Versatile micro-optical bench for photonic integration in quantum technology

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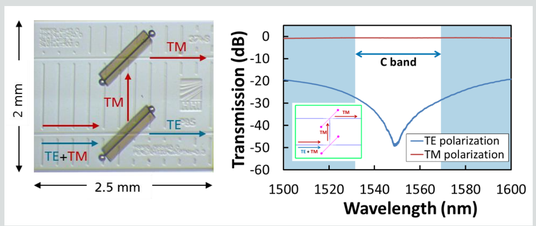
(1) Introduction

- Efficient exploitation of quantum-mechanical effects (photon entanglement, etc.) in **free-space optical setups** possible
- Field applications so far limited by scalability due to cost, size, robustness, and temperature requirements
- **Photonic integration** in semiconductor and dielectric material systems for optical communications proven and state of the art
- Integration of bulk-optical components not possible in standard photonic integration platforms

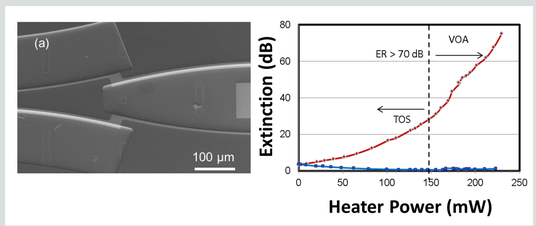
Challenge: Combination of free-space and integrated optics on a single chip

(2) Polymer-based photonic integration platform PolyBoard

- Single-mode waveguides optically **transparent from 400 nm to 1650 nm** with low birefringence
- Complete hybrid **photonic integration platform** for optimal combination of active and passive optical functionalities
- Waveguide-integrated multi-mode interference couplers (MMIs) for power handling and arrayed waveguide gratings (AWGs) for wavelength multiplexing
- Thin-film elements for temp.-insensitive polarization and wavelength routing
- Thermo-optic switches, attenuators, and tunable Bragg reflectors



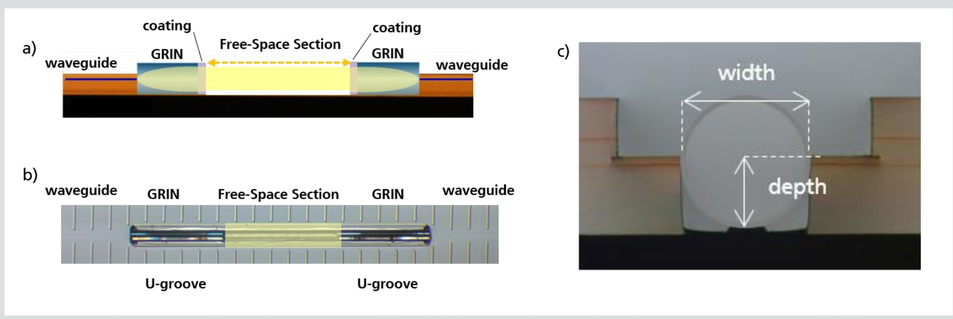
Integrated polarizing beam splitter with 0.7 dB total loss and 50 dB extinction ratio. [1]



Thermo-optic switch with 0.5 dB on-chip loss and > 70 dB extinction ratio.

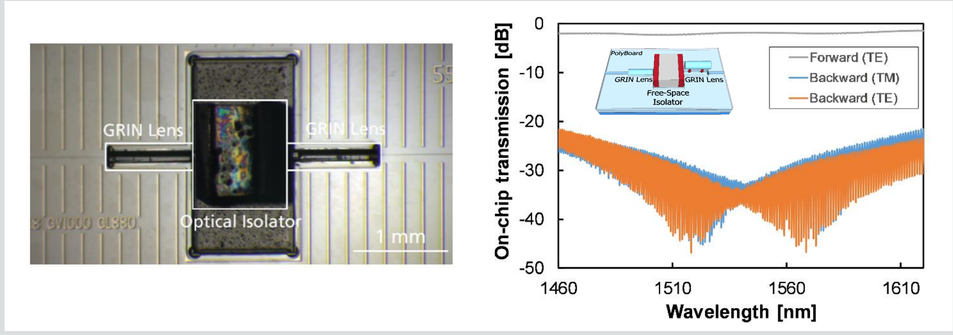
(3) Micro-optical bench for non-reciprocal optics

- Definition of U-grooves with **lithographic precision on wafer-scale** during fabrication and precise in-situ etching depth control with accuracy better 1 µm
- Integration of **GRIN lenses** with passive pick-and-place approach; no active alignment needed



Schematic (a) and top-view (b) of fabricated on-chip free space section (left). Cross section of etched U-groove with indicated GRIN lens position (right). [1]

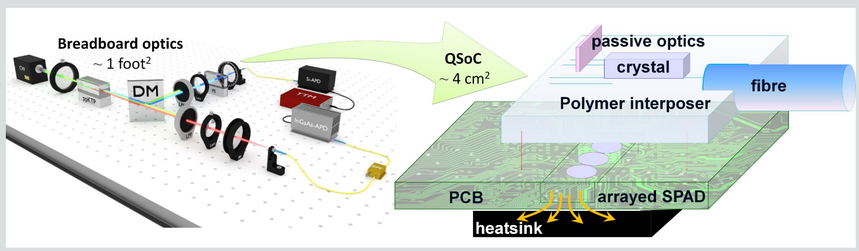
- **On-chip free-space section** with collimated beam created by GRIN lenses [2]
- Collimation allows for insertion of bulk optical components, e.g. magneto-optic crystals for **optical isolators and circulators** [3]



Micrograph of optical isolator in micro-optical bench on PolyBoard (left) and optical transmission through the device (right).

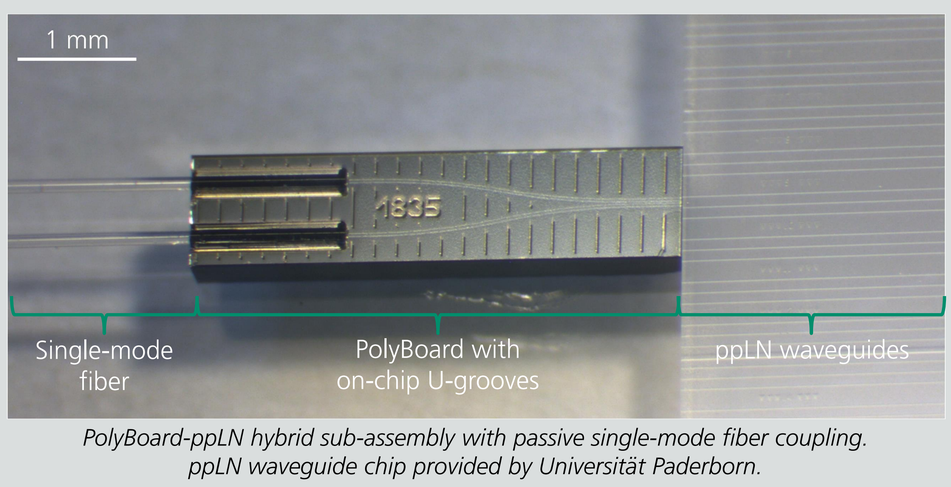
Highly efficient on-chip optical isolator in PolyBoard
>33 dB peak isolation // 140 nm 20-dB-isolation bandwidth // 1.4 dB on-chip loss

(4) Micro-optical bench for quantum technology – the UNIQORN approach

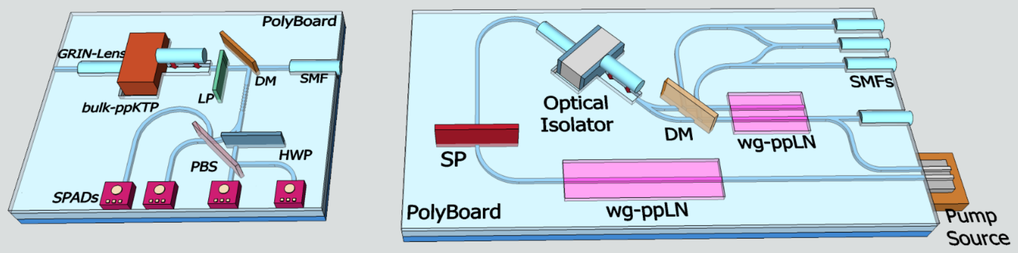


- **Miniaturization of proven free-space optical setups** by on-chip integration of non-linear optical crystals into micro-optical bench on PolyBoard platform
- Utilization of well-studied non-linear optical effects in ppLN, KTP and AlGaAs for generation of single or entangled photons
- Polarization and wavelength handling as well as coupling to optical fibers and Si SPADs in PolyBoard platform
- Operation at **room temperature**; only localized on-chip heating for phase matching

Development of a quantum System-on-Chip platform (QSoC)
- UNIQORN-showcases in quantum communications: Photonic sources and detectors for polarization and time-bin entanglement, QRNGs, and squeezed light
- QSoC platform adaptable for needs in quantum sensing and computing applications



PolyBoard-ppLN hybrid sub-assembly with passive single-mode fiber coupling. ppLN waveguide chip provided by Universität Paderborn.



Schematics of selected QSoCs to be developed in UNIQORN: Polarization-entanglement source with on-chip detection (left) and squeezed-state source (right).

[1] Kleinert, M., et al. "Photonic integrated devices and functions on hybrid polymer platform." Physics and Simulation of Optoelectronic Devices XXV. Vol. 10098, 2017.
[2] Happach, M., et al. "On-chip free beam optics on a polymer-based photonic integration platform." Optics express 25.22 (2017): 27665-27670.
[3] Conradi, H., et al. "High Isolation Optical Isolator: A new Building Block for PolyBoard Photonic Integrated Circuits." 2018 ECOC. IEEE, 2018.

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 820474.

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