Silicon nitride platform for visible, near and mid-infrared integrated photonics

Prof. Dr. Ing. Pascual Muñoz
Photonic IC Group – Photonic Research Labs
Universitat Politècnica de València – www.prl.upv.es - Valencia (Spain)

Co-founder, Board of Directors
VLC Photonics S.L. – www.vlcphotonics.com – Valencia (Spain)

Facility Manager
UPVfab, the micro-fabrication R&D and pilot line facility – www.fab.upv.es
Photonic integration ecosystem in Spain
Actors that have outstanding international reputation on PICs

Research and Technology Organisations
Universitat Politècnica de València – PRL – Photonic IC
University of Málaga (UMA)
University Carlos III Madrid (UC3M)
Instituto de Microelectrònica de Barcelona (IMB-CNM-CSIC)
– Brought generic photonic integration to Spain
– Advanced PIC modeling and design
– Terahertz photonic chips
– The reference cleanroom in Spain

Start-ups (some from the RTOs) working on PICs
Medlumics – Optical coherence tomography
VLC Photonics (from PRL) – A photonic integration company
QuSIDE (from ICFO) – Quantum on chip
Alcyon Photonics (from UMA) – Design and IP development
Ommatidia – LIDAR
iPRONICS (from PRL) – Programmable photonic chips

http://www.secpho.org/actoagenda/who-is-who-en-fotonica-integrada/

Next 22nd May 2020 – 12 h CET (in English)
About the Photonic IC group – facilities

Photonic testing labs – 500 m² (~6M€)
Digital 40Gbps
RF analog signals 50 GHz

Class 10.000 – 500 m² (~10M€)
6 inch wafers - automation
Process gases (SiH4, SiCl2H2, NH3, Ar, O2, N2, H2, CHF3, CF4)
Deposition: PECVD, LPCVD, sputtering (RF/DC)
Lithography: contact mask aligner double side alignment.
Etching: wet and dry (ICP-RIE)
Metrology: SEM, FESEM, FIB, FTIR, profiler, ellipsometer
Assembly: µTransfer-Printing, Flip-chip

http://www.prl.upv.es/
https://www.fab.upv.es
**Photonic integration: applications, materials & platforms**

**Rationale for a Silicon nitride Broadband Photonic Integration Platform**

**Photonics ...**
- is used in numerous applications
- applications are linked to wavelength
- Visible (VIS): bio-photonics
- Near-infrared (NIR): tele/datacom
- Mid-infrared (MIR): sensing

**Materials used in integration ...**
- Transparency in the band of interest
- Absorption/emission in the band

**Wanted requirements ...**
- To support a wide range of wavelengths
- Base in abundant materials

**Silicon and compounds are excellent candidates**

---

*R. Kitamura, L. Pilon, and M. Jonasz. “Optical constants of silica glass from extreme ultraviolet to far infrared at near room temperature,” Applied Optics, vol. 46, no. 33, pp. 8118+, Nov. 2007. [http://dx.doi.org/10.1364/ao.46.008118](http://dx.doi.org/10.1364/ao.46.008118)*

---

**Si$_3$N$_4$ is transparent from 400 to 6700 nm**

**Must avoid using SiO$_2$**

---

We, 13th May 2020

P. Muñoz © EPIC OTM Mid-IR Photonics
Institute of Microelectronics Barcelona
Centro Nacional de Microelectrónica - CSIC

Adscription & location

Clean Room Characteristics
1,500 m² (2,900 m² services)
“House in House” structure
Class 100-10,000 (ISO 5-7)
Wafer size 100-150 mm
Stepper + EBL.
CMOS ICs
MEMS/NEMS
Nanofabrication

Operations
From TRL 2 to TRL 9 (concept → market)
25% yearly income is from industry

Industrialized technologies
Radiation detectors
SiC rectifiers for space
Chemical sensors ISFETs

Producto desarrollado:
Sensores químicos ISFETs y MEMFET para sistemas de Lenguaje Electrónica.
Empresa o institución a la que se ha transferido:
AlphaMOS. Francia
Ventaja principal que el desarrollo aporta a la empresa o a sus productos:
Medida de pH, iones y otros analitos con dispositivos muy pequeños y de bajo coste.


Carlos.Dominguez@imb-cnm.csic.es
Jad.sabek@imb-cnm.csic.es

P. Muñoz @ EPIC OTM Mid-IR Photonics
We, 13th May 2020
Si3N4 Photonic Integration Technologies at CNM

Visible (340 nm), Near (300 nm) and Mid-infrared (650 nm) – High quality LPCVD Si3N4 films

Applications: generic

BIO PHOTONICS

TELE/DATACOM

SENSING

\[ \lambda \text{ [\text{cm}^{-1}]} \]

\[ \text{VIS} \quad 25000 \quad 14000 \quad \text{NIR} \quad 4000 \quad 2500 \quad 1900 \quad 1500 \]

\[ 0.4 \quad \text{VIS} \quad 0.714 \quad \text{NIR} \quad 2.5 \quad 4 \quad 5.3 \quad 6.7 \]

MIR

SiO2

Si3N4

Si
Silicon Nitride Multi-Project Wafer runs


Three waveguide cross-sections (nitride film 300 nm height, shallow 150/300, deep 300 and mini-deep 150 nm)

Thermo-optic tuners
Selective area trenching
Blocks developed: waveguides, inverted taper, MMI couplers, Mach-Zehnder Interferometers, Sagnac interferometers, Arrayed Waveguide Gratings, ring resonators, …

MWP#0, MPW#1, MPW#2, MPW#3 & MPW#4 finalized

MPW#5 Course and Mask deadline along 2020
Cells size L 5.0x10 mm² & Cells size M 5.0x5.0 mm²

MPW runs at VCL Photonics
mpw@vlcphotronics.com

We. 13th May 2020
P. Muñoz @ EPIC OTM Mid-IR Photonics
SiNx Broadband Photonic Integration Platform
Silicon nitride membrane based – 2nd PoC run finished

Mask CNM-999
Run 13137-MIR

DoE chips λ
1-2 μm
2-3 μm
3-4 μm

Next actions (paused during COVID-19 lock-down)
Process refinements to improve the under-etch @ CNM
OFDR based PIC characterization @ UPV
SiNX Broadband Photonic Integration Platform
Process Design Kit (PDK), building blocks & technology roadmap

<table>
<thead>
<tr>
<th>Wavelength band</th>
<th>PDK 2020</th>
<th>PDK 2021</th>
<th>PDK 2022</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1-2 µm</td>
<td>2-3 µm</td>
<td>3-4 µm</td>
</tr>
<tr>
<td>Waveguide</td>
<td>SHWVG</td>
<td>DEWVG</td>
<td>WVGX</td>
</tr>
<tr>
<td>Couplers</td>
<td>Y-B</td>
<td>DC</td>
<td>MMI</td>
</tr>
<tr>
<td>Optical I/O</td>
<td>SPGC</td>
<td>PSGC</td>
<td>SSC</td>
</tr>
<tr>
<td>Tuning</td>
<td>EA-MOD</td>
<td>TO-MOD</td>
<td></td>
</tr>
<tr>
<td>Filter</td>
<td>RR</td>
<td>AWG</td>
<td>DBR / DFB</td>
</tr>
<tr>
<td>Hybrid actives</td>
<td>SOA</td>
<td>Laser</td>
<td>PD</td>
</tr>
</tbody>
</table>

Color code: Green=Available, Grey=Not Available. Abbreviations: SHWVG Shallow waveguide, DEWVG Deeply etched waveguide, WVGX Waveguide crossing, Y-B Y-branch, DC Directional coupler, MMI Multi-Mode Interference coupler, SPGC Single Polarization Grating Coupler, PSGC Polarization Splitting GC, SSC Spot-Size Converter, EA-MOD Electro-Absorption Modulator, TO-MOD Thermo-Optic Modulator, RR Ring Resonator, AWG Arrayed Waveguide Grating, DBR Distributed Bragg Reflector, SOA Semiconductor Optical Amplifier, PD Photo-Detector

Need cooperation with III-V epitaxy / device supplier for hybrid photonic integration

We, 13th May 2020
P. Muñoz @ EPIC OTM Mid-IR Photonics
Conclusion: Silicon nitride platform for visible, near and mid-infrared integrated photonics

What are we offering? What are we looking for?

- Multi-Project Wafer run schedule

<table>
<thead>
<tr>
<th></th>
<th>2019</th>
<th>2020</th>
<th>2021</th>
</tr>
</thead>
<tbody>
<tr>
<td>PoC #1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PoC #2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MPW#0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MPW#1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MPW#2</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- What are we offering?
  - Short term: early access to MPW#0 (Nov'20) for proof of concept of mid-infrared photonic chips
  - Mid/long term: a broad-band (VIS-NIR-MIR) active + passive photonic integration platform

- What are we looking for?
  - Technology side: cooperation with III-V epitaxy and device suppliers for hybrid photonic integration
  - Application side: early adopters and seed demonstrators
Thank you! … and acknowledgements

Excellent Science R+D+I Projects
Silicon Nitride Spectrometers
2017-2019
Broadband hybrid SiN platform
2020-2022

Research facilities valorization
PIC characterization services
2017-2019

Infrastructure Acquisition Program
PIC characterization equipment
2018-2019
µ-fabrication cluster automation
2019-2020

Marie Curie Innovative Training Netw.
MICROCOMB – Si3N4 freq. combs
2019-2022

R+D+I Industrial Contracts
PIC BBs for Generic Foundries
2016-2018
Application Specific SiN PICs
2019-2021

Personal acknowledgements:
Prof. Carlos Domínguez (CNM)
& clean room team (CNM)
Photonics Research Labs team (UPV)
R&D department (VLC Photonics)
Prof. Fernando Rey (ITQ)
Prof. Antonio Arnau (CI2B)

EPIC Online Technology Meeting on Mid-IR Photonics
13th of May, 2020 – 15:00-17:30 h CEST