THALES

Applications of Micro-transfer printed III-V on silicon nitride for microwave photonics and sensing

Vincent Billault

Thales Research&Technology (TRT), France

vincent.billault@thalesgroup.com

Pro & cons of standard photonics plateform

Photonic integrated circuits

- Extremely reduced footprint → high density integration
- New/improved functionalities (nonlinear photonics, optical phase sensitive circuits)
- Driven by electronics IC industries → future electronics / photonics co-integration

Standard technological platforms

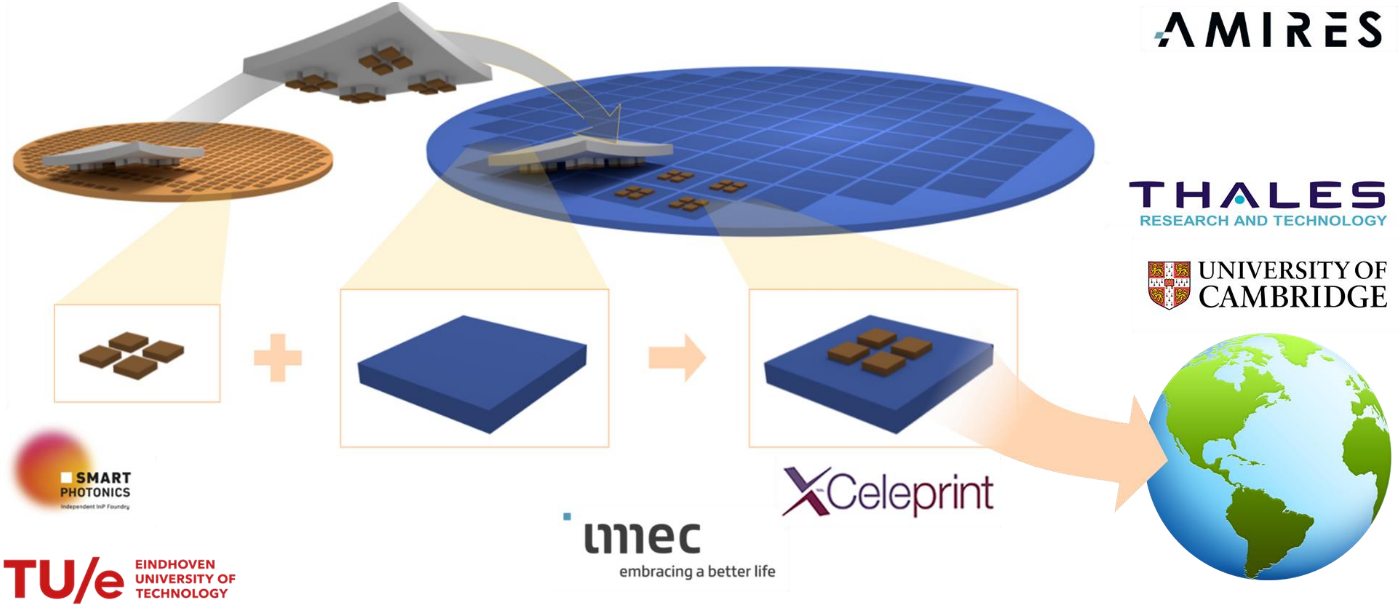
PIC PLATFORM ATTRIBUTES	Indium Phosphide	Silicon Nitride	Silicon (CMOS) photonics
Passive components	✓	✓✓✓	✓✓
Lasers	✓✓✓	✗	✗
High speed modulators	✓✓✓	✗	✓✓
Switches	✓✓✓	✓	✓✓
Optical amplifiers	✓✓✓	✗	✗
High speed detectors	✓✓✓	✗	✓✓✓
Power handling	✓✓	✓✓✓	✓
Fiber-chip coupling	✓✓	✓✓✓	✓
Footprint	✓	✓	✓✓✓
Chip cost	✓	✓✓	✓✓

For more and more complex PICs : **Hybrid integration is required**

InP technology : key for lasers and amplifiers

Silicon Nitride : major tech for low loss propagation (delay lines, external cavities, OPAs)

Micro transfer printing of III-V on SiN : INSPIRE

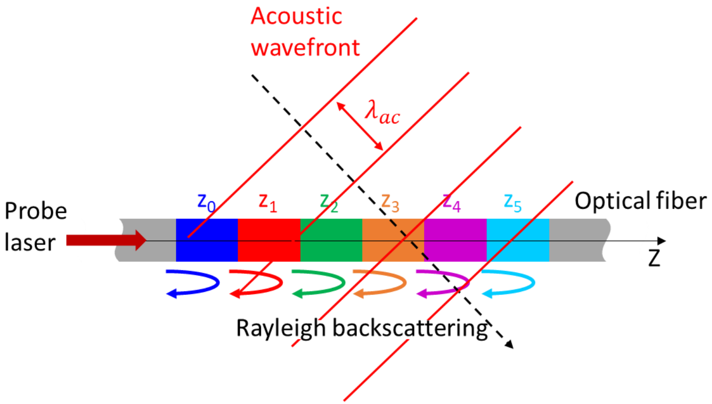


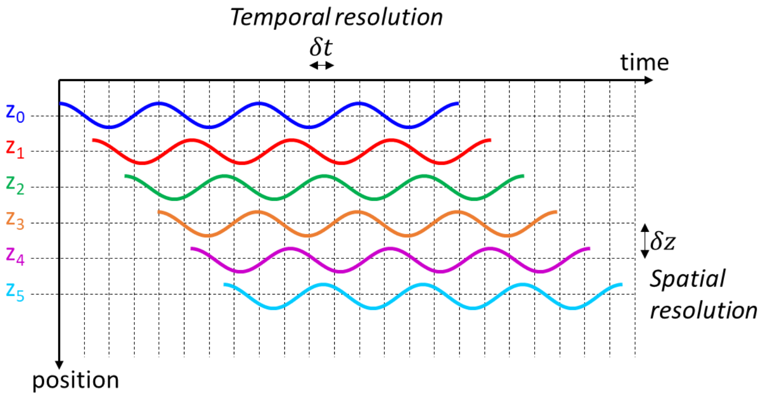
Establish world-first platform combining low-loss waveguides with InP actives to sustain Europe's industrial leadership in photonics;

Micro-transfer printed III-V on silicon nitride for distributed acoustic sensing

Distributed Acoustic Sensing (DAS)

- Distributed Acoustic Sensing (DAS) relies on Rayleigh retrodiffusion of a probe light on defects distributed along the fiber
- The amplitude and phase of the backscattered light enable to retreive the strain condition along the fiber, resolved in time and space



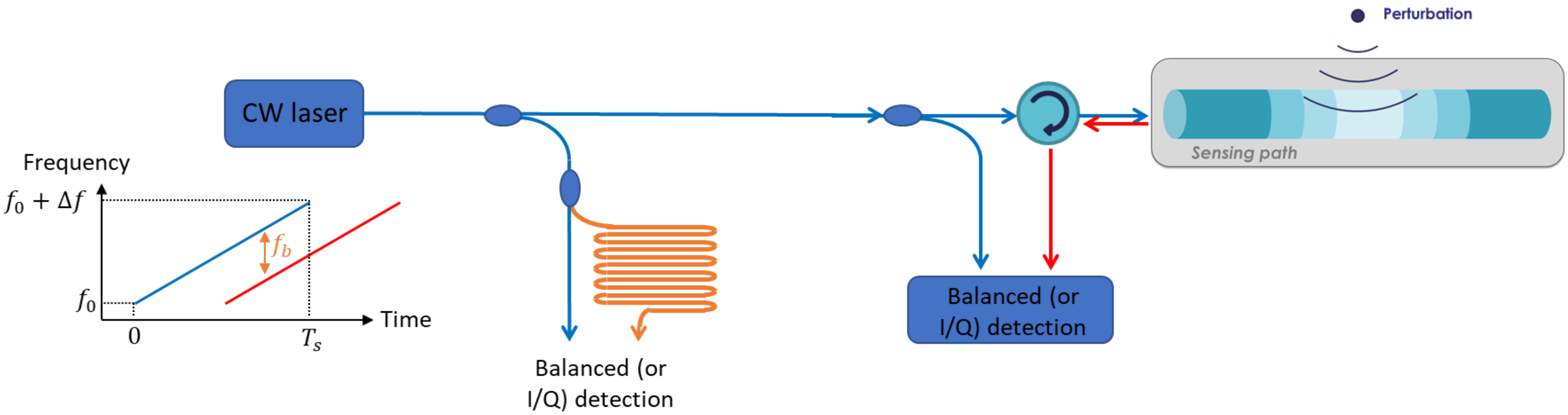


- Applications in structural health monitoring of buildings, roads, rails, pipeline, wells, perimeter surveillance, ocean acoustic monitoring, …

DAS with Optical frequency domain reflectometry (OFDR)

Measurement of local perturbation with frequency modulated laser (FMCW)

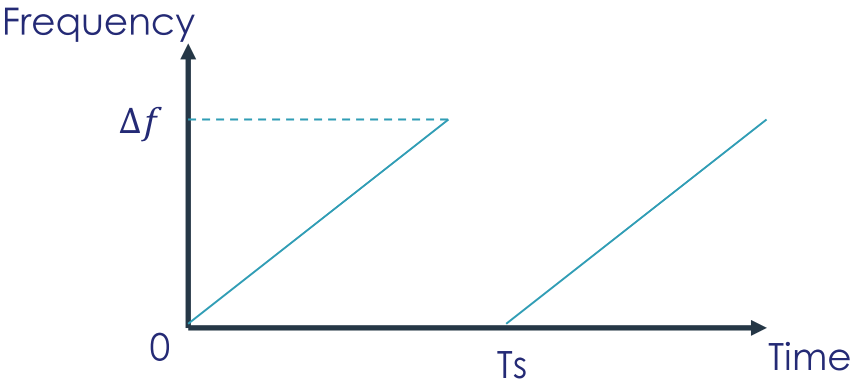
- Distance information coded in frequency
- Fourier transform of the backscattered signal => amplitude and phase changes induced by the perturbation
- Reference interferometer to measure/correct the chirp nonlinearities



Measurement of strain in an optical fiber

Laser key figures

- Laser linewidth
  - Impact the detection sensitivity
  - Determines the maximum length that can be interrogated
- Laser tunability
  - Impacts the sensor spatial resolution and acoustic bandwidth



Sensor spatial resolution

- $\delta z = c/2n\Delta f$
- $\Delta f \ = \ 10 \text{ GHz} \Rightarrow \delta z \ = \ 1 \text{ cm}$

Sensor acoustic bandwidth

- $B_{\text{ac}} = 1/2Ts$
- $T \ = \ 100 \ \mu s \Rightarrow B_{ac} \ = \ 5 \text{ kHz}$

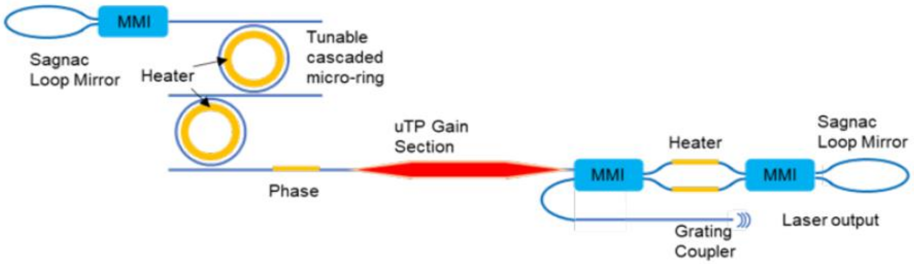
	Frequency span Δf	Repetition rate $1/Ts$	Laser linewidth
commercial	4 GHz	10 kHz	10 kHz

Need of a low linewidth laser, with a large frequency bandwidth of tuning → **InP + SiN**

Laser design and performances

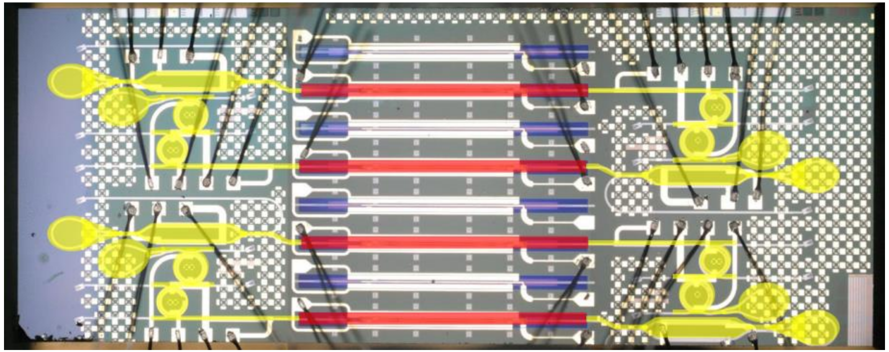
Laser design

- µtransfer gain section on passive SiN circuit (sagnac mirror and cascaded micro-ring for frequency selection)



- Different variations of ring sizes, coupling gap to the rings to change the tunability of the laser :
  - Tradeoff between quality factor of the cavity and tunability for high speed tuning.

Picture of the chip after wire-bonding

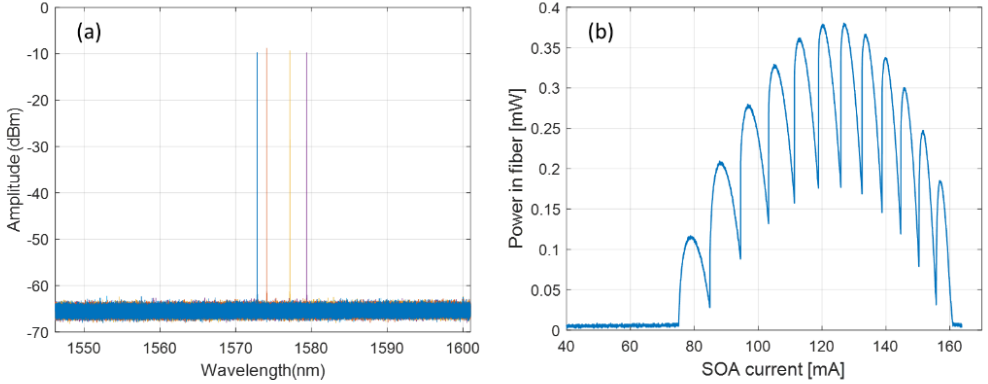


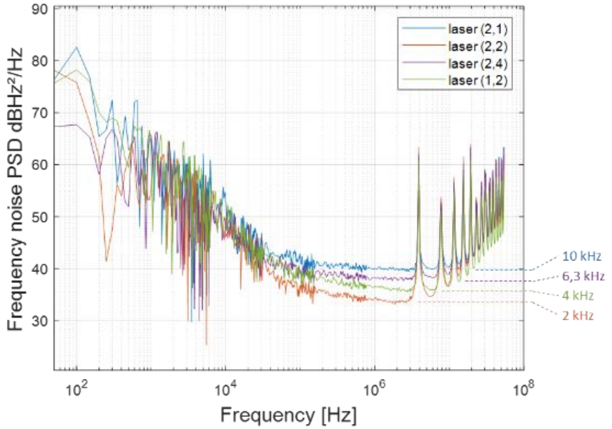
Laser performances

Optical properties

- lasers fully functional (-6 dBm in fiber with grating coupler) in telecom band

- Quality factors [30 - 60] kHz
  - kHz linewidth class lasers[1]
  - Validates laser linewidth engineering capability by design



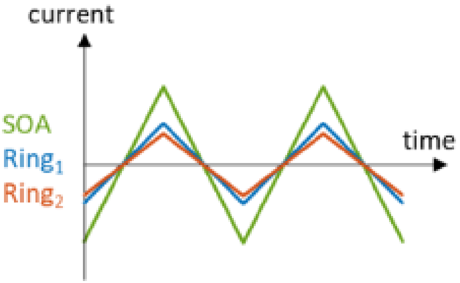


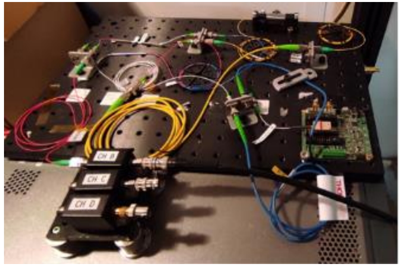
B. Pan *et al.*, "III-V-on-silicon nitride narrow-linewidth tunable laser based on micro-transfer printing," *2023 Optical Fiber Communications Conference and Exhibition (OFC)*, San Diego, CA, USA, 2023, pp. 1-3, doi: 10.1364/OFC.2023.Th3B.5.

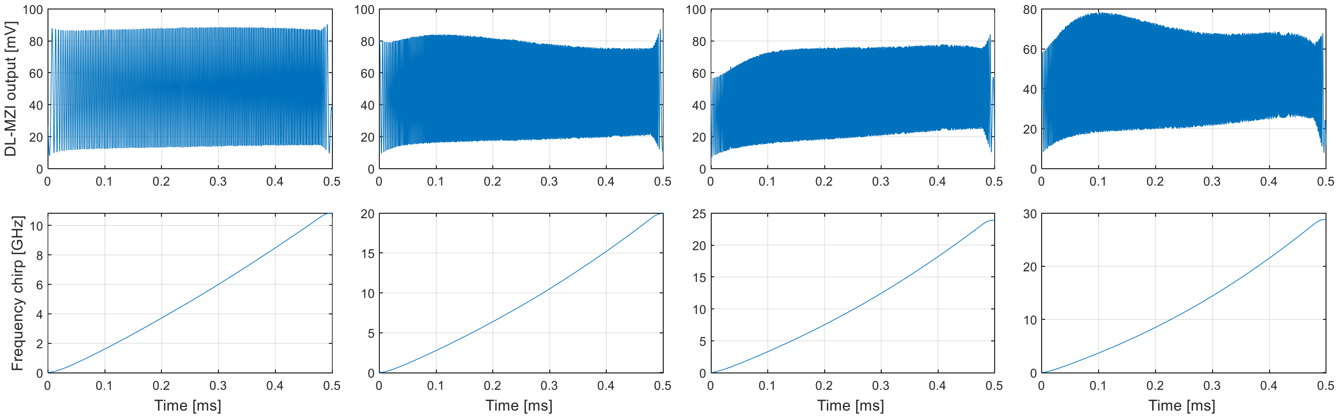
Laser tunability

Use of an external calibration interferometer

- 2 kHz sawtooth modulation
- Measurement of the chirp bandwidth
- Up to 30 GHz (with non linearities)



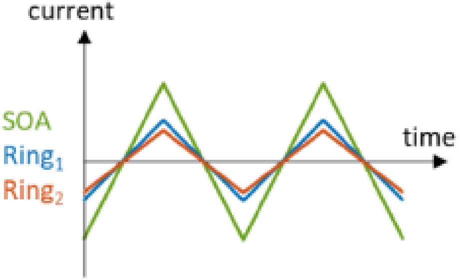


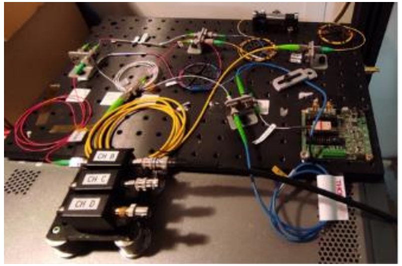


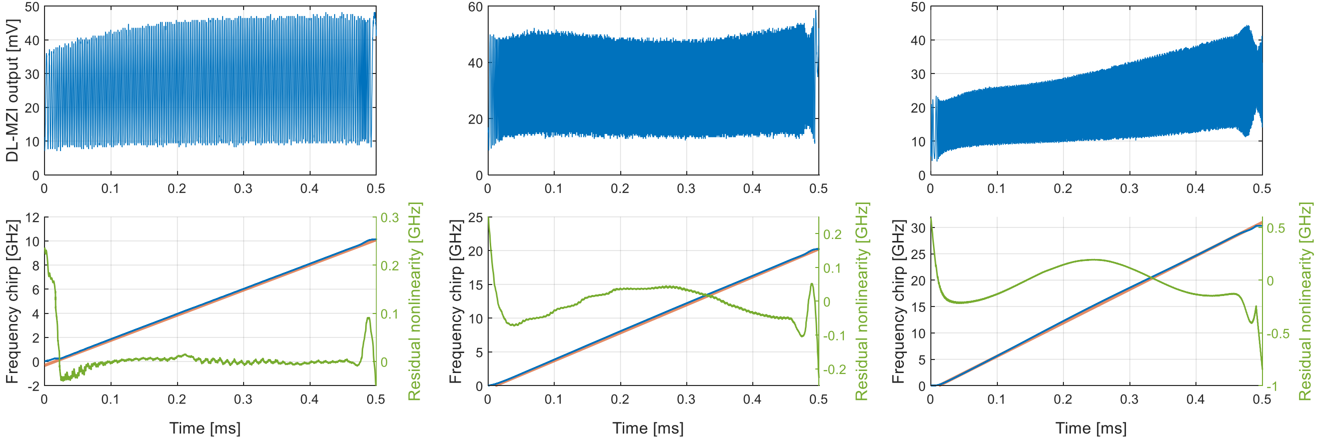
Laser tunability

Use of an external calibration interferometer

- 2 kHz predistortion wavefront
- Measurement of the chirp bandwidth
- Up to 30 GHz (with +/- 1% residual nonlinearity)



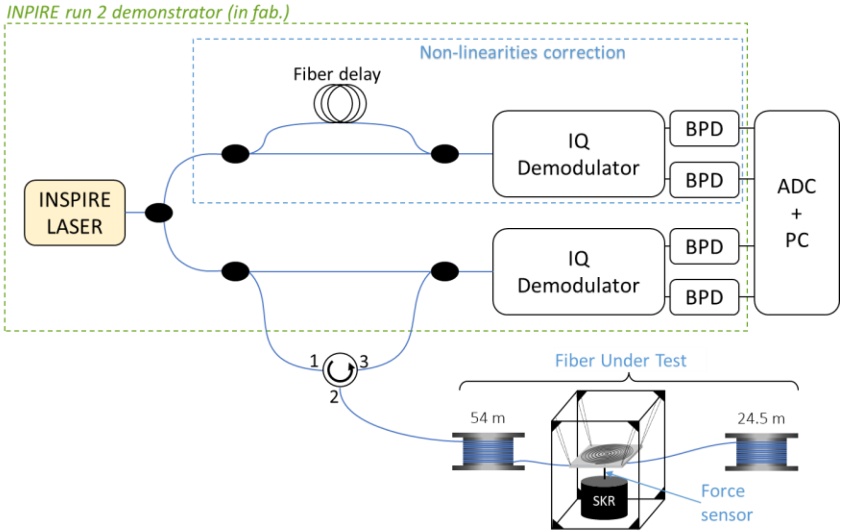




Experimental set-up

INSPIRE laser connected to THALES DAS set-up

- Probing of a calibrated sensor with known mechanical modes
- Objective: excite a mode of the sensor and measure its phase signature



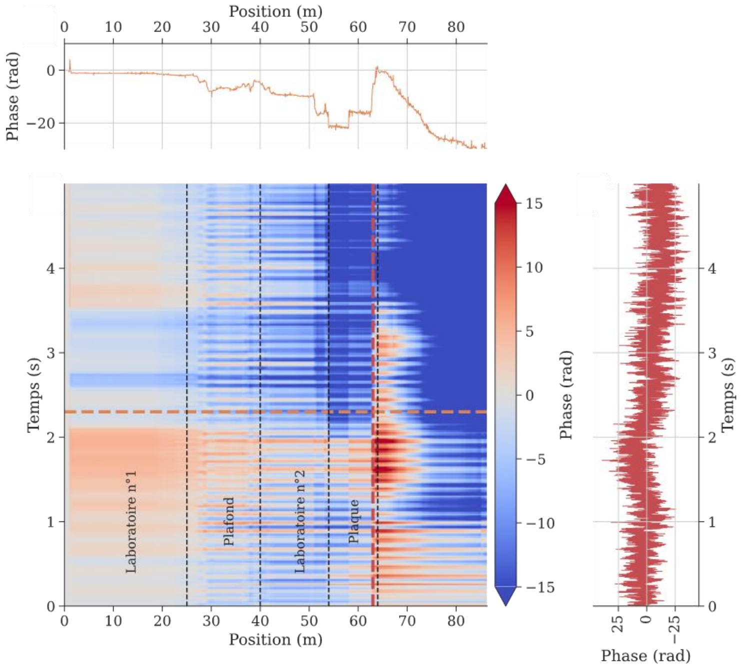
OPEN

THALES

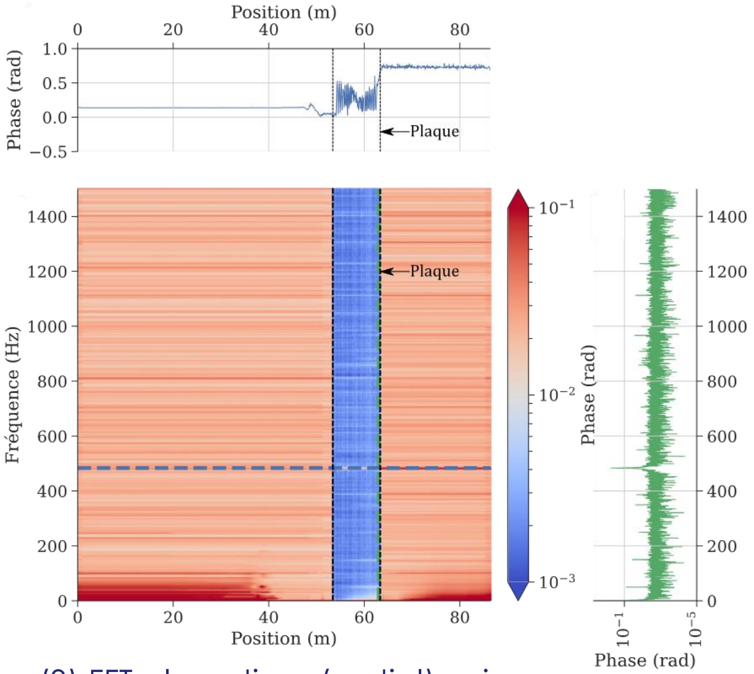
OFDR signal processing pipeline

(1) FFT of the beating signal time trace

(4) Filtering at excitation frequency



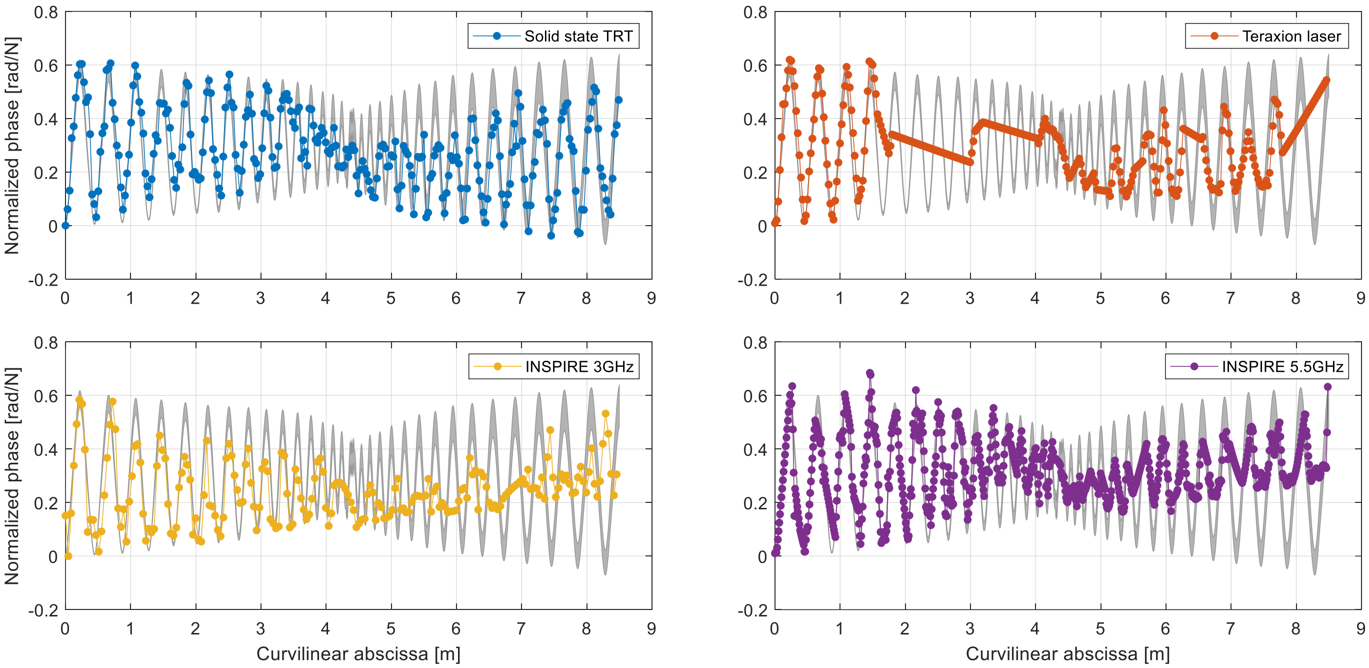
(2) Pilling successive acquisitions



(3) FFT along time (vertial) axis

Experimental results

Frequency modulation rep. rate set at 3 kHz for all the lasers



- INSPIRE laser performs as good as SSL and better than Teraxion COTS laser.
- **Overperforms all lasers in terms of spatial resolution**

Conclusion

Narrow linewidth largely tunable laser

- mm range resolution for acoustic sensing (kHz interrogation)
- Laser linewidth engineering by design
- Calibration of FM wavefront to minimise non linearities

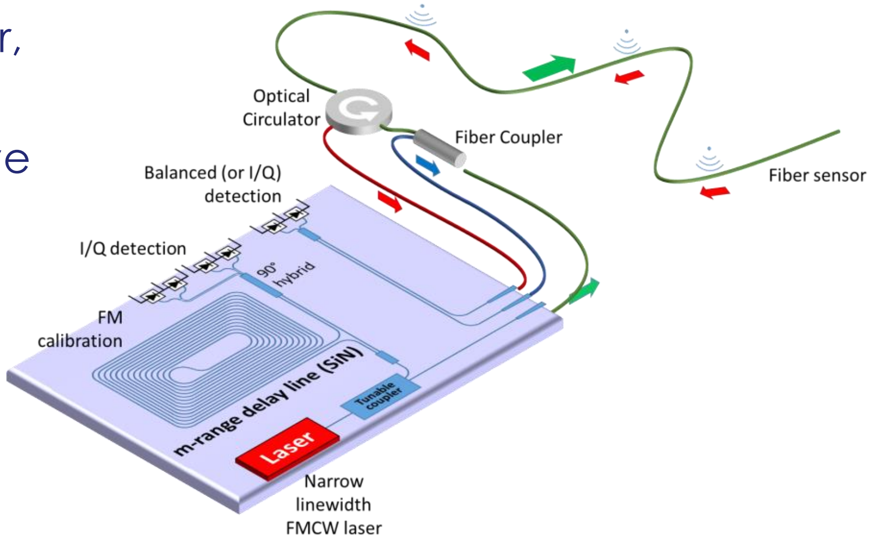
	Frequency span Δf	Repetition rate $1/Ts$	Laser linewidth
commercial	4 GHz	10 kHz	10 kHz
INSPIRE laser	Up to 30 GHz	Up to 5 kHz (1 kHz for 30 GHz chirps)	[1 – 10 kHz] linewidth

Future prospect : all integrated Sensor fiber readout

Integration of sensor fiber readout on a photonic integrated circuit

- Active components (narrow linewidth laser, balanced photodiodes)
- Meter-range delay line (high quality passive SiN)

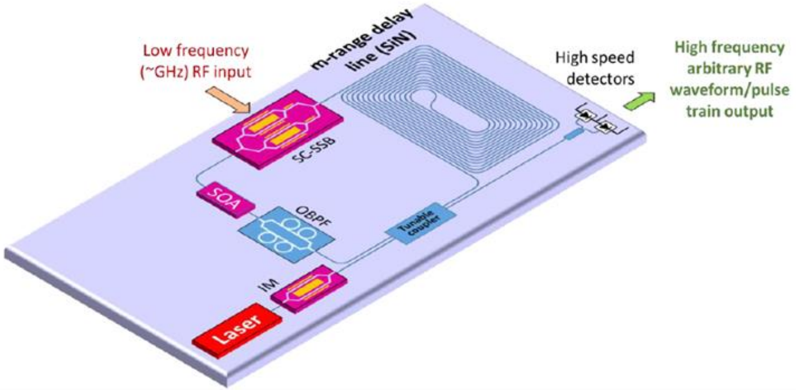
- **On-chip calibration of the frequency modulation**
- **On-chip I/Q demodulator with balanced photodiodes.**



Future prospect : all integrated microwave photonic circuit

Integration of frequency shifting loop on a photonic integrated circuit

- Frequency shifting loop : Photonic microwave circuit for
  - High instantaneous bandwidth signal generation (chirps, pulses, arbitrary wavefronts)
  - Signal processing (Real time analog integer/fractionnal Fourier transform,…)



- **Integration of Laser, m-range delay line, SOA, frequency shifter (SSB) on a same chip possible through heteroheneous integration**

Thank you very much !

www.inspire-h2020.eu

www.linkedin.com/company/INSPIREH2020