III-V/Si photonic integrated circuits for sensing applications

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Silicon photonics for a wide wavelength range

Hybrid and heterogeneous integration of III-V components on SiPh

* Possibility to extend Si waveguide structures to longer wavelengths by removing the BOX, use Silicon-on-sapphire, use silicon-on-SiN... but less mature
Face-up assembly / Flip-chip integration

- Back-end integration
- Known good die
- Face up: Active alignment
- Flip-chip: Passive alignment (+/- 0.5um 3sigma in plane)

Flip-chip integration at imec (for InP diode lasers)

III-V/silicon (die-to-)wafer bonding

- High throughput integration
- Lithographic alignment of III-V device to silicon

Alignment-tolerant III-V-Si coupling interface

- Broadband, robust optical interface
- No exposed laser facets
- Intrinsically hermetically sealed
III-V/Si micro-transfer printing

III-V integration on SiPhotronics through micro-transfer printing

Device processing, release, pick-up & print

Transfer of released, micro-scale III-V devices to a Si target wafer

III-V/Si PICs for spectroscopic sensing
III-V/Si photonic integrated circuits for spectroscopy: near field

III-V/Si photonic integrated circuits for spectroscopy: far field

Use case: transdermal blood constituent analysis
Diabetes is a major 21st century health challenge

Blood constituent analysis (1.5-2.5 um)
Use case: transdermal blood constituent analysis
Transdermal measurement of glucose / lactate / ethanol

Results
Transdermal sensor performance:
- Determination coefficient \( R^2 \):
  - 0.985 glucose / 0.992 lactate / 0.964 ethanol
- RMSEP = 0.7 mM glucose / 0.049 mM lactate / 0.02755045 ethanol
- MAPE = 1.7% glucose / lactate, ethanol not relevant

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III-V-on-silicon laser arrays
InP type II diode lasers integrated on silicon using die-to-wafer bonding

Technology
(On-chip) absorption spectroscopy in the SWIR

Ingredients:
- III-V-on-silicon laser arrays / tunable lasers
- III-V-on-silicon photodetectors
- III-V-on-silicon broadband sources
- Integrated spectrometers & filters

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III-V-on-silicon widely tunable lasers
GaSb/Si extended cavity tunable lasers based on face-up assembly

R. Wang et al., Optica 4(8), p.972-975 (2017)

\( \text{IMEC} \) WALTER SCHOTTKY INSTITUT Center for Nanotechnology and Nanomaterials

III-V-on-silicon widely tunable lasers
GaSb/Si extended cavity tunable lasers

Key performance:
- @2200nm channel
  - Tuning range: 1300nm
  - Output power: 0.1-0.3 mW CW @150mA current
  - Output power: 0.3-0.6 mW CW @500mA current
  - SMSR: > 30 dB
  - Threshold: 50mA
  - Power consumption: @150mA 0.3 W

Courtesy of Broils Sensor Technology

<table>
<thead>
<tr>
<th>Wavelength (nm)</th>
<th>Threshold (mW)</th>
<th>Noise bandwidth (GHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1700-1800</td>
<td>50</td>
<td>200</td>
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<tr>
<td>1900-2000</td>
<td>50</td>
<td>200</td>
</tr>
<tr>
<td>2100-2200</td>
<td>50</td>
<td>200</td>
</tr>
<tr>
<td>2300-2400</td>
<td>50</td>
<td>200</td>
</tr>
</tbody>
</table>

Photodetector:
- Responsivity: 1 A/W, MTF: > 1×10^6 Hz, Linear response: > 1 MHz, Cut-off wavelength: > 2600 nm

J.-Zhang et al., to be published

III-V-on-silicon tunable lasers
InP/Si extended cavity lasers on full SiPh platform through micro-transfer printing

III-V-on-silicon photodetectors
InP type II photodetectors integrated through die to wafer bonding

<table>
<thead>
<tr>
<th>Layer</th>
<th>Material</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>P-contact</td>
<td>InGaAs</td>
<td>100 nm</td>
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<tr>
<td>P-cladding</td>
<td>P-InP</td>
<td>1.5 µm</td>
</tr>
<tr>
<td>SCH</td>
<td>P-AlGaAsSb</td>
<td>250 nm</td>
</tr>
<tr>
<td>MQW Barrier</td>
<td>GaAs:Sb:Te</td>
<td>9 nmx7</td>
</tr>
<tr>
<td>MQW Well</td>
<td>GaAs:Sb:Te</td>
<td>2.6 nmx6</td>
</tr>
<tr>
<td>SCH</td>
<td>GaAsSb</td>
<td>130 nm</td>
</tr>
<tr>
<td>N-contact</td>
<td>N-InP</td>
<td>200 nm</td>
</tr>
</tbody>
</table>
COVID-19 pandemic
- Wear face masks
- Keep social distance
- Ventilation

Datasheet Sensirion SCD30 Sensor Module
CO₂, humidity, and temperature sensor
- NDIR CO₂ sensor technology
- Integrated temperature and humidity sensor
- Best performance-to-price ratio
- User-channel detection for superior stability
- Small form factor: 35 mm x 25 mm x 7 mm
- Measurement range: 400 ppm – 10,000 ppm
- Accuracy: ±30 ppm ± 3%
- Current consumption: 19 mA @ 7 mA, per 2 s
- Fully calibrated and linearized
- Digital interface UART or I²C

CO₂ NDIR sensing on-chip

Hollow waveguide platform combined with MidIR LEDs and detectors
CO2 NDIR sensing on-chip

- Confinement factor in air = 100%
- Propagation loss 2dB/cm for 300um WG core

- Light source: InAsSbP p-i-n
- Detector: InAsSb p-i-n (PV)
- Light path: Integrating cylinder

Blank Si substrate
KOH Si etching
Au deposition/lift-off
LED/PD bonding

Patterned resist
After lift-off
After LED integration
Au-Au direct bonding of both substrates

CO2 NDIR sensing on-chip

Equivalent path length

Small: ~ 5x5mm chip size
Cheap: wafer scale fabrication

X. Jia et al., Sensors, 21(16), p.5347 (2021)
Thank you for your attention
IPC was presented in a virtual format 18 – 21 October 2021. All technical sessions are currently available for on-demand viewing to registered attendees until 18 November 2021.