Hybrid Photonic Integration for Quantum Technologies

From optical benches to integrated circuits

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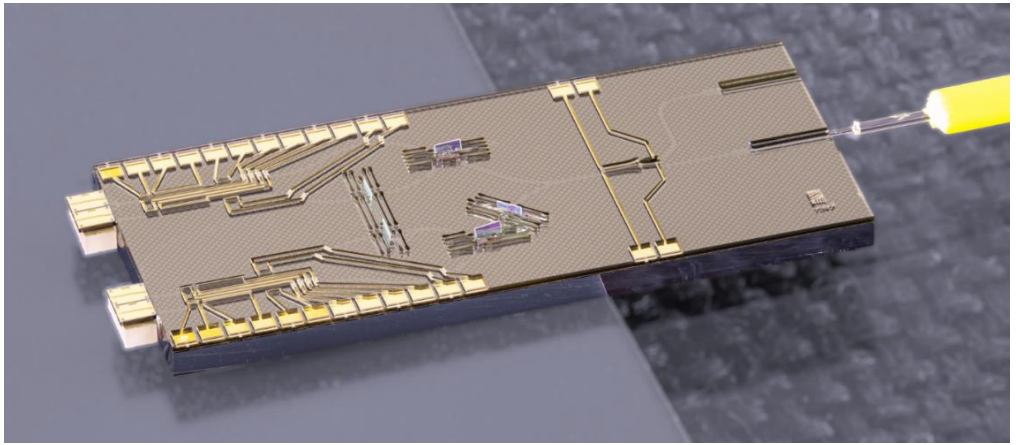
Photonic Components Department



Photonic Integration

Monolithic and hybrid approaches

Monolithic Integration

Waveguides and actives on same die
→ Semiconductor material system

\+ Optical sub-assembly = fabricated chip

\- Limited by properties of material

Hybrid Integration

Waveguides and actives seperate dies
→ actives: semiconductor
→ passives: Silica, Si_3N_4, polymer
→ NLO: ppLN, ppKTP, …

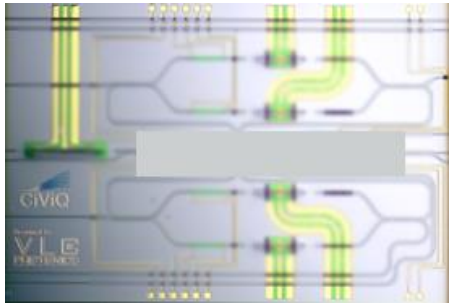
\- Additional assembly necessary

\+ Combination of optimal components and novel functionalities

Photonic Integration

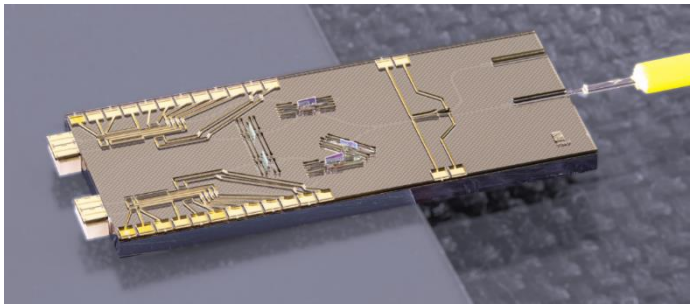
Monolithic and hybrid approaches

Monolithic Integration



CV-QKD-Tx
→ Monolithic InP PIC

Hybrid Integration



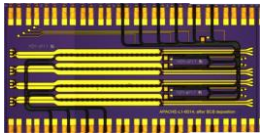
DV-QKD-Tx
→ Hybrid InP + Polymer PIC

Hybrid Photonic Integration at HHI

for quantum communications

Laser

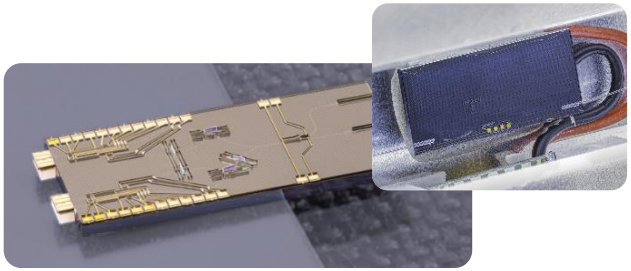
Receivers & Detectors



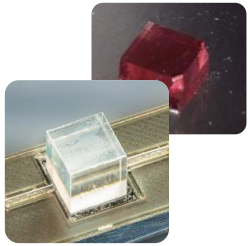
Modulators

SPADs

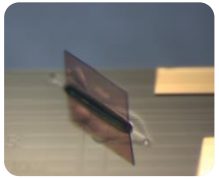
Single components – InP



Hybrid PIC – PolyBoard



Crystals



Filters

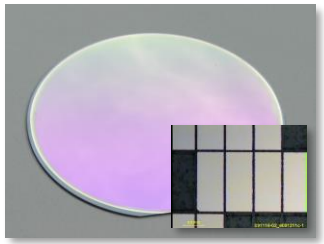
Micro-optical elements

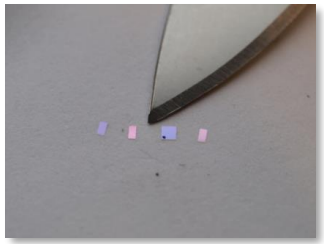
Slots & Thin Film Elements

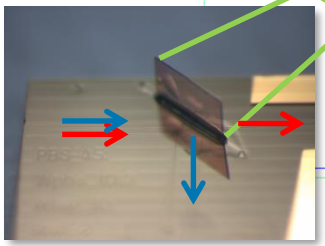
Efficient on-chip filtering

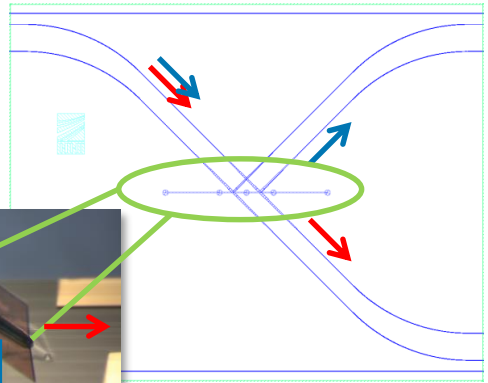
Thin-film elements are based on dielectric layer stacks

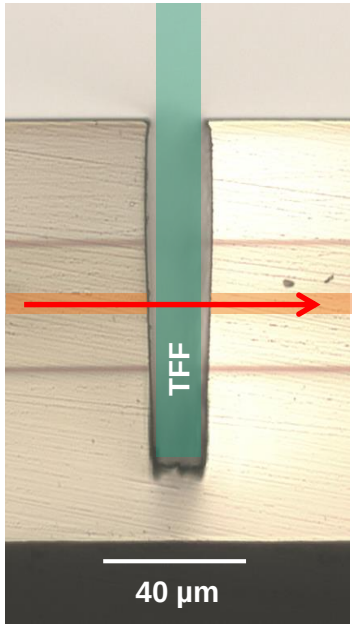
- Various efficient filter characteristics
  → wavelength, polarization etc.
- Small footprint
- Temperature-insensitive







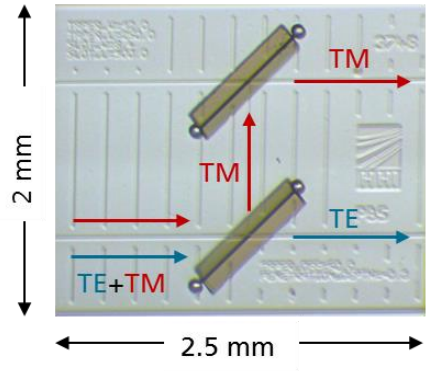


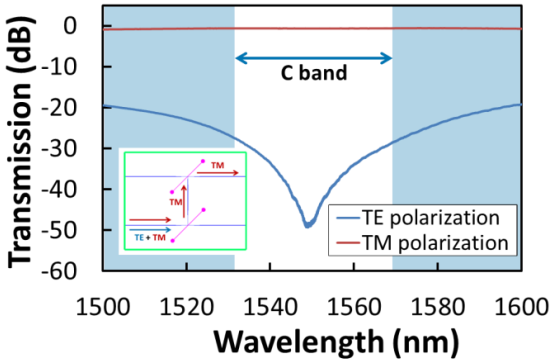


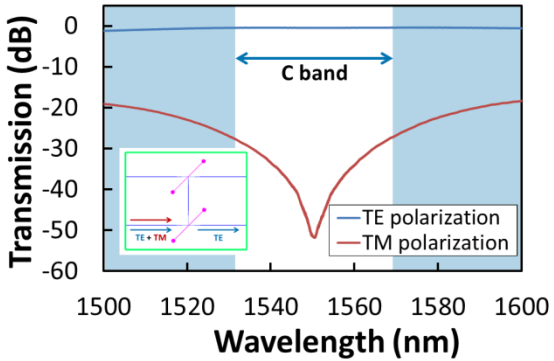
Slots & Thin Film Elements

Example: Efficient polarization splitter

- Footprint: some mm²,
- Total insertion loss: <0.7 dB (fiber-chip-fiber)



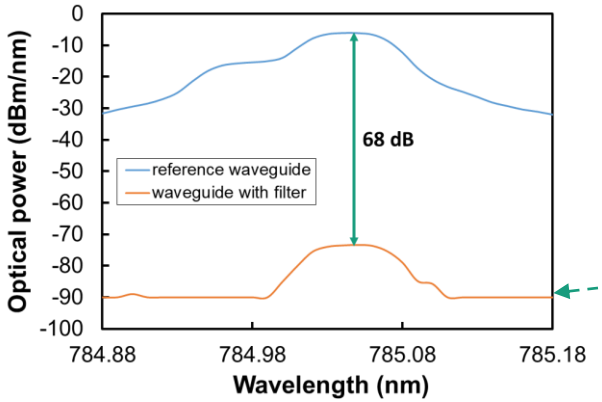


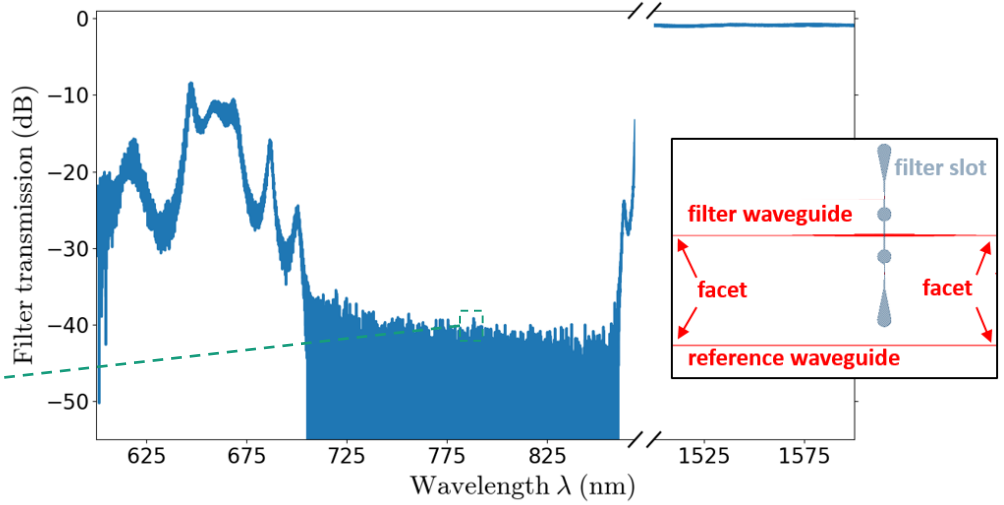


Slots & Thin Film Elements

Example: Pump suppression filter

- Pass: C band / stop: around 785 nm
- 68 dB pump suppression on chip

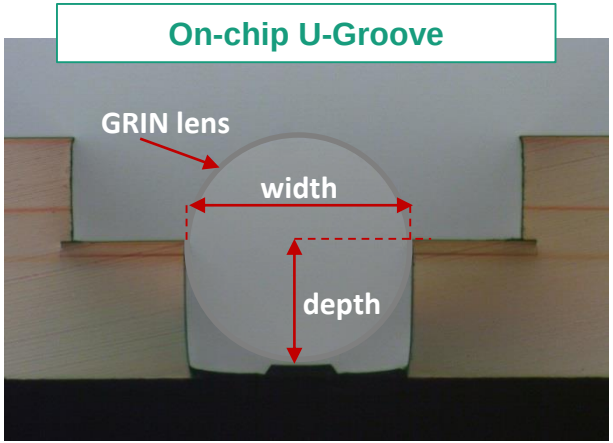


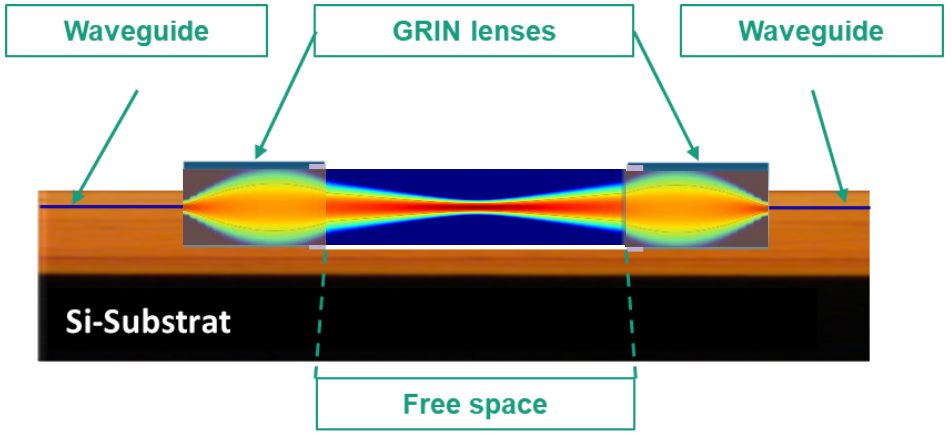


Micro-Optical Bench

On-chip free-space sections

Beam collimation with GRIN lenses in on-chip U groove

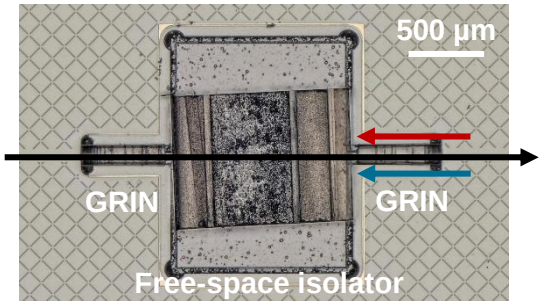




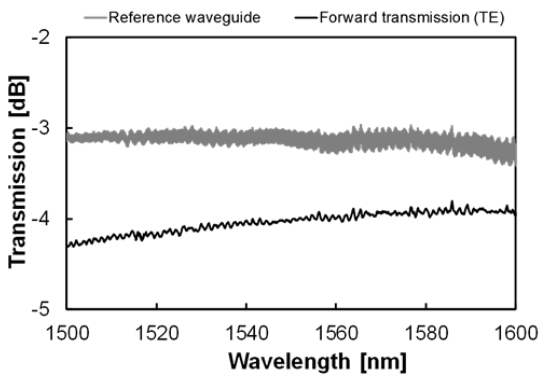
Free-space sections with lengths up to 10 mm
→ insertion of non-linear + non-reciprocal crystals

Micro-Optical Bench

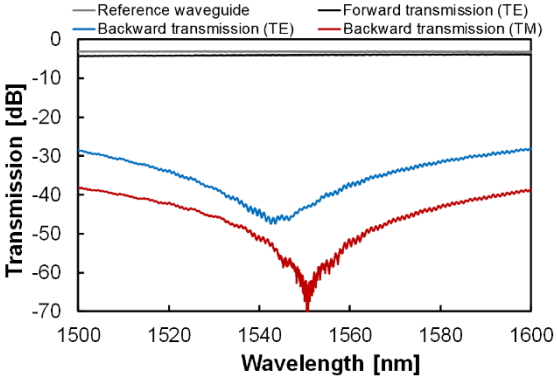
Example: Integrated optical free-space isolator



On-chip integrated free-space isolator



<1 dB on-chip loss in forward transmission

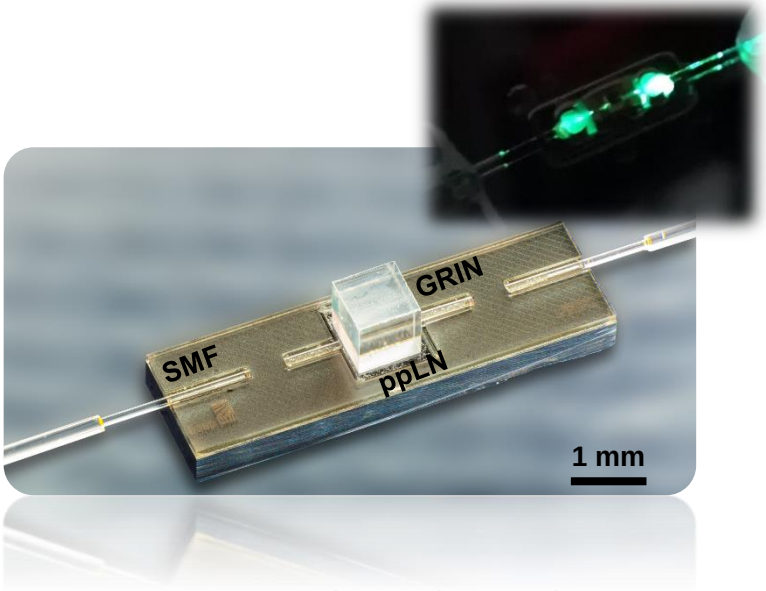


>40 dB peak isolation

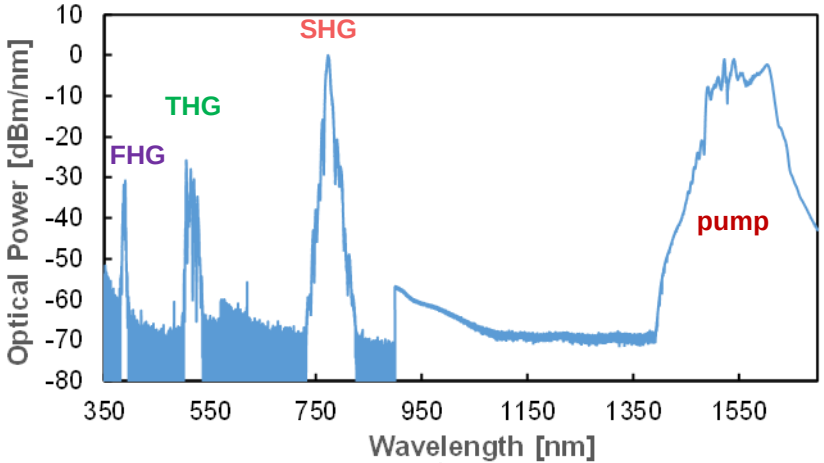
<1 dB @1550 nm // > 28 dB isolation over 100 nm bandwidth

Micro-Optical Bench

Example: Non-linear optics with ppLN



ppLN crystal in PolyBoard



Optical spectrum

Higher harmonic generation

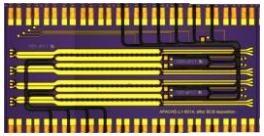
1550 nm → 775 nm + 515 nm + 387 nm

Hybrid Photonic Integration at HHI

for quantum communications

Laser

Receivers & Detectors



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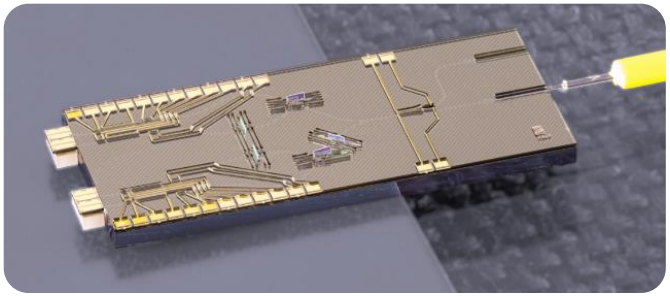
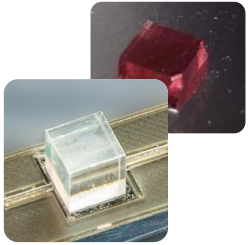
Single components – InP



Hybrid PIC – PolyBoard



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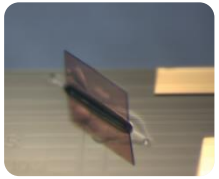


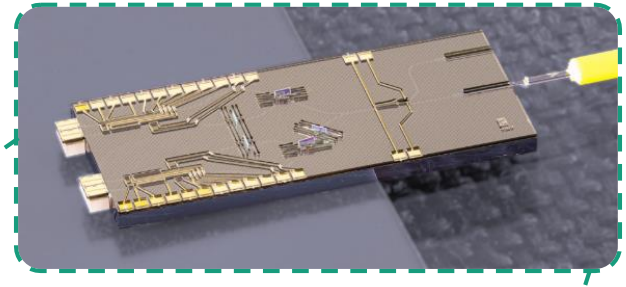
Filters

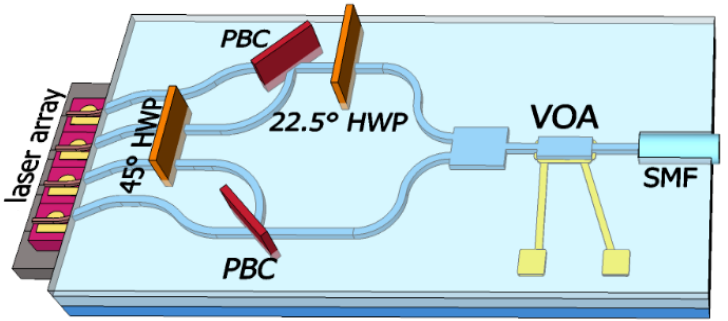
Micro-optical elements

Hybrid Photonic Integration

DV-QKD transmitter for polarization encoding

- Pulse sources
- Polarization handling
- Attenuation
- Optical isolation





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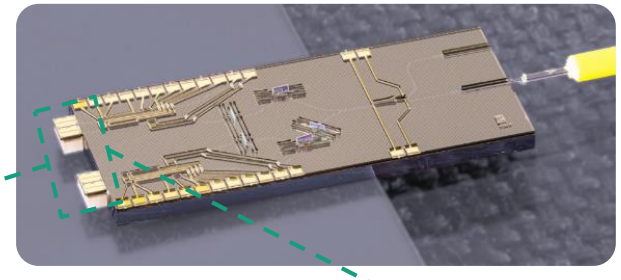
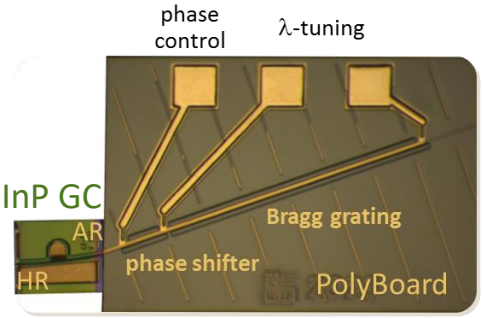
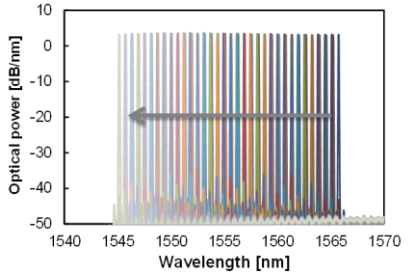
Hybrid Photonic Integration

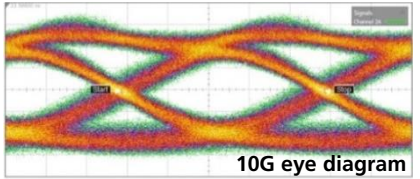
DV-QKD transmitter for polarization encoding



- Pulse sources
  → Tunable laser
- Polarization handling
- Attenuation
- Optical isolation



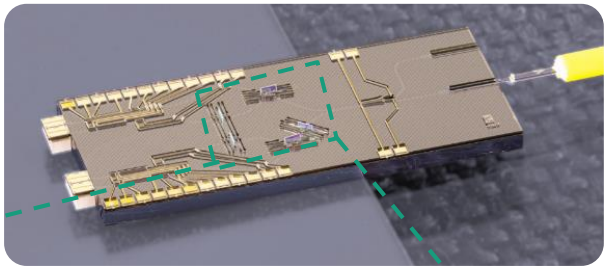




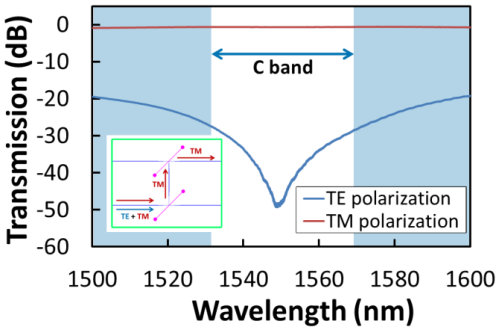
20 nm tuning range //
10 Gbit/s direct modulation

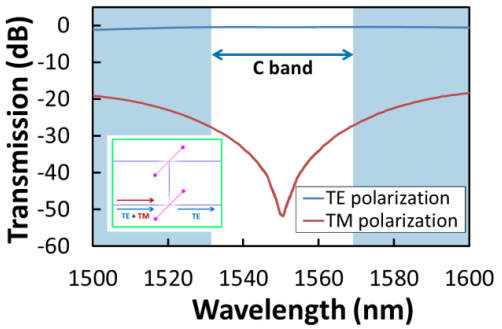
Hybrid Photonic Integration

DV-QKD transmitter for polarization encoding



- Pulse sources
  → Tunable laser
- Polarization handling
  → Thin-film filters
- Attenuation
- Optical isolation





> 45 dB max. polarization extinction ratio // > 25 dB PER over C band // HWPs with >20 dB rotation efficiency

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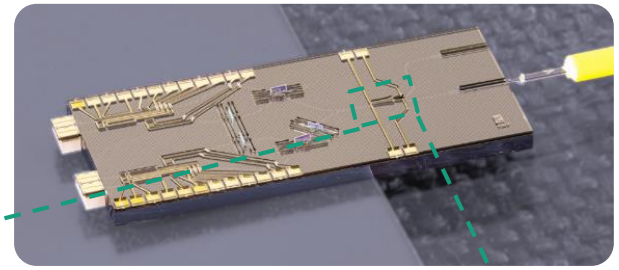
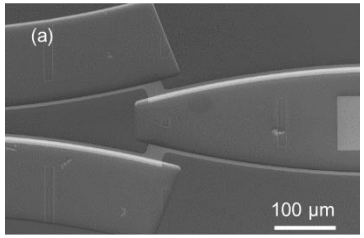
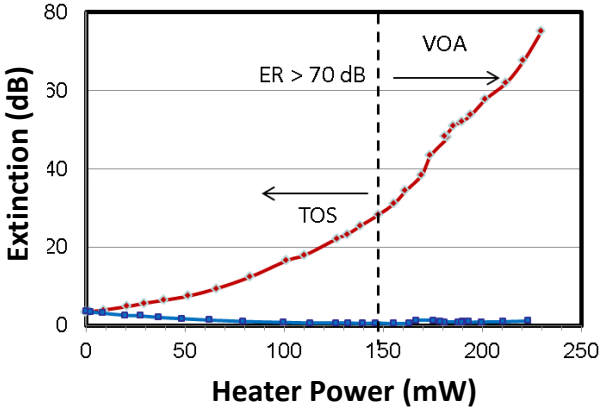
DV-QKD transmitter for polarization encoding



- Pulse sources
  → Tunable laser
- Polarization handling
  → Thin-film filters
- Attenuation
  → Thermo-optic VOA
- Optical isolation



< 0.4 dB excess loss //
> 70 dB extinction ratio
→ Weak coherent pulses



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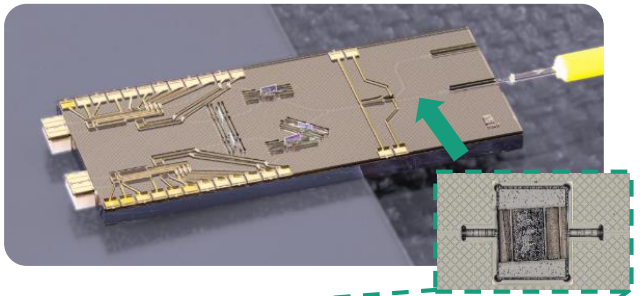
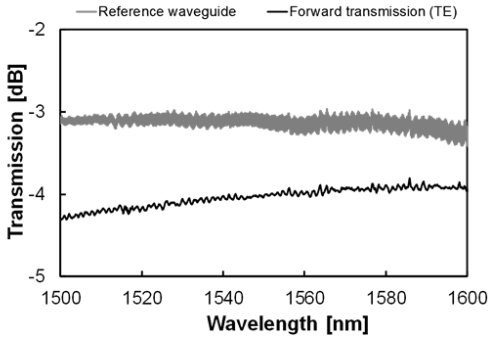
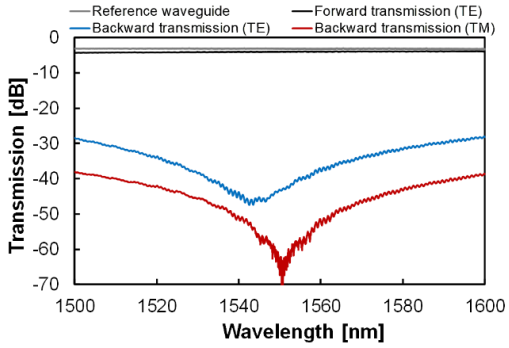
Hybrid Photonic Integration

DV-QKD transmitter for polarization encoding

- Pulse sources
  → Tunable laser
- Polarization handling
  → Thin-film filters
- Attenuation
  → Thermo-optic VOA
- Optical isolation
  → Micro-optics







<1 dB on-chip loss // >28 dB isolation over 100 nm

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Hybrid Photonic Integration

Time-bin entanglement source

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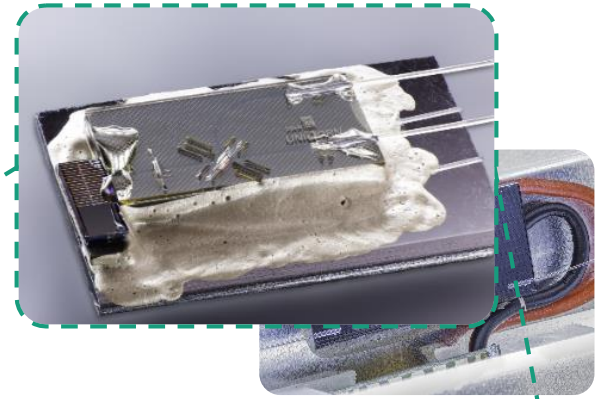
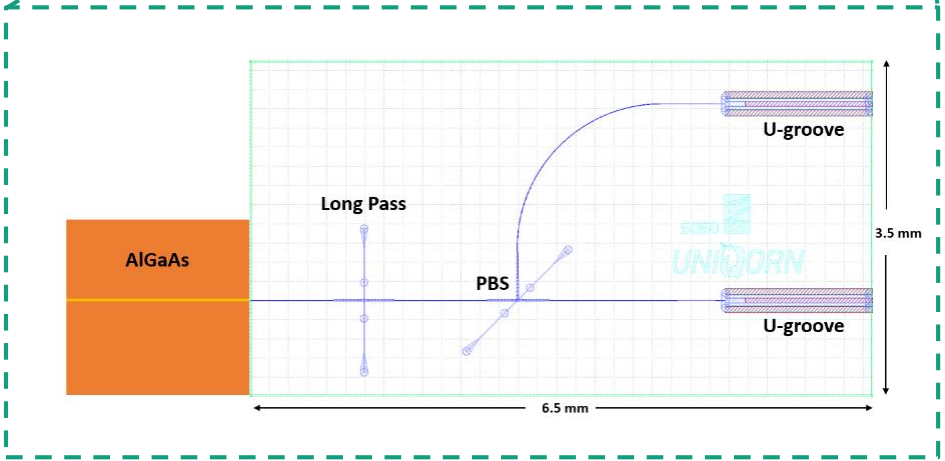
- Photon pair generation
  → Bragg reflection waveguide
- Polarization handling
  → PBS thin film filter
- Pump suppression
- Delay line interferometer





Hybrid Photonic Integration

Time-bin entanglement source

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- Photon pair generation
  → Bragg reflection WG
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  → Thin-film filter
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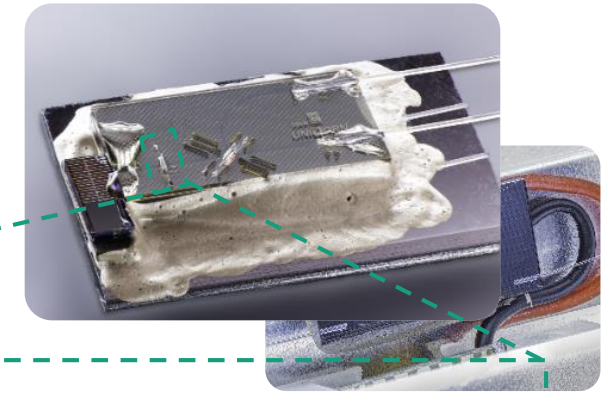

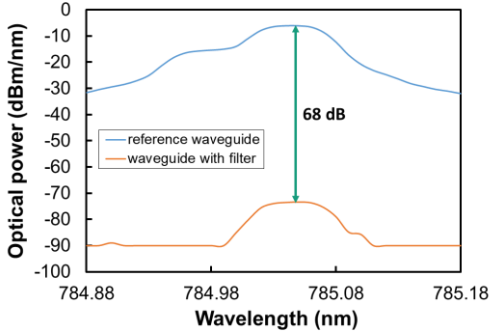

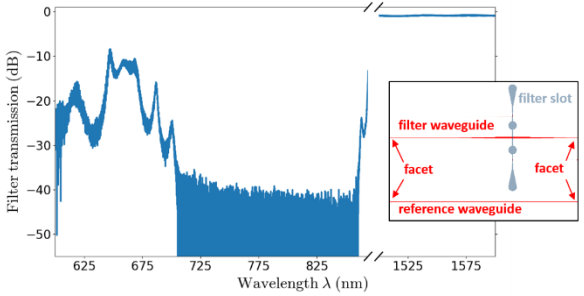

68 dB suppression of pump light @ 775 nm //
0.9 dB loss for signal/idler @ 1550 nm

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Hybrid Photonic Integration

Time-bin entanglement source

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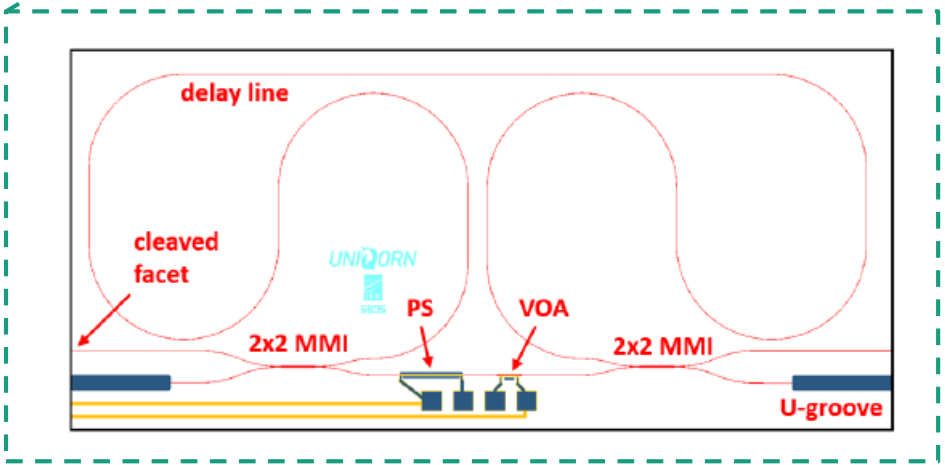
- Photon pair generation
  → Bragg reflection WG
- Polarization handling
  → PBS thin film filter
- Pump suppression
  → Thin-film filter
- Delay line interferometer
  → Asymmetric MZI



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Time-bin entanglement source

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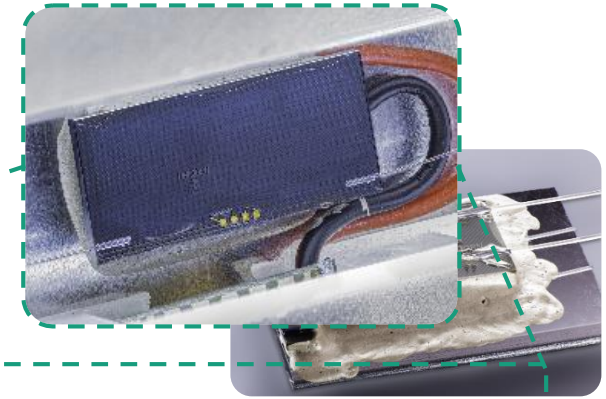
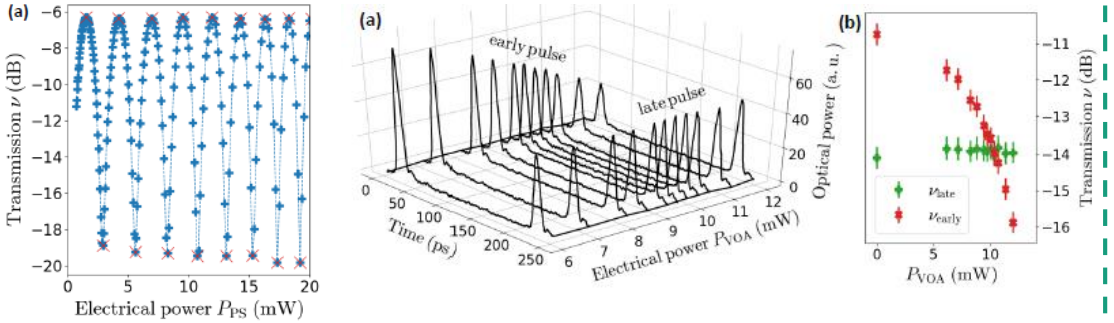


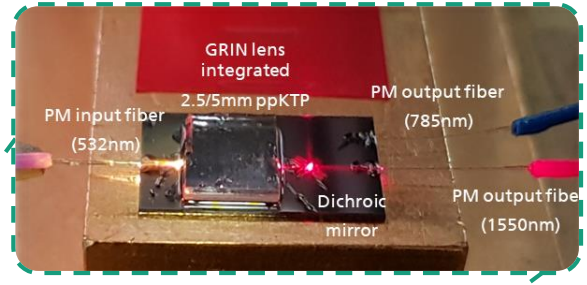


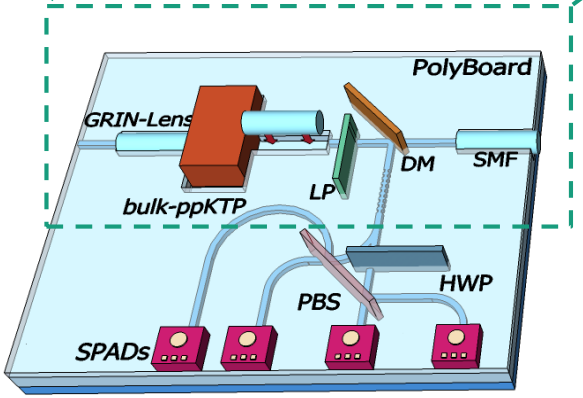
Tuning and stabilization with thermo-optic phase shifter and VOA

Hybrid Photonic Integration

Polarization entanglement source

- Pump suppression (532 nm)
  → Thin-film filter
- Signal/idler splitter (785 nm / 1550 nm)
  → Thin-film filter
- Photon pair generation





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WE PUT SCIENCE INTO ACTION.

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