E-O MATERIALS AND DEVICES FOR DATA CENTER AND QUANTUM PHOTONICS APPLICATIONS

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E-O MATERIALS AND DEVICES RESEARCH
HIGH-PERFORMANCE INTEGRATED PHOTONIC ELECTRO-OPTIC DEVICES

High-bandwidth

Lithium Niobate Modulators
PN junction Modulators
Photonics crystal modulators
Nano photodetectors

Compact

Barium Titanate modulators

Data center value chain

Quantum photonics

Silicon foundry process flow compatible energy-efficient structures
IEEE 2020 bandwidth assessment indicates need for 1.6Tbps.

Reaching limitations for bandwidths silicon-based modulators.

High bandwidth modulators based on silicon photonics with post-processed electro-optic materials.
Investments have quadrupled in the past 5 years. Next 10 years will focus on viability at scale and path to commercialization.

Silicon based quantum technologies are getting bulk of the investment.

Silicon Photonics could be that path.

Energy efficient, compact phase shifters based on silicon photonics with post-processed electro-optic materials
IMEC’s State-of-the-Art Fabrication Facilities
@Leuven Headquarters (25km east of Brussels, Belgium)

- Silicon Photonics Prototyping in 200mm FAB
- Advanced Silicon Photonics R&D (mostly) in 300mm FAB
Imec-USA Nanoelectronics Design Center.

Photonics Design.

Electro-optic materials and process flows.

Electronics Design.
### HI-PED PROGRAM OBJECTIVES

<table>
<thead>
<tr>
<th>Integrated Modulator Performance Targets</th>
<th>Year 1 (2020-2021)</th>
<th>Year 2 (2021-2022)</th>
<th>Year 3 (2022-2023)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RF Bandwidth</td>
<td>50GHz</td>
<td>70GHz</td>
<td>100GHz</td>
</tr>
<tr>
<td>Operating Wavelengths</td>
<td>C,L,O</td>
<td>C, L,O</td>
<td>C, L, O</td>
</tr>
<tr>
<td>Target Vpi-L</td>
<td>3V-cm (2V-cm)</td>
<td>2V-cm (1V-cm)</td>
<td>&lt;1V-cm (&lt;0.5 V-cm)</td>
</tr>
<tr>
<td>Insertion Loss (fiber-to-fiber)</td>
<td>&lt;6dB</td>
<td>&lt;4dB</td>
<td>&lt;2dB</td>
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</table>

Explore silicon photonics foundry compatible electro-optical material integration processes and structures for the development of compact, energy-efficient, ultra-high-performance modulators for communication, and compute applications targeting 100GHz bandwidth and CMOS compatible drive voltages.
TECHNOLOGY OVERVIEW.
CURRENT STATE OF THE ART.
Abel et al., “A strong electro-optically active lead-free ferroelectric integrated on silicon”, Nature Comm. 4, 1671 (2013)

THIN FILM LITHIUM NIOBATE RESEARCH TRACK.
## WHY TFLN - COMPACT HYBRID SILICON EO-MATERIAL MZM

![Diagram showing a light source, PIC, PS, MZM, and optical output.](image)

<table>
<thead>
<tr>
<th></th>
<th>Silicon modulators</th>
<th>Conventional LN</th>
<th>LN on Silicon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length (mm)</td>
<td>&lt; 6</td>
<td>&gt; 60</td>
<td>8</td>
</tr>
<tr>
<td>$V_{nl}L$ (V.cm)</td>
<td>2 to 3</td>
<td>&gt; 10</td>
<td>2 to 3</td>
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<tr>
<td>Optical loss (dB/cm)</td>
<td>~ 1</td>
<td>0.3</td>
<td>&lt;0.4</td>
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<tr>
<td>Extinction ratio (dB)</td>
<td>~ 10</td>
<td>&gt; 20</td>
<td>&gt;20</td>
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<tr>
<td>RF bandwidth (GHz)</td>
<td>&gt; 40</td>
<td>&gt; 100</td>
<td>&gt; 100</td>
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<tr>
<td>Power Handling</td>
<td>10mW</td>
<td>&gt;200mW</td>
<td>&gt;1W</td>
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<tr>
<td>Integrability with silicon photonics</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Linearity</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>
PRIOR ART TFLN

- Optimized modulator structure for low power design
  - Asymmetrical optical waveguides
  - Electrode spacing optimized to reduce RF loss
    - Addition of SiO2 buffer layer between LN and gold
  - Buffer layer between electrodes to lower optical loss

- Targeting bandwidth larger than 100GHz


FOUNDROY COMPATIBLE FABRICATION LACKING at present DUE TO LITHIUM RELATED ISSUES

CALL TO ACTION

IN CONCLUSION

▪ What makes the research program interesting?
  ▪ Pre-competitive research track enabling longer term roadmaps for industry partners
  ▪ Pure phase shift modulators
  ▪ Ultra-high bandwidth (100GHz+) devices
  ▪ Integration with 200mm and 300mm Silicon foundry platforms

▪ Imec proposes research roadmap & invites the industry
  ▪ Inviting industry partners in the data center space and quantum photonics space
  ▪ Partners subscribe to the full program or parts thereof and can request additional specific work next to the program
at imec, we shape the future