moduleqnc
quantum & neuromorphic computing

Integrated photonics - (almost) the entire optical table on a fingernail

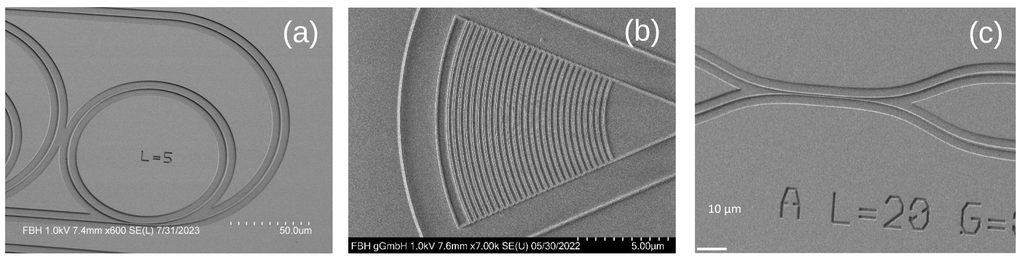
Photonic platforms and integrated waveguide structures

1 Motivation

- atomic and ionic qubits: Preparation and addressing require different laser wavelengths with controlled properties
- Necessary steps: laser light generation, stabilization, modulation, switching and distribution
- Scaling of qubit numbers: strong parallelization required, only feasible through *integrated optical* platforms
- Which material system offers which possibilities?

2 AlGaN/AlN platform

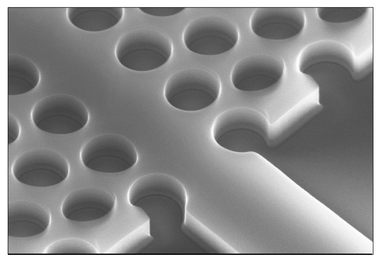
- **Wide transparency window** (from 0.25 to 10 µm)
  - AlN: **0.13 dB/cm** waveguide loss in C-band demonstrated
- High electro-optical coefficient → **fast switching**
- **High non-linearity** in the visible range → Generation of complex photonic states
- Fabrication methods compatible with III-V semiconductor technology
- **Heterogeneous integration** possible



Examples of photonic components made of AlGaN/AlN: Example SEM images of (a) a ring resonator, (b) a grating coupler and (c) evanescent couplers.

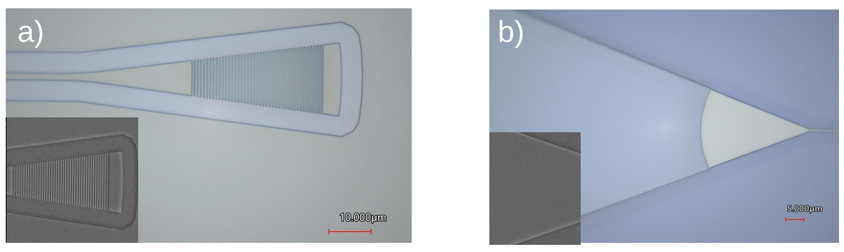
3 SOI - Silicon on Insulator

- The "classic" solution with active components on **6"** / **200 mm wafers**
- **Scalable** through mix-and-match lithography to combine optical stepper and electron beam
- Waveguide loss approx. **1 dB/cm**
- Free-standing waveguides for MEMS and Mid-IR
- Grating coupler or SU-8 edge coupler
- **Phase shifters & modulators:**
  - thermo-optical
  - depletion type
- Integration options: Si_3N_4, AlN, 2D materials (e.g. for photodetectors)



4 Silicon nitride - Si_3N_4

- Excellent **balance** between low propagation losses and compact circuits
- **6" or 200 mm wafers**
- **Scalable** through mix-and-match lithography to combine optical stepper and electron beam
- Waveguide loss down to **5 dB/m**
- Suitable for non-linear optics with $\chi^{(3)}$

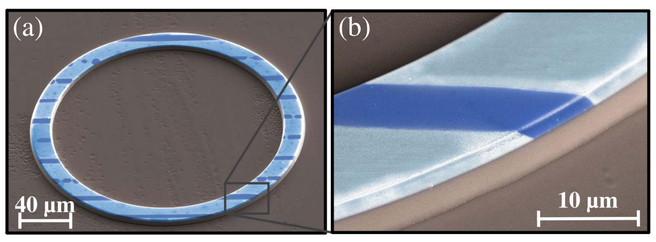


Examples of particularly challenging components made of Si_3N_4: Grating coupler with an ordinary grating in a) and an apodized grating in b), each with a layer thickness of 200 nm and a critical dimension of approx. 70 nm.

5 LNOI - Lithium niobate on insulator

Strong material effects enable **a wide range of functionalities**:

- Waveguides with low losses
- Very-high quality resonators
- Non-linear optical frequency conversion via $\chi^{(2)}$ **processes** with quasi-phase matching and **high efficiency**
- **Photon-pair generation**
- Quantum memories (with erbium doping)



Example of an active LNOI component for frequency conversion: SEM image of a periodically poled ring resonator Dark blue/light blue: $LiNbO_3$ domain with z-axis up/down. Dark brown: quartz substrate

For inquiries, email us at experts@module-qnc.de

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