self aligned &amp; elevated extrinsic base</th>
<th>Low parasitic coll. design</th>
<th>Optimized base link</th>
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IHP’s focus: More than Moore technologies

IHP: 0.13 µm BiCMOS

Source: ITRS Roadmap 2005

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Teaming Up!
Joint Lab Silicon Photonics
Why silicon photonics?

Traffic growth

Source: Cisco Systems,

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Why silicon photonics

Transport networks

SE = spectral efficiency
= per channel bit-rate / channel spacing [bit/s/Hz]

(Source: P. Winzer, Bob Tkach Alcatel-Lucent)

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Why silicon photonics

Transport networks

• multiplexing
• higher order modulation formats

(Source: P. Winzer, Alcatel-Lucent LEOS Newsletter)

High performance complex coherent TRx technology

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Why silicon photonics

High-performance computing / data center

Length: ~100m
# links: ~5-10K
BW: ~10Gbps/link
Power: ~50mW/Gb/s/link

Price: few$ per Gbps
Reliability!

Source: IBM Bert Offrein

MareNostrum (Barcelona) 62TFlops
About 5000 fiber cables

MareNostrum central switch racks:
About 1700 fiber cables/rack today

Low-cost high-bandwidth short-reach interconnects

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Why silicon photonics

Fiber to the home (FTTH etc)

Source: Cisco White Paper

Optical network unit etc

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Why silicon photonics

Radio access networks

Remote radio-head hauling etc

Source: Fujitsu Global

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Photonic electronic integration

- Future transmission systems should provide
  - Higher power efficiency
  - Lower cost
  - Higher capacity

- Key enabling technology: photonic-electronic integration

Source: 100G Ultra Long Haul DWDM Framework Document, OIF

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About complexity

Transimpedance amplifier

Most complexity on electronic side


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Parasitics often dominate achievable bandwidth and drive ability.

Minimizing R, C, L calls for optics really close to the transistors.

Monolithic / frontend-of line photonic electronic integration or Photonic Electronics
Photonic CMOS

SOI-CMOS
- Luxtera (130nm)
- IBM (90nm)

Bulk CMOS with SPE / poly-SOI
- Samsung (65nm)
- MIT/TI (28nm)
Communication ICs

Typical driver IC technologies: GaAs, InP, SiGe

IHP 40Gbit/sec modulator driver
IHP 40Gbit/sec transimpedance amplifier

Figure of merit
breakdown-voltage $\times f_T$

Photonic BiCMOS

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Photonic BiCMOS?

High performance BiCMOS usually implemented on bulk silicon

1) Fabrication incompatibility

BiCMOS deep sub-collector implant

Source: http://www.iue.tuwien.ac.at/phd/puchner/node48_app.html

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Photonic BiCMOS?

High-speed electronics power hungry

Driving easily >400mW

Excellent heat dissipation vital for high-speed

2) Buried oxide incompatible with HBT heat dissipation

Heat dissipation through buried oxide (SiO$_2$) 1.4W/mK

Heat dissipation through bulk silicon 149W/mK

Source: Intel

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Reconciliation – Local SOI

1) Fabrication incompatibility
2) Buried oxide incompatible with HBT heat dissipation


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IHP SiPh technology

\[ \text{signal [dBm]} \]

\[ \text{wavelength [µm]} \]

\[ 220\text{nm} \quad \text{c-SOI} \]

\[ 65\text{nm} \quad \text{nanorib} \]

Oxide

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IHP SiPh technology

Linear loss measurements

1.9 dB/cm

-0.35 dB/cm
Fiber coupling - grating couplers

Standard linear

Typically
- -4dB insertion loss
- 30nm 1dB bandwidth

Linear enhanced

Typically
- -1.5dB insertion loss
- 30nm 1dB bandwidth

S. Lischke
Accepted, ACP, Beijing, 2013

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Germanium photodetectors

Ge waveguide photodiode

Cross section

S. Lischke

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E/O waveguides for modulators

Phase shift by free carrier dispersion

![Diagram showing phase shift and absorption losses](image)

$\Delta V = 5V$

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Modulators – resonant structures

S. Meister et al, OPTICS EXPRESS, 2013

U = 3 \ V_{pp}

E = 160 \text{ fJ/bit @ 25Gb/s}

Injection type operation

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Depletion type MZ modulators

D. Thomson et al, IEEE STQE, 2013

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Modulator with 10Gbit/sec driver

Phase shift + tuning

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Driver design

Simplified schematic

Design for 10Gbit/sec operation.

Differential output: 5.6V

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Cross sections

Mixed substrate
Photonic BiCMOS: Driver + Mach-Zehnder modulator

L. Zimmermann et al, ECOC, 2013
Conclusions

• Photonic BiCMOS first driver + MZM results
• Local SOI technology to reconcile BiCMOS and SOI

• Photonic BiCMOS for
  – High-performance SiPh
  – System integration
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