Designing high power hybrid integrated tunable lasers for automotive LiDAR

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PIC International
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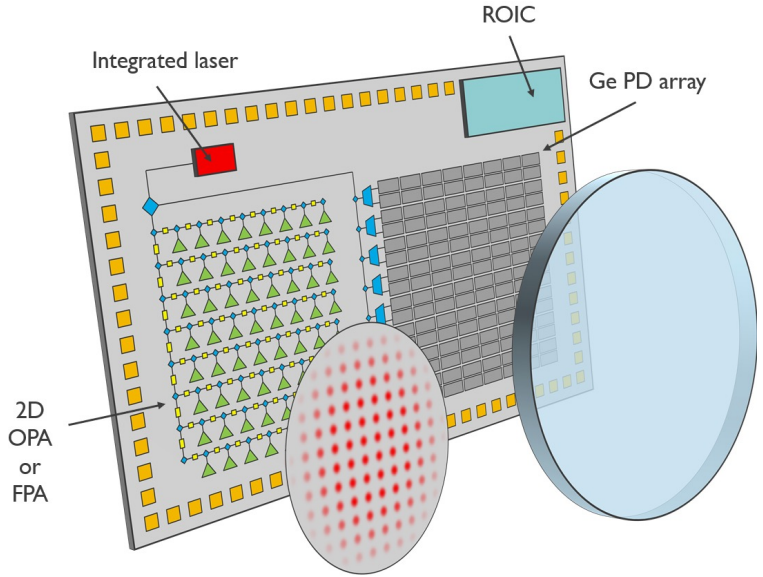
PhotonDelta – *www.photondelta.com*

Context

FMCW LiDAR: on-chip laser design

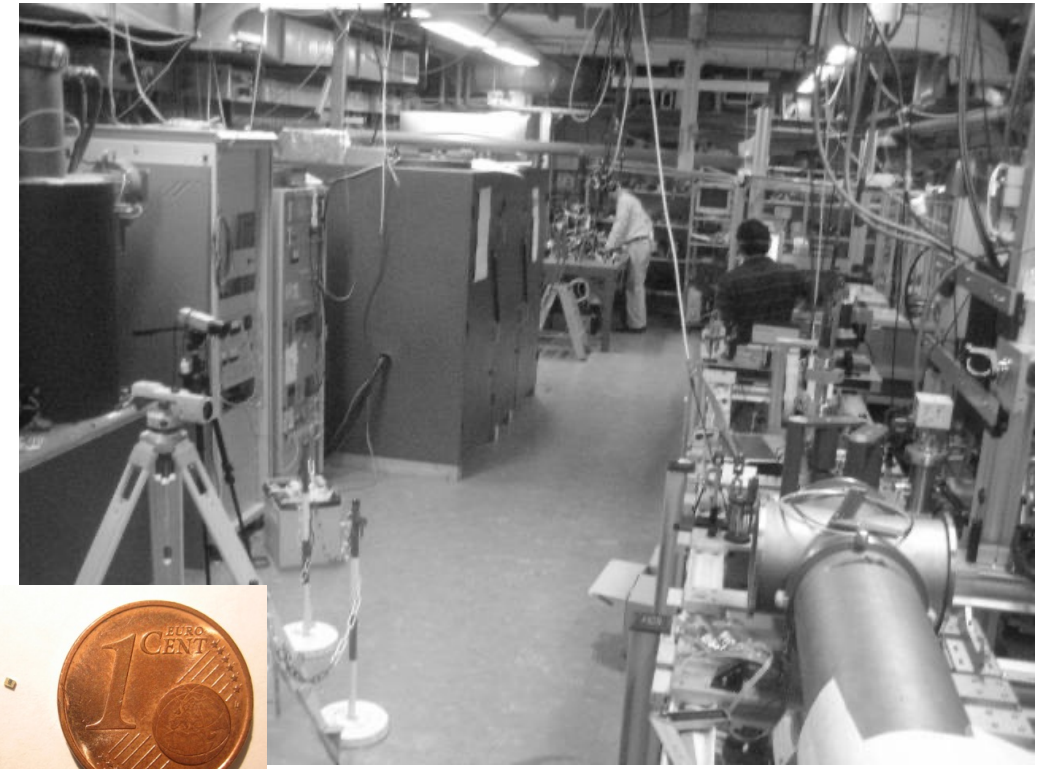
- Specs
- Design strategies
  - Linewidth
  - Output power
  - Chirp
- Integration strategy
  - Hybrid integration
- But first...
  - Personal introduction
  - imec & iSiPP introduction

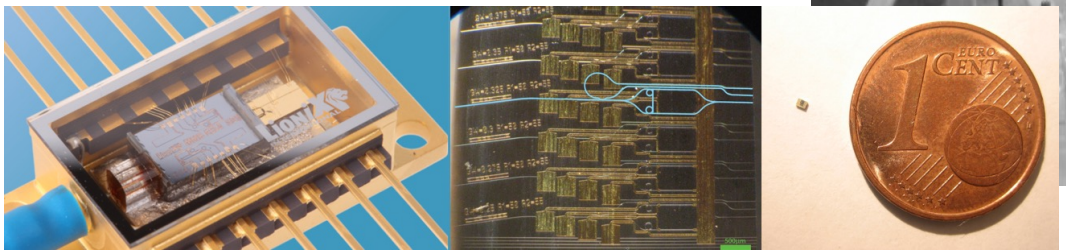


Personal introduction

dr. ir. Ruud Oldenbeuving

- BSc, MSc, PhD: Laser Physics and Nonlinear Optics
- 20+ years of experience with lasers
- 15+ years of experience with integrated photonics
- 1st world-wide to design and fabricate and characterize ultra-narrow linewidth tunable InP-SiN hybrid laser
- Hybrid PIC laser thought-leader
- Since October 2021 @imec-NL





imec, the leading independent R&D hub in nanoelectronics and digital technologies

Founded in **1984**

Unique ecosystem, collaborating with **600+ industrial partners**

>€3.5B invested in **leading-edge semiconductor fabs (200mm and 300mm pilot lines, 12,000m²)**

5,500 employees

Focus on **industry-relevant technology solutions** for health and life sciences, mobility, industry 5.0, agrifood, smart cities, sustainable energy, etc.

2022: € 845M revenue, 162 patent applications, 1,300 Web-of-Science publications

imec's silicon photonics offering

iSiPP200(N), iSiPP300(N), iSiPP50G

- 20+ years of research, 10+ years of prototyping, 6+ years of production
- SOI, SiN, Ge, ...
- >8,500 cumulative **200mm wafer** starts (~2,000 in 2021)
- Research on **300mm wafer** pilot line => high volume throughput

- Collaborating with leading telecom, datacom and artificial intelligence companies

Imec's automotive FMCW LiDAR systems

To measure 300m distant targets with a resolution of 10 cm

Laser parameter	Focal Plane Array (FPA)	Optical Phased Array (OPA)
Linewidth (*)	<100 kHz	
Chirp rate	MHz	
Chirp excursion	>3 GHz	
Wavelength tuning	n/a	
Output power (on-chip)	500 mW	

(*) lower is better

Achievable via
hybrid integration

Why photonic hybrid integration?

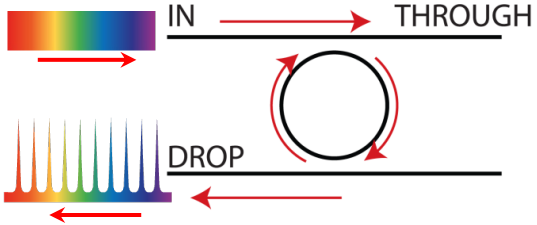
Combining strengths of different platforms; best of all worlds

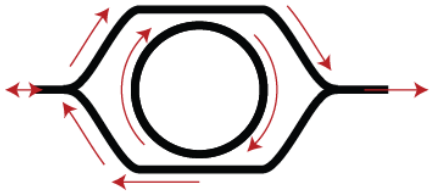
	Silicon	Silicon Nitride	Indium Phosphide
Propagation loss			
Tapering			
Power consumption of heater			
Detectors			
Light source			
Fast modulator / phase shifter			
Optical-power handling			

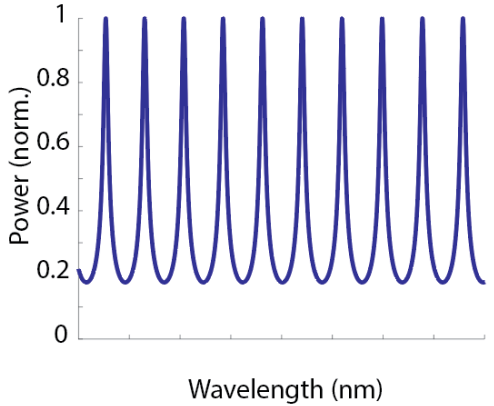
Frequency selection and narrowing linewidth

Via hybrid integrated external cavity laser

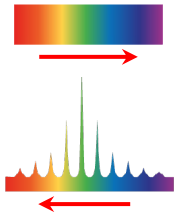
- Single ring resonator

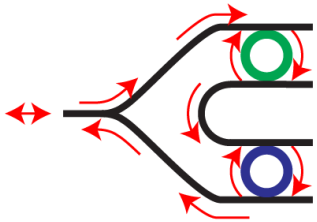


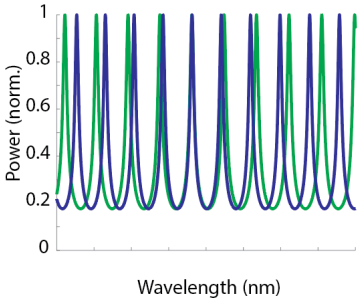


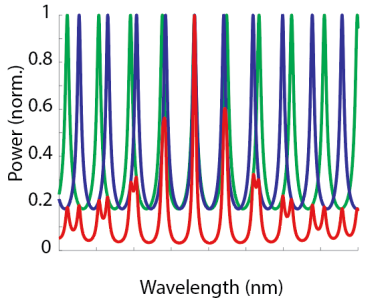


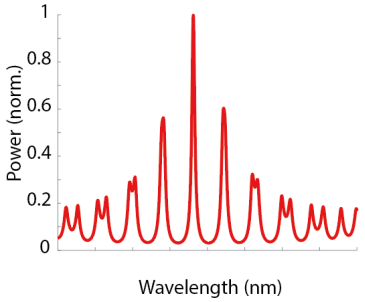
- Double ring resonator (Vernier effect)



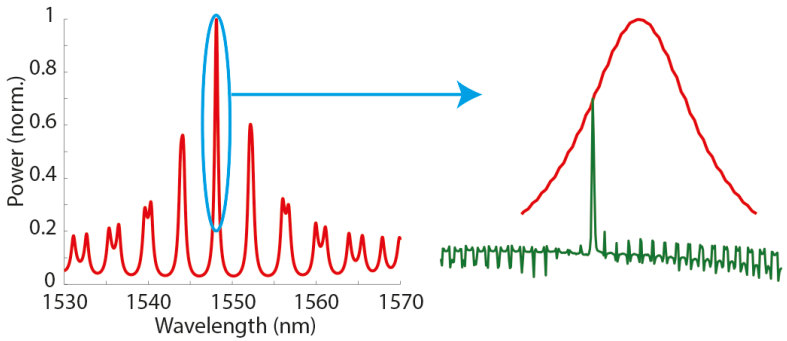


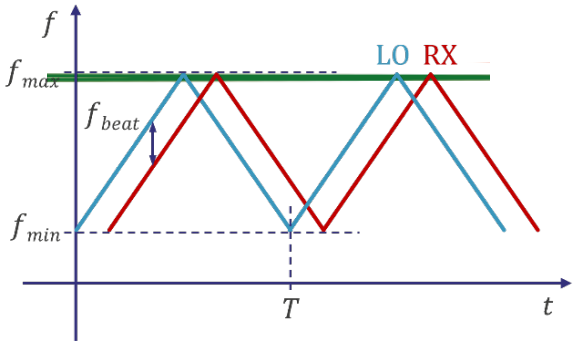






FMCW operation





3 GHz chirp ~10 cm resolution

- For FMCW:
  - Linear chirp
  - Equal output power
  - Stable linewidth
- Frequency chirping: higher chirp => higher depth resolution
- Chirp is limited by the width of the Vernier peak
- Chirp via phase section tuning (slow)
- Chirp via ring resonator tuning (slow)
- Chirp via current tuning of gain (fast)

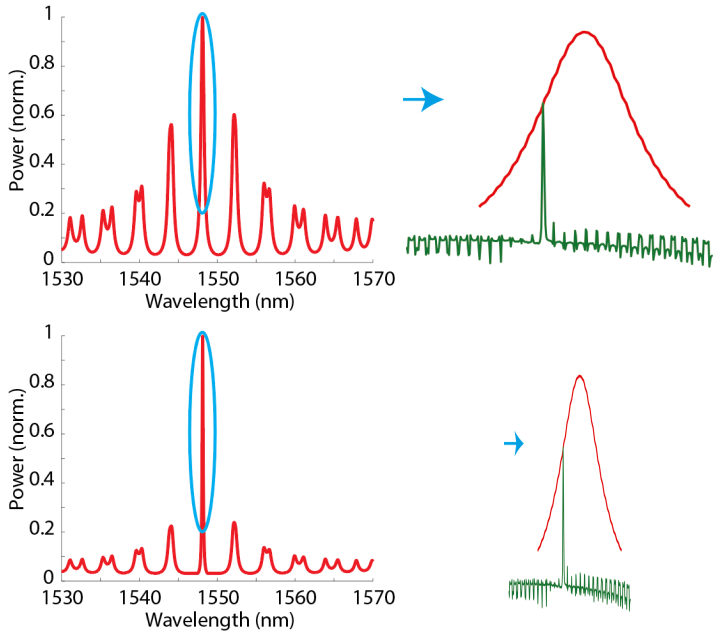
Lowering the linewidth

Goes at expense of frequency chirp

- Schawlow-Townes

$$\Delta\nu_{\text{laser}} = \frac{4\pi\, h\nu\, (\Delta\nu_c)^2}{P_{\text{out}}}$$

Increase laser power
Increase cavity photon lifetime
(via ring resonator increased Q-factor)

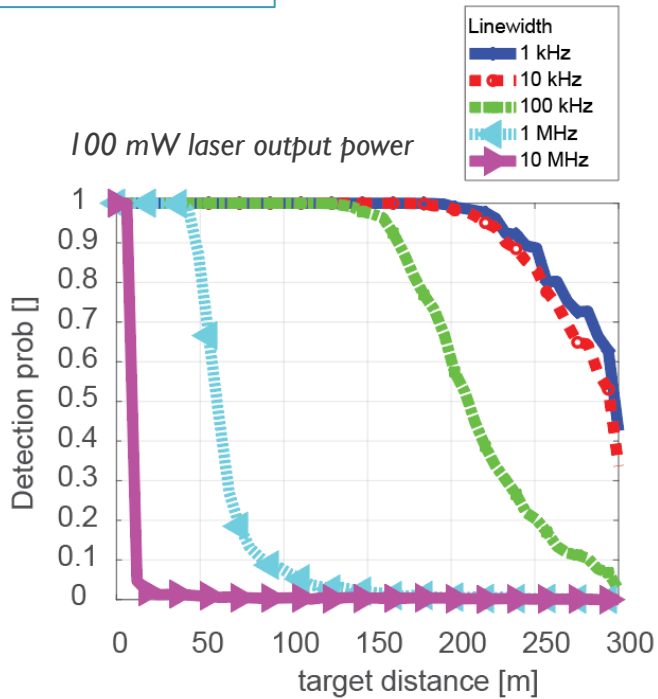


~25 kHz [1] **R.M. Oldenbeuving** *et al* (2013) Laser Phys. Lett. 10 015804 (2012)
~1 kHz [2] Y. Fan (...), **R.M. Oldenbeuving**, *et al.* IEEE phot. journal 8 (6), 1-11 (2016)
~300 Hz [3] J.P. Epping, **R.M. Oldenbeuving**, *et al.* OFC, ATu1A. 4 (2019)
~40 Hz [4] Y. Fan (...), **R.M. Oldenbeuving**, *et al.* Opt. Express 28 **15** (2020)

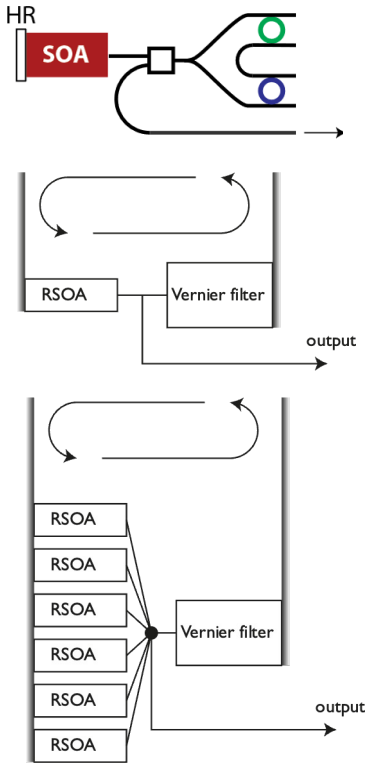
Linewidth and output power

Coherence length required beyond roundtrip distance

SoTA: 150 mW, 1 kHz



Higher power?

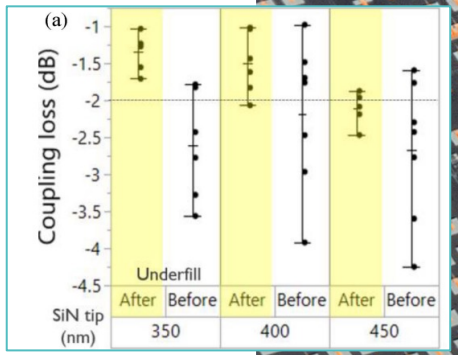


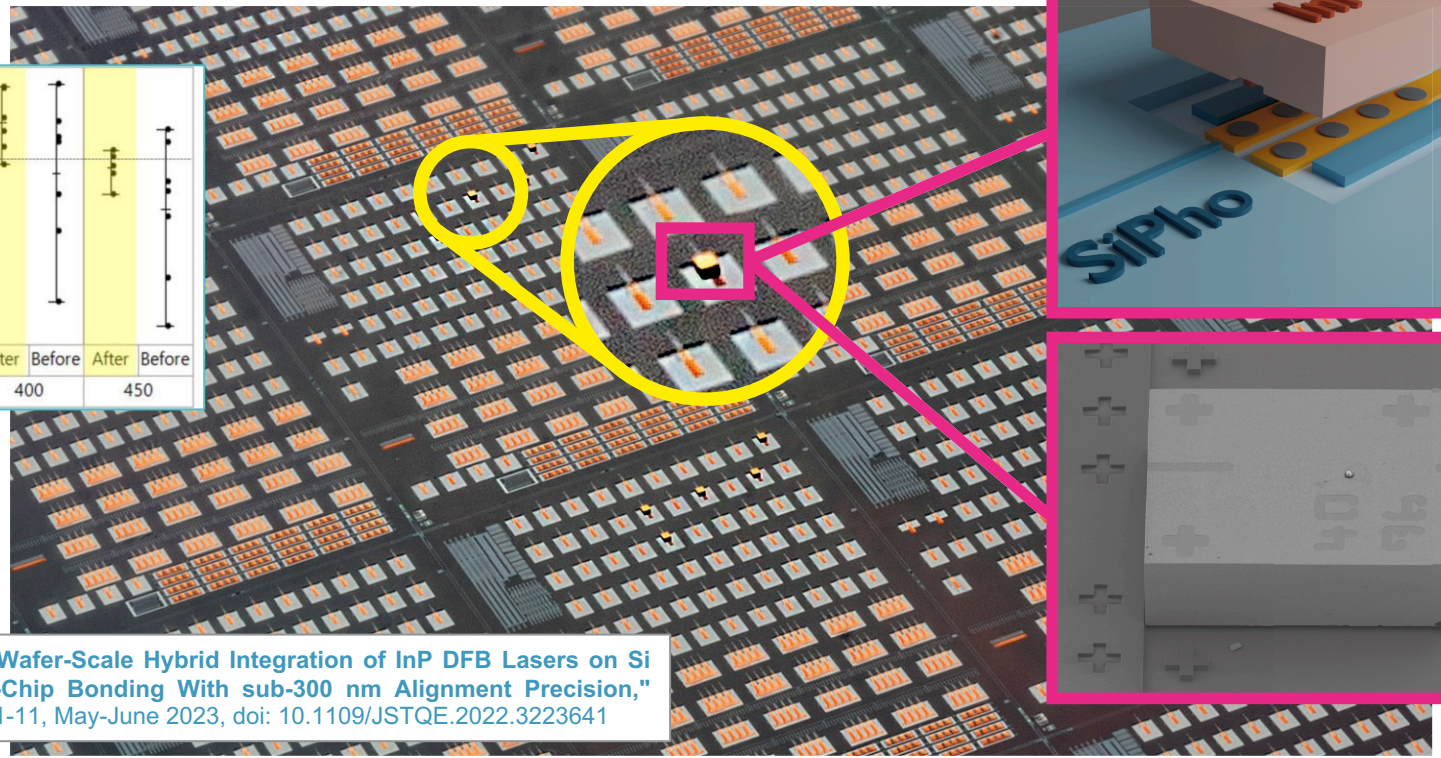
- Don't amplify in series
- Amplify in parallel

- For LiDAR:
- Single gain: 30-80mW, typ. 50mW
- Double gain: 60-160mW, typ. 100mW
- Quadruple gain: typ. 200mW expected
- (etc...) scalable method

Scaling production for automotive industry

Hybrid integration via flip-chip method





A. Marinins *et al.*, **"Wafer-Scale Hybrid Integration of InP DFB Lasers on Si Photonics by Flip-Chip Bonding With sub-300 nm Alignment Precision,"** in *JSTQE* 29(3) pp. 1-11, May-June 2023, doi: 10.1109/JSTQE.2022.3223641

Take away message

Everything must be designed together, to fit properly

Thank you for your attention

embracing a better life