Highlights research & GaAs and GaSb optoelectronics for integration with silicon photonics

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Research strategy: vertical integrated optoelectronics technology

- Novel III-V heterostructures, epitaxial technology, and materials physics
- Novel optoelectronics devices, device physics, and nanophotonics
- Applications tailored laser sub-systems and applied optics
Core technology: Molecular Beam Epitaxy

- Leading expertise on III-N/Bi-V alloys
- Site-controlled epitaxy of nanostructures on NIL-patterned substrates

5 MBE systems for synthesis of InP, GaAs, and GaSb-based compounds

Optica, 3, 139 (2016)
Nano Letters, August 7, 2017
DOI: 10.1021/acs.nanolett.7b01766
Mission: “To develop technologies that reshape the competitive landscape of Finnish industry”
Optoelectronic devices

**NIL-based DFB/DBR laser diodes**
GaAs/InP/GaSb

**VECSELs/SDLs**

**PICs for on-chip communication**

**High efficiency GaInNAs solar cells**

Current (mA) vs. Voltage (V) for AM1.5 simulation (Xenon lamp)

Test structures

18 SOAs
44 I/O
8W 590 nm VECSEL in clinical trial: telangiectasia treatment

Emmi Kantola et al., STQE 10/2018

TECHNICAL SPECIFICATIONS

<table>
<thead>
<tr>
<th>Specification</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavelength</td>
<td>585 ±5 nm</td>
</tr>
<tr>
<td>Power</td>
<td>up to 8.6 W in cw</td>
</tr>
<tr>
<td>Size</td>
<td>64 x 26 x 60 cm³</td>
</tr>
<tr>
<td>Weight</td>
<td>approx. 30 kg</td>
</tr>
</tbody>
</table>

Treatment parameters

<table>
<thead>
<tr>
<th>Specification</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spot size</td>
<td>1.4 mm diameter</td>
</tr>
<tr>
<td>Pulse length</td>
<td>10–100 ms</td>
</tr>
<tr>
<td>Fluence</td>
<td>0–52 J/cm²</td>
</tr>
<tr>
<td>Scan patterns</td>
<td>Line, square, hexagon</td>
</tr>
<tr>
<td>Scan area</td>
<td>From single spot up to 1 cm²</td>
</tr>
<tr>
<td>Spot spacing</td>
<td>Low, medium and high density</td>
</tr>
</tbody>
</table>
Highlights multi-junction solar cells

AMETIST ERC Advanced Grant
2017-2022

Predicted efficiency @ 1000-sun

AM 1.5G
GaInP/GaAs/GaInNAsSb

Concentration normalized current density (mA/cm²)

3-junction (one sun)
3-junction (CPV @ 100 sun)

One sun 31%

37%

GaInP/GaAs/GaInNAsSb

In/N/Sb composition increasing

GaInNAsSb & GaAsNBi lattice matched to GaAs

Simulation

3J monolithic, 942-sun
4J wafer bonded

Efficiency (%)
Number of junctions

Thin-film light-trapping structures

http://tf2devices.com/
Bringing light to Si-photonicss

**III-V/Si heterogeneous integration**

Wafer bonding (UCSB, INTEL, LETI, Ghent…)


**Challenges**
- Sample size difference
- Alignment
- Yield
- Volume
- Manufacturing

Hybrid integration of III-V components

Allows a large variety of materials (e.g. III-Vs, LiNbO3), and components → high functionality
Is there anything but InP/Si?

- GaAs
- InP
- GaSb
- AlGaInP
- GaInAs
- GaInNAsSb

Wavelength (nanometers)
GaInNAs/GaAs uncooled gain chips

- GaInNAsSb/GaAs QWs have high band-gap offset → temperature stable
- High quality material for 1.2 µm – 1.3 µm
- **Higher absorption** (faster modulators)
- GaAs is a volume production technology in microelectronics
- GaAs/Ge compatible to group IV

M. Guina: “MBE of dilute nitride optoelectronic devices” – in Molecular Beam Epitaxy, edited by M. Henini, Elsevier 2013
Temperature stability

InP

GaAs

Bringing High-Performance GaInNAsSb/GaAs SOAs to True Data Applications

Giannis Giannoulis, Ville-Markus Korpijärvi, Nikos Iliadis, Jaakko Mäkelä, Jukka Viheriälä, Dimitrios Apostolopoulos, Mircea Guina, and Hercules Avramidopoulos
Uncooled 1.3 µm GaAs EAMs

[Diagram of a device with labeled parts: Si WG, oxide, EAM, contact, Silicon]

[Graph showing optical throughput (dB) vs. wavelength (nm) with different V_{EAM} values]

[Image of a silicon wafer with labeled regions: p, n, S, G]

12.5 Gbps

Guina et al., ECOC 09/2018, ROME
1.3 µm GaInNAs QW laser on Ge

Guina et al., “Quantum-well Laser Emitting at 1.2 µm-1.3 µm Window Monolithically Integrated on Ge Substrate”

2017 European Conference on Optical Communication (ECOC)

DOI: 10.1109/ECOC.2017.8345837
A programmable integrated source: hybrid integration of Si-photonics and GaSb SLEDs

http://www.h2020-miregas.eu

http://www.h2020-miregas.eu
**High power 1.9–2 µm SLED**

- $\text{Ga}_{0.78}\text{In}_{0.22}\text{Sb}/\text{AlGaAsSb QWs}$
- $L_{\text{RWG}} = 3 \text{ mm}, L_{\text{cs}} = 0.7 \text{ mm}, \alpha = 7^\circ$
- CW, room temperature

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- **Power vs. Current**
- **Voltage vs. Current**
- **Intensity vs. Wavelength**
- **Intensity vs. Slow axis far field divergence angle**

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2.55 µm SLD

- \( \text{Ga}_{0.54} \text{In}_{0.46} \text{As}_{0.13} \text{Sb}_{0.83}/\text{Al}_{0.25} \text{Ga}_{0.75} \text{As}_{0.02} \text{Sb}_{0.98} \)
- Device: \( L_{\text{RWG}}=2.4 \text{ mm}, L_{\text{cs}}=0.1 \text{ mm}, \alpha = 8^\circ \)
- \( P_{\text{avg}} \) of 3.3 mW (500 ns; 22% DC; 440kHz, RT)
- > 5 mW average power @ 10 °C

2.60 µm SLED (room temperature)

- GaIn_{0.5}As_{0.18}Sb QWs (1.8 % strain)
- L_{RWG}=1.7 mm, L_{cs}=0.3mm, α = 7°
- Pulsed: 100KHz, 10 % duty cycle
- FWHM ~ 100 nm
2.65 µm SLD (room temperature)

- $\text{GaIn}_{0.48}\text{As}_{0.23}\text{Sb}$ QWs (1.4 % strain)
- Without cavity suppression element: $L_{\text{RWG}}=3$ mm, $\alpha = 7.5^\circ$
- 100 KHz, 40 % duty cycle
- FWHM value of ~200 nm at 20 °C
Low loss GaInNAs/GaAs gain waveguides with U-bend geometry for single-facet coupling in hybrid photonic integration

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We report a low loss U-bend waveguide for realization of GaAs-based gain elements employed in hybrid photonic integration. This architecture allows us to position the input and output ports of the gain waveguide on the same facet and thus alleviates the geometrical constrains in hybrid integration, i.e., the need for precise alignment with silicon photonic waveguides on both ends of the III–V chip. As an exemplary demonstration, we report the loss and gain characteristics of GaInNAs/GaAs U-bend waveguides operating at 1.3 μm. In particular, we demonstrate a bending loss as low as 1.1 dB for an 83 μm bending radius. Efficient laser diode operation is also demonstrated. Published by AIP Publishing. https://doi.org/10.1063/1.504

(a)
Thank you!

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