

# Photon Chip Implementation

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## **Zusammenfassung**

The Implementierung of photonic Komponenten on wafers (e.g., TFLN or Si photonics) enables scalable, low-latency Systeme 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 Quanten computers (LNOI/PhoQuant) [?].\*\* This introduction is basierend auf Strom literature (2024–2025) and highlights fabrication Prozesse (ion slicing, wafer bonding), preferred techniques (MZI integration), and Relevanz for signal processing. Practical: Tabelle of methods, outlook on hybrid PICs. Sources: Nature, ScienceDirect, arXiv. \*\*A new optoelectronic chip das integrates terahertz and optical signals is key to millimeter-präzise Entfernung Messung and high-performance 6G mobile communications [?].\*\*

# 1 Basics: Why Wafer Integration in Communication Engineering?

The fabrication of photonic Komponenten 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 Übergang to high-Volumen manufacturing is accelerated by specialized TFLN foundries, solch as the QCi Foundry, welche will accept the erst commercial pilot orders in 2025 [?]. Globaly, 2025 (International Year of Quantum Science and Technology) highlights the strategic Wichtigkeit of photonics for competitiveness [?].\*\* Wafer-based Prozesse (e.g., ion slicing + bonding) enable monolithic integration of  $> 1000$  components/wafer, with losses  $< 1$  dB and bandwidths  $> 100$  GHz. Important Hinweis: The technology is hybrid-analog: Optical waveguides for kontinuierlich processing, combined with electronic control. This reduces latency (ps range) and Energie (pJ/bit), essential for reell-Zeit 6G Anwendungen.

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

# 2 Realization: Key Processes for Component Integration

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

- **Ion Slicing and Wafer Bonding:** For thin films (e.g., LiTaO<sub>3</sub> on Si); enables high Dichte without substrate losses [?].
- **Etching and Lithography:** Mask-CMP for waveguide microstructures; präzise Strukturen ( $< 100$  nm) for MZI arrays [?].
- **Monolithic Integration:** Co-packaging of electronics/photonics; reduces latency in hybrid Systeme [?].
- **Flexible Wafer Scaling:** Mechanically flexible 300 mm platforms for cost-effektiv production [?].

Beispiel: Wafer bonding for LNOI (Lithium Niobate on Insulator): Thickness  $t = 525$  µm, implantation dose  $D = 5 \times 10^{16}$  cm<sup>-2</sup>, resulting layer thickness  $h \approx 400$  nm.

# 3 Preferred Components and Operations on Wafers

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

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

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Tabelle 1: Preferred Components: Implementation on Wafers and Applications

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

Selected sources on wafer Implementierung (focused on photonic Komponenten; links to PDFs/abstracts):

- **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-Skala integrated-photonics fabrication (2024):** First 300 mm platform for flexible PICs; Prozess: bonding + etching. Relevance: Scalable RF chips for mobile networks. [?]
- **Lithium tantalate photonic integrated circuits for Volumen manufacturing (2024):** Ion slicing + bonding for LiTaO<sub>3</sub> wafers; Dichte > 1000 components/wafer. Relevance: Low losses for 6G transceivers. [?]
- **L NOI for Quantum Computers (PhoQuant):** Fraunhofer IOF is developing a photonic Quanten computer basierend auf \*\*L NOI\*\*, wo fabrication methods stem from semiconductor manufacturing and are sofort scalable. This demonstrates the deployability of the L NOI platform for highly komplex Quanten architectures [?].
- **Fabrication of heterogeneous L NOI photonics wafers (2023/2024 Update):** Room-Temperatur bonding for L NOI; präzise waveguides. Relevance: Hybrid opto-electronics for signal processing. [?]
- **Fabrication of on-chip single-crystal lithium niobate waveguide (2025):** Mask-CMP etching for TFLN microstructures. Relevance: Real-Zeit filters for broadband communication. [?]
- **The integration of microelectronic and photonic circuits on a single wafer (2024):** Monolithic co-integration; Anwendungen in optical networks. Relevance: Latency reduction in 6G. [?]

These documents show: Transition to high-Volumen 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-effektiv 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 Prozess high-Frequenz radio signals with millimeter precision, opening new Anwendung Felder in robotics and autonomous vehicles [?].\*\*

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