Integrated optics at mid-IR wavelengths

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Brief historical background (1)

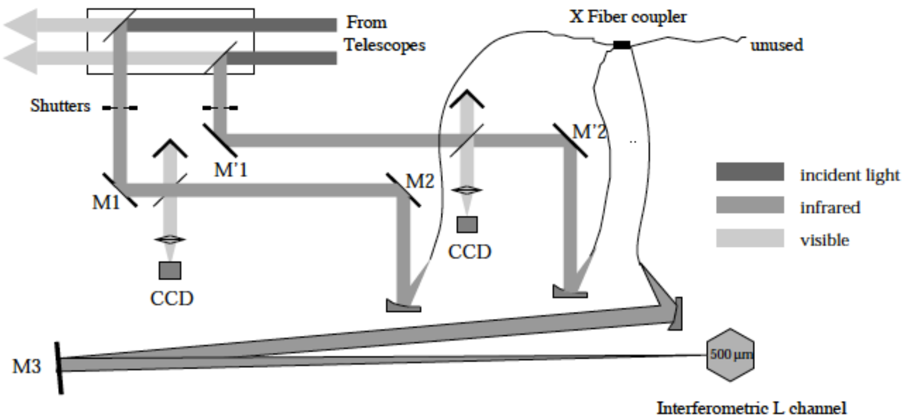
- Originally, the idea of mid-infrared integrated optics came out in the context of the Darwin mission

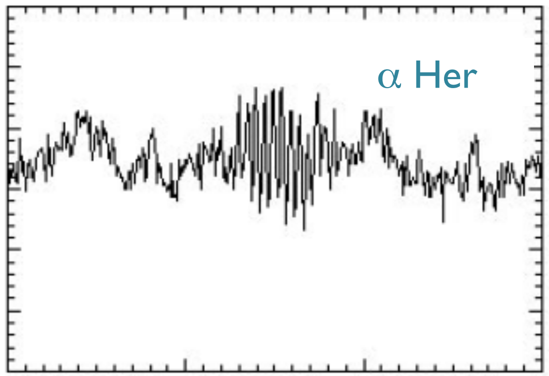
- The integrated optics concept was having its first success with IONIC/IOTA

- Could an IO approach be applicable for nulling at longer wavelengths ? This question was timeline..

Brief historical background (2)

- Back in 2002/2003: no mid-infrared photonics
- Only the FLUOR team pushed it up to the L' band
- *The TISIS experiment on IOTA (Mennesson et al. 1999)*





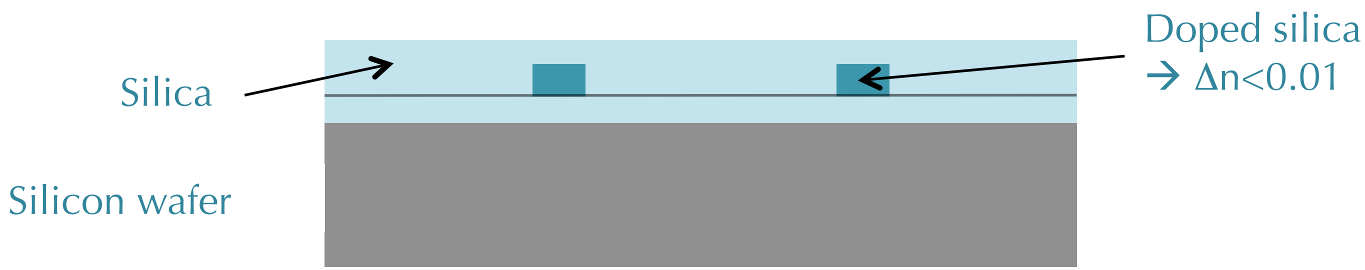
The goal ? Starting from scratch and develop an achromatic, very low-loss, 6-telescope beam combiner, single-mode between 4-20 microns

Evolving context

- Changing context for "space interferometry route"
- But both Darwin and TPF-I triggered new developments in the field of mid-infrared photonics
    - mid-IR single-mode fibers (Ksendzov 2007, 2008)
    - mid-IR integrated optics (Labadie 2006, Vigreux 2007)
- Growing field of astrophotonics (AWG & SWIFT spectrometers, IO combiner, pupil remapping arrays)
- Keep and expand the technological know-how on the mid-IR topic

The near-infrared astronomical IO

- Relies on established technological platform that originates from the telecom field
- e.g. the PIONEER H-band beam combiner based on silica-on-silicon technology (Benisty et al. 2009)



- Good matching with SM fibers (comparable Δn and core dimensions)

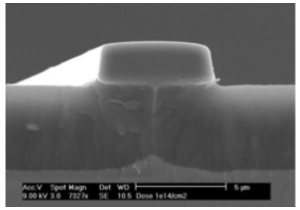
The mid-infrared astronomical IO

- No single "universal" mid-IR technological platform

  → *Dedicated R&T (Design, try-and-test approach)*

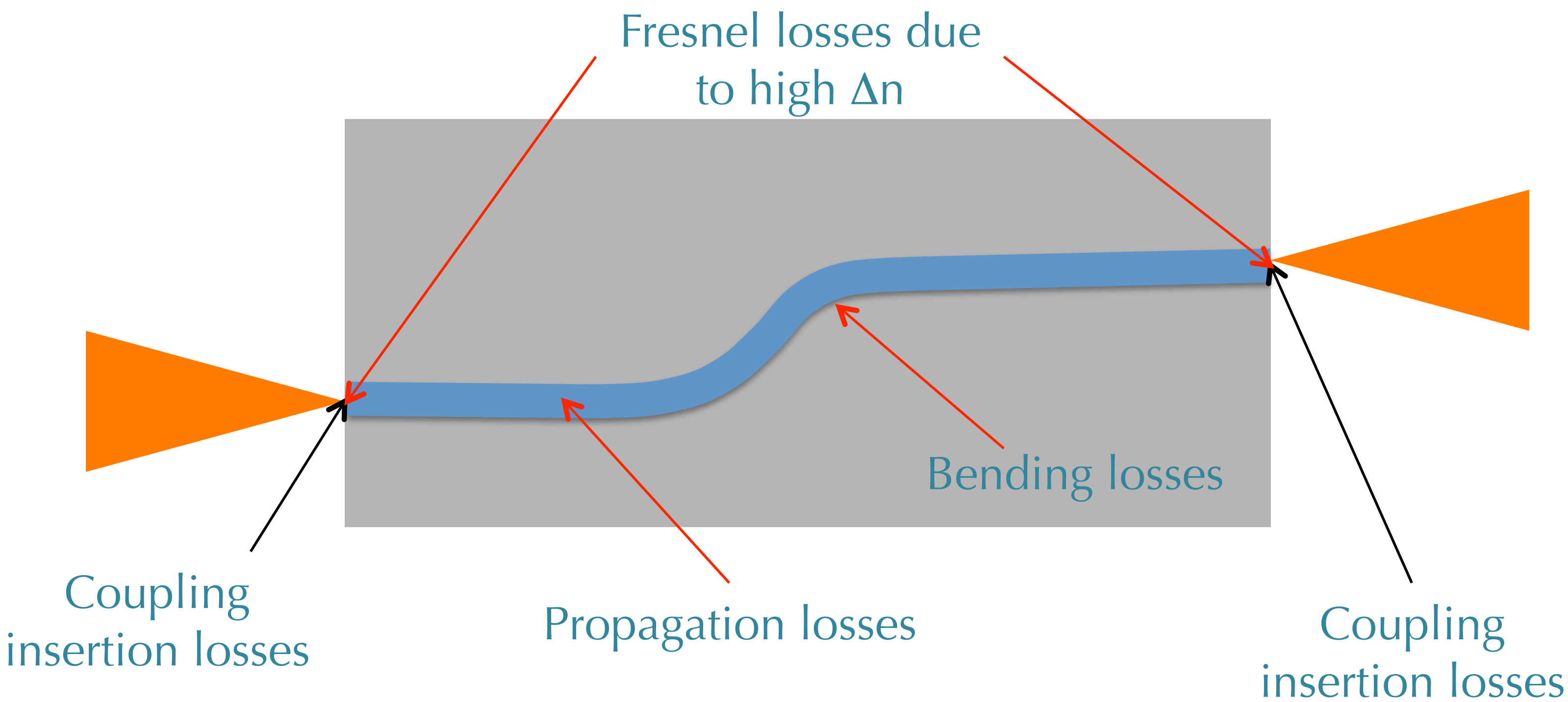
  → *Different IR materials with different transmission windows*

- Silicon-on-Insulator (SOI): exploit transparency of silica (SiO_2) up to 3.1 μm. *Multimode* waveguides produced with losses 0.7dB/cm (Mashanovic et al. 2011).



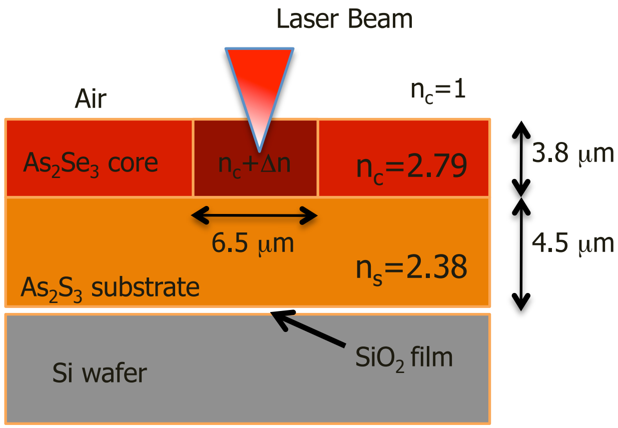
- Silicon-on-Sapphire (SOS): guiding up to 7 μm, with *single-mode* losses <2dB/cm (Li et al. 2011).

- Etched telluride waveguides: guiding up to 20 μm, single-mode with losses ~4dB/cm (Vigreux et al. 2011)

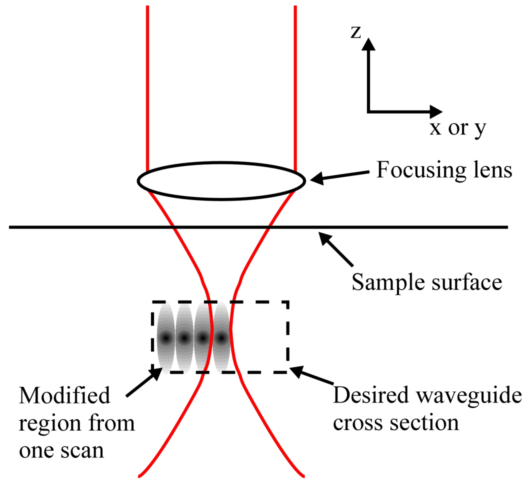

Fresnel losses due
to high Δn
Bending losses
Coupling
insertion losses
Propagation losses
Coupling
insertion losses

Laser-written devices

CW laser writing



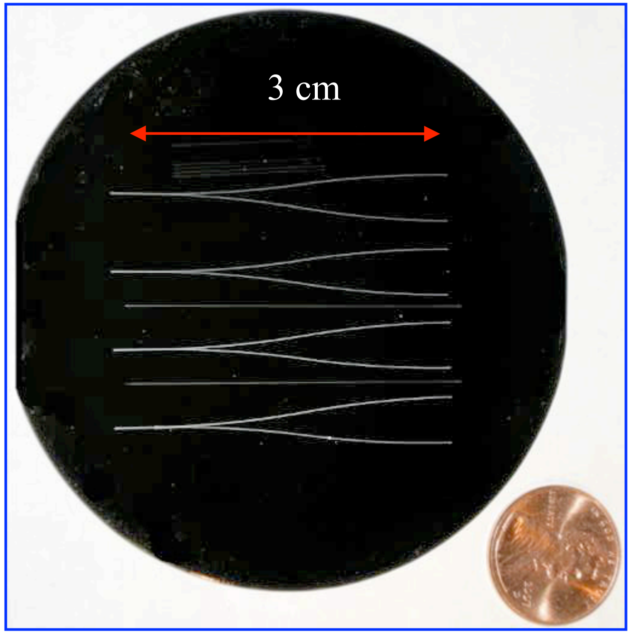
Ultrafast laser inscription



- Lighter infrastructure compared to classical waveguide etching
- Insert symmetry in the coupling process by having the waveguides embedded
- Control of the Δn by mean of CW power level or pulsed energy

Proof-of-concept

CW laser writing



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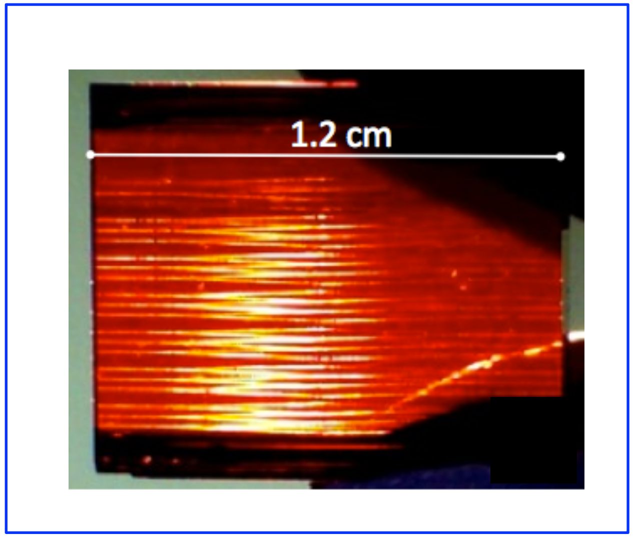
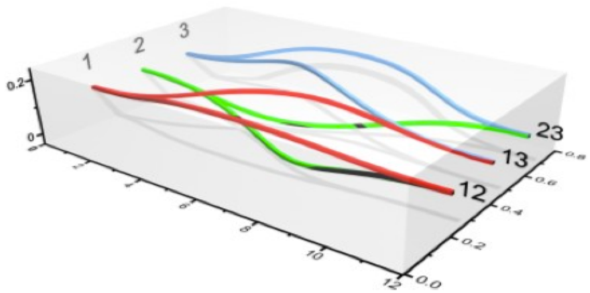




Labadie, L. et al., A&A (2011)

Rodenas, A. et al., Opt. Lett. (2012)

Data results

Labadie, L. et al., A&A (2011)

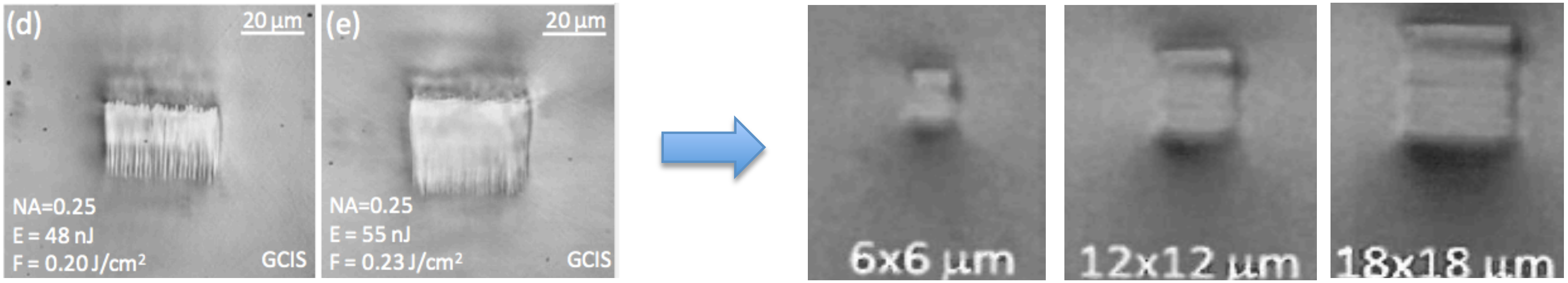
Rodenas, A. et al., Opt. Lett. (2012)

Labadie, L. et al., SPIE proc. (2013)

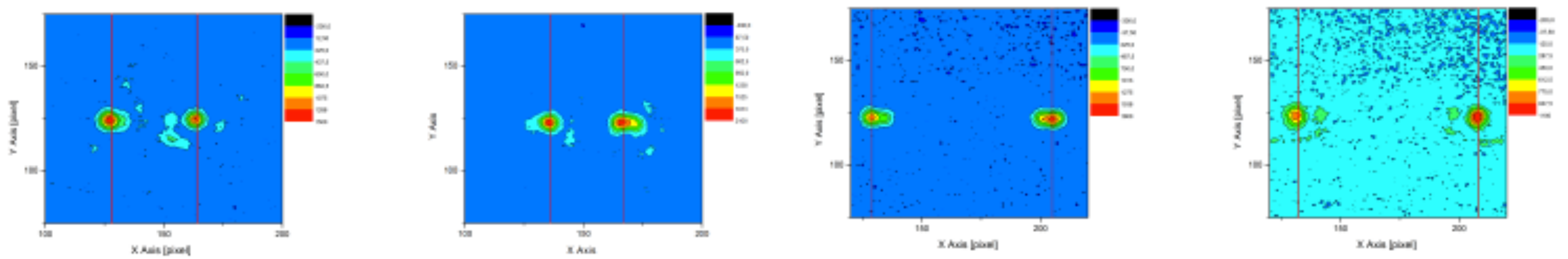
	2D & 2-telescope Y junction	3D & 3-telescope combiner
Material	As2Se3/As2S3	Research glass GCIS
Transparency	<12 μm	<12 μm
Δn	0.04	<0.012
Modal behavior	SM for λ>8.6μm	SM for λ>9μm
Interferometric contrast	0.981+/-0.001	99.53% (mean), 99.89% (peak)
Propagation losses	0.6dB/cm (channel WG)	~1-2dB/cm (function)
White-light fringes	No	Yes (9μm<λ<11μ)

Optimization

- Optimization needs to follow proof of concept (=improving the waveguides quality)

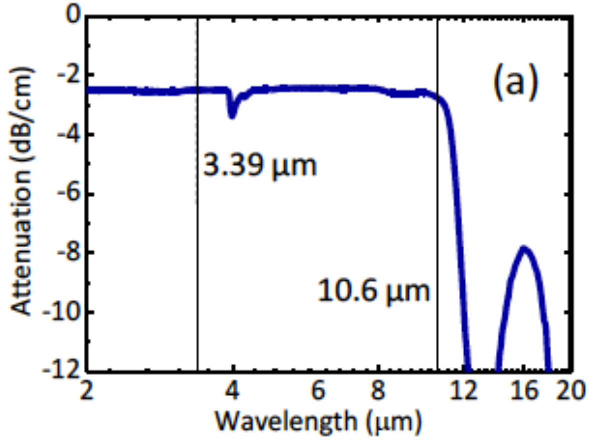


- Checking splitting ratio of all the beam combiners

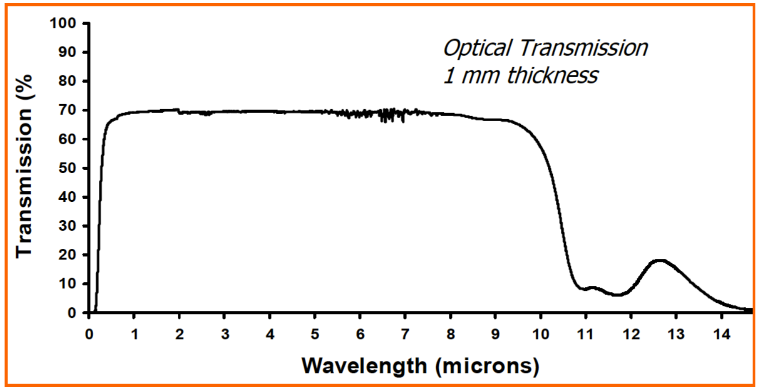


Optimization

- Controlling the spectral coverage of glasses
  - Research glass



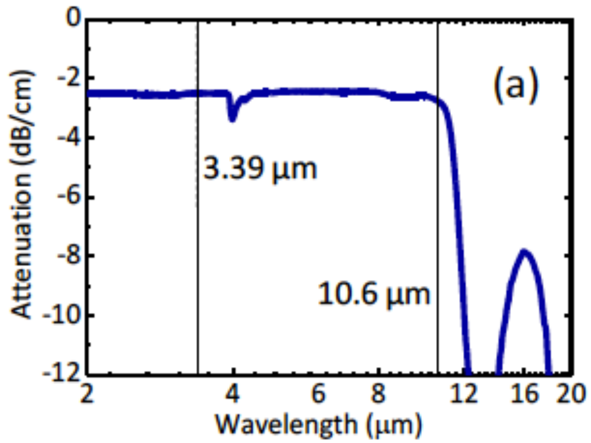
  - Commercial glass (GLS)



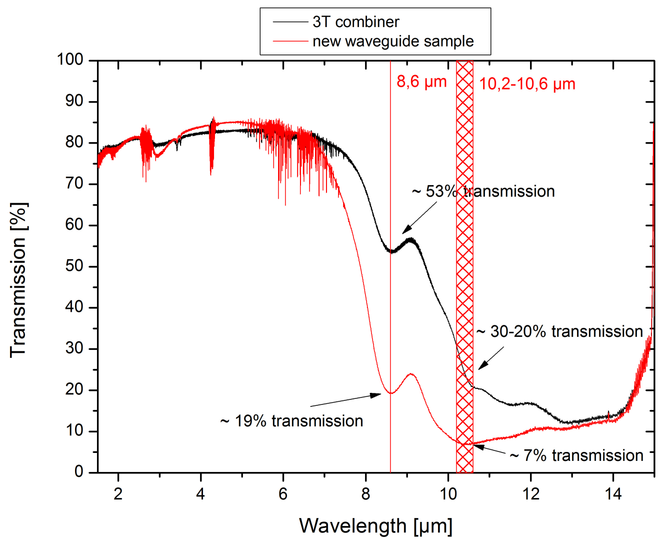
Optimization

➢ Controlling the spectral coverage of glasses

➢ Research glass

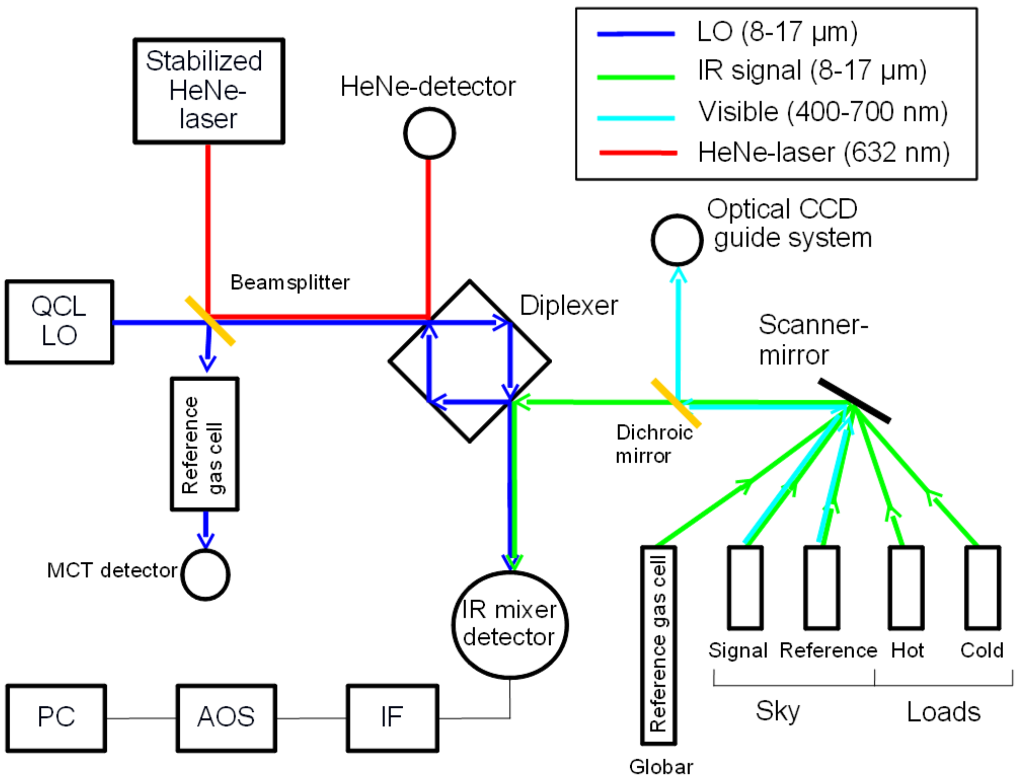


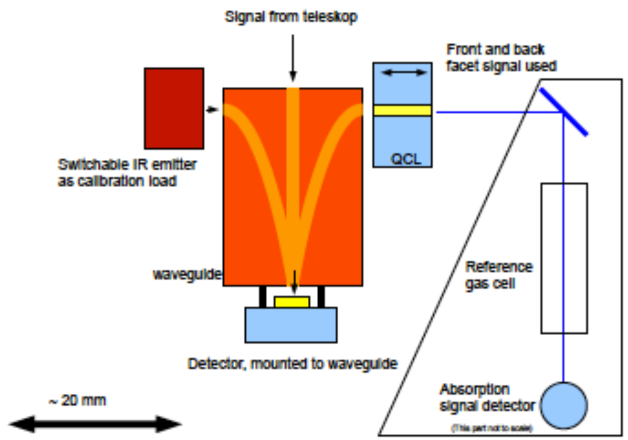
➢ Commercial glass (GLS)



mid-IR IO outside interferometry

➢ Heterodyne spectroscopy

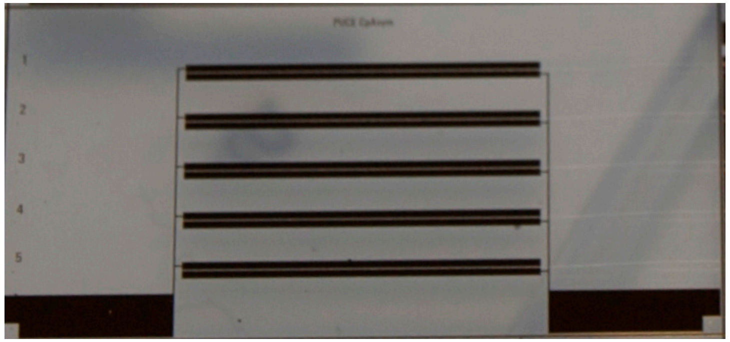




Tunable Heterodyne Infrared Spectrometer (PI Guido Sonnabend)

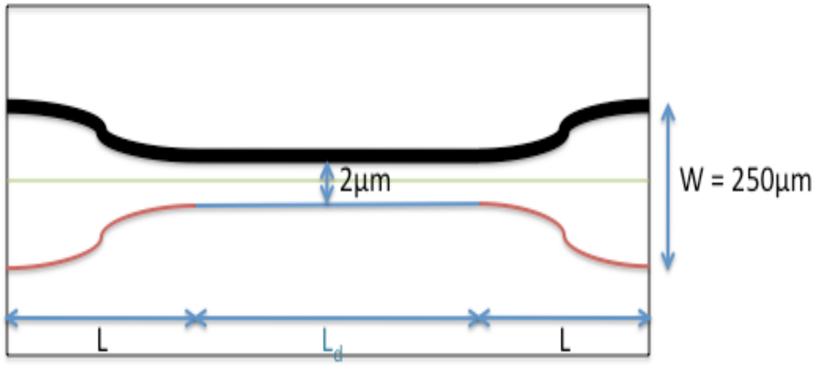
The $LiNbO_3$ active functions

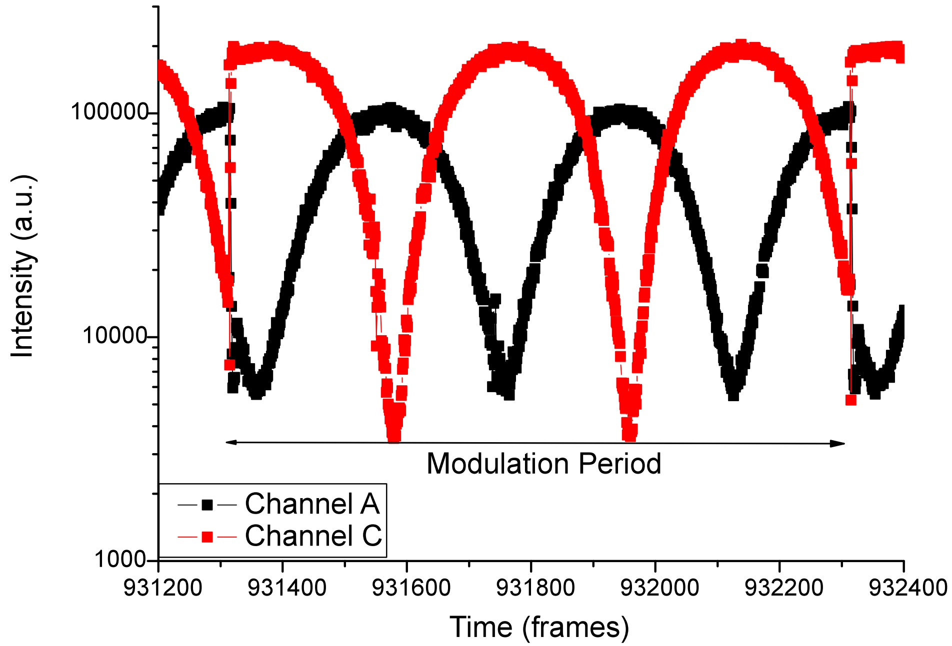
Active Directionnal Couplers: On-Chip Amplitude Tuning @ 3.39um



20mm x 10mm $LiNbO_3$ sample

Heidmann, S. et al. (2013), Optics Letters





Conclusion

- We have demonstrated a number of proof-of-concepts for mid-IR integrated optics
- Progress towards a well-thought optimization of such devices, primarily for ground-based interferometry
  - Accurate estimate of the losses (propagation and bend losses)
  - Specify one (or two maximum) priority band
  - "Side" aspects: polarization, coatings, maximizing coupling, bend losses
  - Prototyping an end-to-end interferometric component (single-mode 3-4mu fibers are commercially available!)
- Explore on punctual basis opportunity for applications outside interferometry