NEW PLATFORM SOI310-PHMP2M FOR PHOTONIC INTEGRATED CIRCUIT OF CEA LETI’ MPW ACTIVITY

LETI CONFIDENTIAL  CMP annual meeting| Fournier Maryse
Our research fields

CEA LETI: 1700 researchers (190 PhD), 2200 patents (40% licensed), 250 M€/year
→ Nanocharacterization platform, 300 mm and 200 mm lines for nanoelectronics, MEMS, 3D integration, photonics
→ 8000 m² of clean rooms
Goal
- Offer more traffic capacity (at ever level of the communication channel)

How this can be done
- Offer high-speed optical links for shorter distances.

What has to be done
- Reduce device cost and consumption.
- Integrate more functions on chip.

Driver
- Short distance links is a high-volume market

<table>
<thead>
<tr>
<th>Telecom</th>
<th>DataCom</th>
<th>ComputerCom</th>
</tr>
</thead>
<tbody>
<tr>
<td>1km à 100km</td>
<td>1m à 2km</td>
<td>&lt;1m</td>
</tr>
<tr>
<td>C-Band : 1.55µm</td>
<td>O-Band : 1.31µm</td>
<td>big volume</td>
</tr>
</tbody>
</table>

Roadmap for photonics
Leti clean rooms have state of the art equipment offering a broad range of processes on 200mm & 300mm wafers:

- Deep UV 193 nm lithography with 80nm resolution,
- Dry etching with very low sidewall roughness -Silicon and SiNx waveguides-,
- Amorphous Silicon,
- Germanium epitaxial growth on Silicon,
- p-type and n-type ion implantation,
- Direct bonding and processing of III-V-materials on Silicon: wafer to wafer and die to wafer.

Supporting you from design to prototyping of devices, integrated circuits and packaging solutions.

Leti’s Silicon Photonics-based solutions for optical communications

Supporting you in setting up your supply chain.
STRONG EXPERIENCE IN PHOTONIC ‘s MPW

PhotonFab → 2011

ePIXnet → 2008

SOI 310nm Actives and Passives components Offer

SOI 220nm Passives components Offer

SOI 220nm Actives and Passives components Offer

Flex Offer

OPEN 3D

New Offer

Q4/2016

✓ New platform brings higher performance for grating couplers

✓ New library for $\lambda=1.31 \, \mu m \, TE \, mode$
**Goal:** Validate a generic platform for prototyping application for end users

**Means:**
- To develop the generic photonic technology with 3D integration allowing photonic and electronic convergence.
PHOTONIC WORK FLOW WITH CMP

CMP MPW wafer service
- Customer interface
- Order form
- Support for design, Layout
- DRC
- Dicing & Packaging

LETI
- Mask preparation
- Adding Boarder for fabrication Tracking
- Adding dummies

Fabrication of Photonic circuit on CMOS 200mm Platform

For Dicing & Packaging

Optical and Electrical Tests on test chips

LETI
3D Technology implementation
- Interconnections
- Components stacking
- Metalization

Optional Packaging: Tyndall

Example of Final realization:
EIC & PIC
Tyndall assembly

Electronic IC
RF Input
Si Photonic IC
DC Inputs

Grating Couplers

CEA/LETI/DOPT/SCOOP/Maryse Fournier | PAGE 7
Our Design tool environment & Circuit development

DRM including packaging rules, library and photonic design Kit

- Development of a reference PDK containing all layout information
- Process Design Kit context (DRM): Choose rules in the global offer (EU) DRM. Define the minimum or unique value for each design rule.

Building the library: component modeling

- Creation of component analytical models based on measured behavior
- Parameterization of these models by final user to fit with design constraints

From simple components to complete integrated systems

- Putting things together: simulation of complete circuit, design rule checking and tape-out

Simulation with user-friendly interfaces

- Our libraries are compatible with CADENCE IDE using the Eldo simulator and with ASPIC from the Phoenix software suite

Ring modulator model

Parameters extraction

Microring Modulator Model

Electrical

Optical

Parameters extraction

Electro-optic Modulation: \( (A, Q, \lambda_r) \) as functions of \( I \)

\[
\Delta \lambda_r, \text{total} = -a(\sqrt{1+b \cdot I} - 1) + c \cdot I^2
\]

*Compact models for carrier-injection silicon microring modulators, OSA 2015

RuiWu1,2; Chin-Hui Chen2, Jean-Marc Fedeli3, Maryse Fournier3, Kwang-Ting Cheng1, and Raymond G. Beausoleil2
BASIC BUILDING BLOCKS FOR A TRANSCEIVER PHOTONICS INTEGRATION CIRCUIT (TOP VIEW)

Optical modulator up to 40Gb/s

Laser source

Ring modulator

Waveguides

WDM filters

Fiber coupler

NEW MPW OFFER ON SOI310NM / BOX 800NM

Si310-PHMP2M

- MZ and RR Modulators
- 4 level implants
- Silicidation
- TiN Metal Heater layer
- Tungsten Plugs
- 2 BEOL Metallization for routing
- Friendly Packaging

- SOI substrate HR BOX 800nm / Si 310 nm
- Passive structures (1 mask layers DUV 193nm)
  - CD min 120nm
  - 300nm / 150nm
  - 150nm / 0
  - Optional Slab 65nm (DeepRib WG)
- Germanium PD’s fabrication
  - n and p implant level

A 40 Gbit/s optical link on a 300-mm silicon platform D Marris-Morini et Al. 2014 Optics express
<table>
<thead>
<tr>
<th>Passives components</th>
<th>Heaters</th>
<th>Lateral Ge PIN diode</th>
<th>Carrier depletion PN MZ or RR Modulator</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="passives.png" alt="Image" /></td>
<td><img src="heaters.png" alt="Image" /></td>
<td><img src="diode.png" alt="Image" /></td>
<td><img src="carrier.png" alt="Image" /></td>
</tr>
</tbody>
</table>

**Passives components**

- **Heaters**
  - **Thermal efficiency:**
    - $0.5 > TE > 0.2 \text{nm/mW}$
  - **Sheet resistance:**
    - $5.5 \text{ohm/Sq}$

- **Lateral Ge PIN diode**
  - **Responsivity:**
    - $> 0.75 \text{A/W}$
  - **Dark current:**
    - $< 10 \text{nA @ -1 V}$
  - **Bandwidth -3dB in S21 @ -1V:**
    - $30 \text{GHz}$

**Coupler 1D**

- **Coupler 1D**
  - IL $< -2.5 \text{dB loss}$
  - **Monomode Rib waveguide**:
    - Losses: $< 2.5 \text{dB/cm}$
  - **Multimode Rib Waveguide**:
    - Losses: $< 0.3 \text{dB/cm}$

**Sign in Q1 or Q4 2016 through**

- [http://www.europractice-ic.com](http://www.europractice-ic.com)

**Si310-PHMP2M**

- **Carrier depletion**
  - $V_{\text{pi,Lpi}} < 2.5 \text{V.cm}$
  - Prop Loss $< 2 \text{dB/mm}$
  - Data Rate up to $25 \text{Gbps}$

**Si310-PHMP2M sign in Q4 2016**

- **Very high performance building blocks for $\lambda=1.31 \text{µm}$ and later $\lambda=1.55 \text{µm}$**
- **Compatible Photonics and process 3D from CEA-LETI for Electronics integration**
- **PDKs available via Cadence, Phoenix software, and Mentor Graphics**
- **Technology compatible design rules with 300 mm industrial foundry**

![Image](new_soil.png)
<table>
<thead>
<tr>
<th>Devices:</th>
<th>Type of cell:</th>
<th>Comment:</th>
</tr>
</thead>
<tbody>
<tr>
<td>CrossingSMRib_1310_BB</td>
<td>Black Box</td>
<td>Black Box used for Crossing RIB</td>
</tr>
<tr>
<td>MMI1X2_1310_BB</td>
<td>Black Box</td>
<td>Black Box used for Multimode interferometer 1x2</td>
</tr>
<tr>
<td>MMI1X4_1310_BB</td>
<td>Black Box</td>
<td>Black Box used for Multimode interferometer 1x4</td>
</tr>
<tr>
<td>MMI2X2_1310_BB</td>
<td>Black Box</td>
<td>Black Box used for Multimode interferometer 2x2</td>
</tr>
<tr>
<td>TAPER100_SMDRIB_SMRIB_1310_BB</td>
<td>Black Box</td>
<td>Black Box used for Transition single Mode DEEP RIB / Single mode RIB</td>
</tr>
<tr>
<td>TAPER100_SMRIB_MMRIB_1310_BB</td>
<td>Black Box</td>
<td>Black Box used for Transition single Mode RIB / Multi mode RIB</td>
</tr>
<tr>
<td>TAPER100_SMSTRIP_MMRIB_1310_BB</td>
<td>Black Box</td>
<td>Black Box used for Transition single Mode STRIP / Multi mode RIB</td>
</tr>
<tr>
<td>TAPER100_SMSTRIP_SMRIB_1310_BB</td>
<td>Black Box</td>
<td>Black Box used for Transition single Mode STRIP / Single mode RIB</td>
</tr>
<tr>
<td>gratingCoupler1DTE_1310_BB</td>
<td>Black Box</td>
<td>Black Box used for Fiber grating coupler 1D</td>
</tr>
<tr>
<td>gratingCoupler2DTE_1310_BB</td>
<td>Black Box</td>
<td>Black Box used for Fiber grating coupler 2D</td>
</tr>
<tr>
<td>FABATCEALETI</td>
<td>Fixed</td>
<td>CEA LETI Logo used for MPW contribution</td>
</tr>
</tbody>
</table>
## DK_PHOTONIC_SI310PHMP2M LIB CONTENTS

<table>
<thead>
<tr>
<th>Devices:</th>
<th>Type of cell:</th>
<th>Comment:</th>
</tr>
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<tbody>
<tr>
<td>pc_bend90WG_1310</td>
<td>Parametric</td>
<td>90° Bend Waveguide</td>
</tr>
<tr>
<td>pc_DirectionalCoupler_1310</td>
<td>Parametric</td>
<td>DirectionalCoupler Waveguide</td>
</tr>
<tr>
<td>pc_Racetrack_Resonator_1310</td>
<td>Parametric</td>
<td>Racetrack Resonator Waveguide and heater</td>
</tr>
<tr>
<td>pc_SbendWG_1310</td>
<td>Parametric</td>
<td>Sbend Waveguide</td>
</tr>
<tr>
<td>pc_Yjunction_1310</td>
<td>Parametric</td>
<td>Y junction Waveguide</td>
</tr>
<tr>
<td>pc_straightWG_1310</td>
<td>Parametric</td>
<td>Straight Waveguide</td>
</tr>
<tr>
<td>pc_SealRing_1310</td>
<td>Parametric</td>
<td>Sealring used for MPW contribution</td>
</tr>
<tr>
<td>pc_PiNDIODE_1310</td>
<td>Parametric</td>
<td>Photodiode PiN longitudinal</td>
</tr>
<tr>
<td>pc_MZI_PN MOD_1310</td>
<td>Parametric</td>
<td>Mach Zehnder Modulator</td>
</tr>
<tr>
<td>pc_RR_MOD_PN_1310</td>
<td>Parametric</td>
<td>Ring Racetrack Modulator</td>
</tr>
<tr>
<td>pc_Label</td>
<td>Parametric</td>
<td>Convert Label to Polygon</td>
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The device performances are shown in the table below:

<table>
<thead>
<tr>
<th>Devices:</th>
<th>Specification:</th>
<th>Value:</th>
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</thead>
<tbody>
<tr>
<td>CrossingSMRib_1310</td>
<td>Loss</td>
<td>&lt; 0.25 dB</td>
</tr>
<tr>
<td>MMI1X2_1310</td>
<td>Loss</td>
<td>Output balance</td>
</tr>
<tr>
<td>MMI1X4_1310</td>
<td>Loss</td>
<td>Output balance</td>
</tr>
<tr>
<td>MMI2X2_1310</td>
<td>Loss</td>
<td>Output balance</td>
</tr>
<tr>
<td>TAPER100_SMDRIB_SMRIB_1310_BB</td>
<td>Loss</td>
<td>&lt; 0.03 dB</td>
</tr>
<tr>
<td>TAPER100_SMRIB_MMRIB_1310</td>
<td>Loss</td>
<td>&lt; 0.03 dB</td>
</tr>
<tr>
<td>TAPER100_SMSTRIP_MMRIB_1310</td>
<td>Loss</td>
<td>&lt; 0.03 dB</td>
</tr>
<tr>
<td>TAPER100_SMSTRIP_SMRIB_1310</td>
<td>Loss</td>
<td>&lt; 0.03 dB</td>
</tr>
<tr>
<td>gratingCoupler1DTE_1310</td>
<td>Insertion loss</td>
<td>Peak wavelength @ 11.5° in air</td>
</tr>
<tr>
<td>gratingCoupler2DTE_1310</td>
<td>Insertion loss</td>
<td>Peak wavelength @ 11.5° in air</td>
</tr>
<tr>
<td>Parametric Cells:</td>
<td>Wave Guide type:</td>
<td>Specification:</td>
</tr>
<tr>
<td>------------------</td>
<td>-----------------</td>
<td>----------------</td>
</tr>
<tr>
<td>pc_straightWG_1310</td>
<td>Strip: WG width = 350 nm</td>
<td>Loss</td>
</tr>
<tr>
<td></td>
<td>Rib</td>
<td>Loss</td>
</tr>
<tr>
<td></td>
<td>DeepRib: WG width = 350 nm</td>
<td>Loss</td>
</tr>
<tr>
<td>pc_bend90WG_1310</td>
<td>Strip</td>
<td>Loss</td>
</tr>
<tr>
<td>pc_Racetrack_Resonator_1310</td>
<td></td>
<td>Loss Extinction Rate Quality Factor</td>
</tr>
<tr>
<td>pc_PiNDIODE_1310</td>
<td>OE bandwidth @ -1V</td>
<td>&gt; 25 GHz</td>
</tr>
<tr>
<td></td>
<td>Responsivity @1310nm, -1V</td>
<td>&gt; 0.75 A/W</td>
</tr>
<tr>
<td></td>
<td>Dark current @ -1V, 20°C</td>
<td>&lt; 10 nA</td>
</tr>
<tr>
<td>pc_MZI_PN MOD_1310</td>
<td>EO bandwidth @ -2V</td>
<td>&gt; 15 GHz</td>
</tr>
<tr>
<td></td>
<td>Loss Junction</td>
<td>&lt; 2 dB/mm</td>
</tr>
<tr>
<td></td>
<td>Vpi Lpi @ -2V</td>
<td>&lt; 2.5 V.cm</td>
</tr>
<tr>
<td>pc_RR_MOD_PN_1310</td>
<td>EO bandwidth @ -2V</td>
<td>&gt; 15 GHz</td>
</tr>
<tr>
<td></td>
<td>Insertion loss</td>
<td>&lt; 0.5dB</td>
</tr>
<tr>
<td></td>
<td>VpiLpi @ -2V</td>
<td>&lt; 2 V.cm</td>
</tr>
</tbody>
</table>
Our probe testers enable to make quick wafer-level testing, shortening the path to production: 200mm and 300mm

- 200mm and 300mm
- Electro-Optical Tests up to 67GHz
- Temperature Tests up to 90°C
- Test automation with wafer mappings
Examples of realization
I/O COUPLING TO FIBERS

1310nm (SOI 300nm)

- small footprint focusing 1D/2D couplers
- Insertion loss : 2 dB for 1D / <4 dB for 2D
- BW@-1dB: 27nm
- Reflection at input <20dB

[1] Fowler et al., "Influence of minimal critical dimension on the efficiency of SOI apodized grating couplers"
### PASSIVE COMPONENTS

\[ \lambda = 1.31 \, \mu m \, TE \, mode \]

<table>
<thead>
<tr>
<th>Devices</th>
<th>Coupler 1D</th>
<th>Coupler 2D</th>
<th>Monomode Rib waveguide W400nm</th>
<th>Multimode Rib Waveguide</th>
<th>Thermal efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Performance</td>
<td>IL &lt; 2.5 dB loss</td>
<td>IL &lt; 4.5 dB loss</td>
<td>Losses: &lt; 2.5 dB/cm</td>
<td>Losses: &lt; 0.3 dB/cm</td>
<td>0.5 &gt; TE &gt; 0.2 nm/mW</td>
</tr>
</tbody>
</table>

**Graphs and Images:**
- Line graphs showing wavelength vs. transmission and intensity.
- Images of fabricated devices and waveguides.

**Figure Legends:**
- Group B #8 P0mW
- Group B #8 P2mW
- Group B #8 P4mW
- Group B #8 P6mW
- Group B #8 P8mW
- Group B #8 P10mW
Thermal tuning efficiency depends on:

- Material volume to be heated
- Thermal coupling efficiency
- Expected time response

Thermal efficiency minimum 0.2nm/mW up to 0.475nm/mw → strong dependence of the design
1310nm (SOI300nm) PN JUNCTION MZM (4MM-LONG) CHARACTERISTICS:

- Phase shift: 19°/mm@2,5V
- VpiLpi: 2.4 V.cm
- Prop Loss < 2 dB/mm
- BW@1.25V: 23GHz

Data Rate: 25Gbps
ER: 10 dB
5V pp on each arm
**Ge-based PHOTODETECTION**

**Lateral PIN photodiode**
- Responsivity > 0.6 A/W
- Dark current < 100 nA at 20°C
- Bandwidth up to 40 GHz

**Avalanche Photodiode**
- Gain: 17 @ 6 V
- Bandwidth: 11 GHz

---

PHOTONIC OFFER:
OPEN 3D COMPATIBLE

+ Si310-PHMP2M circuit

CEA/LETI/DOPT/SCOOP/Maryse Fournier

Example of CMOS 65nm (CMOS065) from STMicroelectronics

Micro-bumps after reflow
On CMOS 065
D=25µm

- Wafer size: 200 mm
- Micro-bumps material: Cu post / SnAg 305 solder
  - Minimum pitch: 50 µm
  - Minimum micro-bumps diameter: 25 µm
  - Micro-bumps thickness (typical): Cu 10µm / SnAg 10µm

On top of Alu

UBM Morphological illustration

CEA – LETI OPEN 3D MPW OFFER

Frontside UBM
Metal 2

- Wafer size: 200 mm
- UBM material: TiNiAu
- UBM thickness: 1 µm
- UBM minimum width: 25 µm
- UBM minimum pitch: 50 µm
PHOTONIC AND ELECTRONIC CONVERGENCE

CEA-LETI Photonic MPW offer

PIC_SOI 300nm
Based on 200mm CMOS-platform

Optical interconnects closer to the electronic chip:

- Miniaturization
- High speed transceiver
- Flexible network
- Network on Chip
- High performance components
- High density photonic circuit
- (2D) electronic/photonic integration
- Multi-photonic-layer integration (3D)
- Low cost packaging

Assembled and packaged ONU by Tyndall Institute

[OFC, 2015]
THANK YOU FOR YOUR ATTENTION

Contact: maryse.fournier@cea.fr