

# Introduction to the Implementation of Photonic Components on Wafers

For Communication Engineers: From TFLN Wafers to 6G Integration  
(2024–2025)

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## Résumé

The implementation of photonic components on wafers (e.g., TFLN or Si photonics) enables scalable, low-latency systems for 6G networks. \*\*The global strategy focuses in 2025 on the industrialization of thin-film lithium niobate (TFLN) through specialized foundries [?] and the development of scalable photonic quantum computers (LNOI/Pho-Quant) [?].\*\* This introduction is based on current literature (2024–2025) and highlights fabrication processes (ion slicing, wafer bonding), preferred techniques (MZI integration), and relevance for signal processing. Practical : Table of methods, outlook on hybrid PICs. Sources : Nature, ScienceDirect, arXiv. \*\*A new optoelectronic chip that integrates terahertz and optical signals is key to millimeter-precise distance measurement and high-performance 6G mobile communications [?].\*\*

## Table des matières

# 1 Basics : Why Wafer Integration in Communication Engineering ?

The fabrication of photonic components on wafers (e.g., thin-film lithium niobate, TFLN) revolutionizes communication engineering : Scalable production of integrated circuits (PICs) for RF signal processing, 6G MIMO, and AI-assisted routing. \*\*The transition to high-volume manufacturing is accelerated by specialized TFLN foundries, such as the QCi Foundry, which will accept the first commercial pilot orders in 2025 [?]. Globally, 2025 (International Year of Quantum Science and Technology) highlights the strategic importance of photonics for competitiveness [?].\*\* Wafer-based processes (e.g., ion slicing + bonding) enable monolithic integration of  $> 1000$  components/wafer, with losses  $< 1$  dB and bandwidths  $> 100$  GHz.

**Important Note:** Important Note : The technology is hybrid-analog : Optical waveguides for continuous processing, combined with electronic control. This reduces latency (ps range) and energy (pJ/bit), essential for real-time 6G applications.

Current trends (2025) : Transition to 300 mm wafers for industrial scaling, focused on flexible, cost-effective processes [?].

# 2 Realization : Key Processes for Component Integration

The implementation occurs in multi-stage processes, strongly aligned with semiconductor fabrication (e.g., CMOS-compatible). Core steps :

- **Ion Slicing and Wafer Bonding** : For thin films (e.g.,  $\text{LiTaO}_3$  on Si); enables high density without substrate losses [?].
- **Etching and Lithography** : Mask-CMP for waveguide microstructures; precise structures ( $< 100$  nm) for MZI arrays [?].
- **Monolithic Integration** : Co-packaging of electronics/photonics; reduces latency in hybrid systems [?].
- **Flexible Wafer Scaling** : Mechanically flexible 300 mm platforms for cost-effective production [?].

**Key Formula:** Example : Wafer bonding for LNOI (Lithium Niobate on Insulator) : Thickness  $t = 525$   $\mu\text{m}$ , implantation dose  $D = 5 \times 10^{16} \text{ cm}^{-2}$ , resulting layer thickness  $h \approx 400$  nm.

# 3 Preferred Components and Operations on Wafers

Photonic wafers are suited for linear, frequency-dependent components; analog integration prioritizes interference-based operations for 6G signals. \*\*In addition to TFLN, the silicon nitride (SiN) platform is being promoted to offer PICs for biosciences and sensing [?].\*\*

Preferred : Linear operations (e.g., matrix-vector multiplication via MZI meshes) for AI-assisted routing; non-linear (e.g., logic gates) requires hybrids.

# 4 Literature Review : Latest Documents (2024–2025)

Selected sources on wafer implementation (focused on photonic components; links to PDFs/abstracts) :

Component	Realization Process	Relevance for Communication Engineering
Mach-Zehnder Interferometer (MZI)	Ion slicing + lithography on TFLN wafers	Phase modulation for demodulation (6G, latency < 1 ps) [?]
Waveguide Arrays	Wafer bonding (LNOI) + etching	Parallel RF filtering (> 100 GHz bandwidth) [?]
<b>Optoelectronic THz Processor</b>	<b>Si photonics/InP hybrid PICs</b>	<b>6G transceivers, millimeter-precise distance measurement [?]</b>
Quantum Dot Integrator (InAs)	Monolithic Si integration	Hybrid signal amplification for optical networks [?]
Meta-Optics Structures	CMP mask etching on LiNbO <sub>3</sub>	Gradient filters for BSS in MIMO systems [?]
<b>LNOI Qubit Structures</b>	<b>Semiconductor fabrication (PhoQuant)</b>	<b>Scalable, room-temperature stable quantum computers [?]</b>
Flexible PICs	300 mm wafers with mechanical flexibility	Mobile 6G edge devices (roll-to-roll fab) [?]

TABLE 1 – Preferred Components : Implementation on Wafers and Applications

- **TFLN Foundries and Industrialization** : The **QCi Foundry** (specialized in TFLN) will accept the first pilot orders for commercial production of photonic chips in 2025, marking the industrialization of the platform [?].
- **Mechanically-flexible wafer-scale integrated-photonics fabrication (2024)** : First 300 mm platform for flexible PICs; process : bonding + etching. Relevance : Scalable RF chips for mobile networks. [?]
- **Lithium tantalate photonic integrated circuits for volume manufacturing (2024)** : Ion slicing + bonding for LiTaO<sub>3</sub> wafers; density > 1000 components/wafer. Relevance : Low losses for 6G transceivers. [?]
- **LNOI for Quantum Computers (PhoQuant)** : Fraunhofer IOF is developing a photonic quantum computer based on **LNOI**, where fabrication methods stem from semiconductor manufacturing and are immediately scalable. This demonstrates the deployability of the LNOI platform for highly complex quantum architectures [?].
- **Fabrication of heterogeneous LNOI photonics wafers (2023/2024 Update)** : Room-temperature bonding for LNOI; precise waveguides. Relevance : Hybrid optoelectronics for signal processing. [?]
- **Fabrication of on-chip single-crystal lithium niobate waveguide (2025)** : Mask-CMP etching for TFLN microstructures. Relevance : Real-time filters for broadband communication. [?]
- **The integration of microelectronic and photonic circuits on a single wafer (2024)** : Monolithic co-integration; applications in optical networks. Relevance : Latency reduction in 6G. [?]

These documents show : Transition to high-volume manufacturing (12 000 wafers/year), with a focus on analog precision for communication engineering.

## 5 Outlook : Photonic Wafers in 6G Networks

Wafer integration enables cost-effective PICs for base stations : E.g., optical MIMO with < 1 dB loss. Challenges : Increase yield (currently < 80%). Future : AI-assisted fab (e.g., for dynamic routing chips). **The THz chip from EPFL/Harvard demonstrates the enormous potential of optoelectronic integration to process high-frequency radio signals with millimeter precision, opening new application fields in robotics and autonomous vehicles [?].**

## Références

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