Apropos 18
Advanced Properties and Processes in Optoelectronic Materials and Systems
5th of October 2022

CENTER FOR PHYSICAL SCIENCES AND TECHNOLOGY

Optical heterodyne-based module on silicon platform for sub-THz wireless data transmission

[1] Kalliopi Spanidou, [1] Robinson Guzman, [1] Luis Guerrero, [2] Luis Orbe and [1] Guillermo Carpintero

[1] *Department of Electronic Technology, University Carlos III of Madrid, Spain*

[2] *Synopsys Photonic Solutions, Canada*

uc3m | Universidad Carlos III de Madrid

G.O.T.L.

A European Training Network TERAOPTICS

Outline

- Purpose of this work
- TOWER Semiconductor Silicon Photonics Platform
- The proposed sub-THz transmitter module
- Experimental results
- Conclusions and Future Research

Purpose of this work

❑ Current network challenges: higher capacity, speed, larger bandwidth, low losses, cost

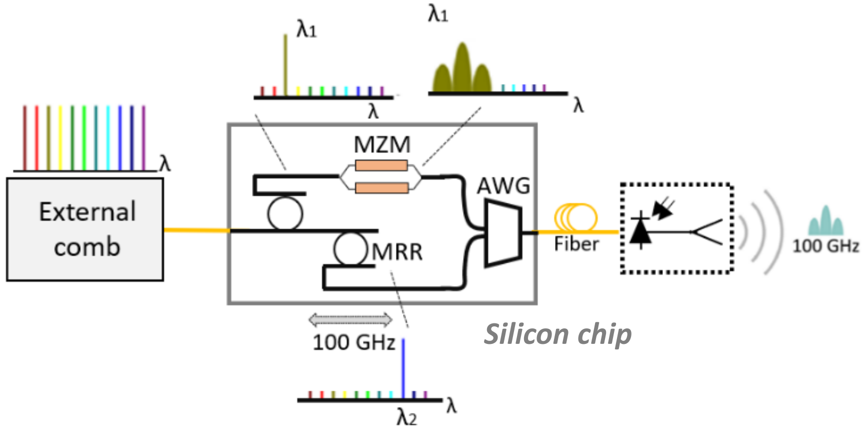
Photonic Integration is the key enabler of the data communications future

Promising solution: integrated together

Photonics	+	**Radio Frequency**

Generation
Detection
Advanced modulation formats
***Broadband** operation*
Low transmission loss
Filtering
Beamforming
Up/down conversion

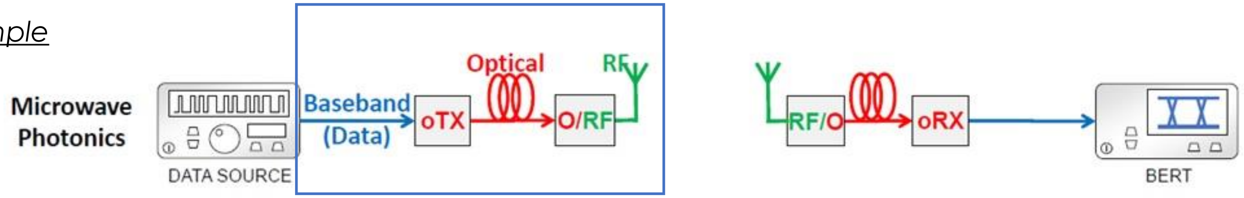
High frequency carrier
Matured technology
Compact antenna arrays
Minimum wireless link loss



high-speed RF Photonics transmitter

- Optical THz generation based on heterodyne scheme
- Wavelength selectors and combiners
- Dual-parallel MZM for QPSK (I/Q) modulation

Example



— Optical domain
— RF domain

TOWER Semiconductor SiPho Platform

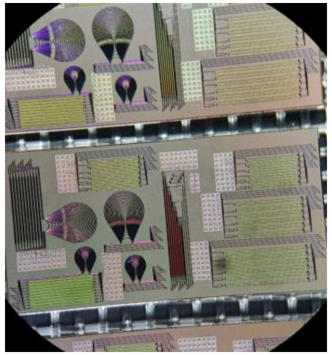
One of the very few open-access silicon foundries!

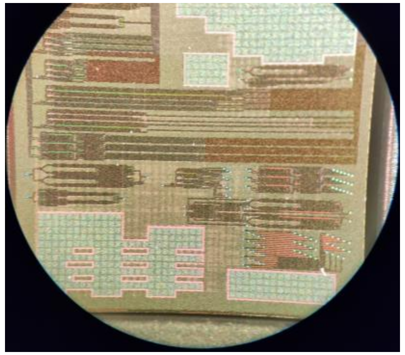

Data center Interconnects


High performance computing


Telecom


Autonomous cars



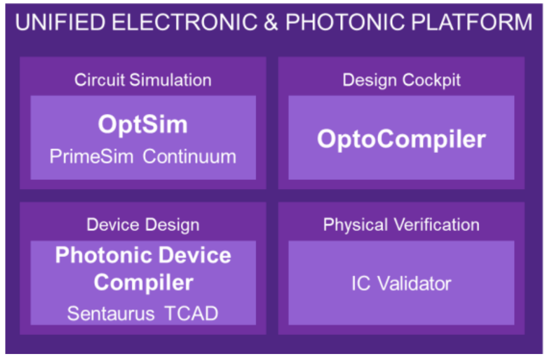


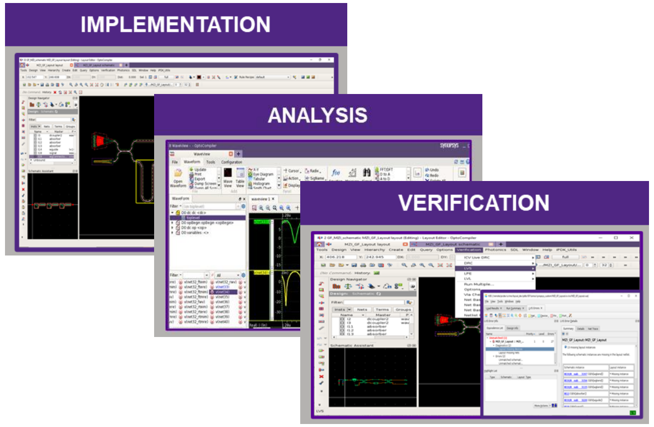
@ towersemi.com

Low loss Si and SiN *waveguides –180 nm SOI process technology–* ***Multi Project Wafer*** *(MPW) runs – CMOS compatible*

Synopsys Photonics Solutions offer:

- Schematic-Driven-Layout using the OptoCompiler platform
- Photonic IC Design Flow for fewer design errors
- PDK-targeted to all Tower Semiconductor SiPho processes





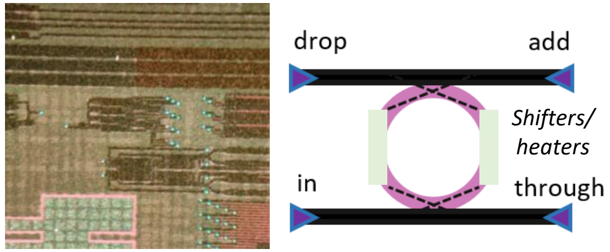
@ synopsys.com

SYNOPSYS®

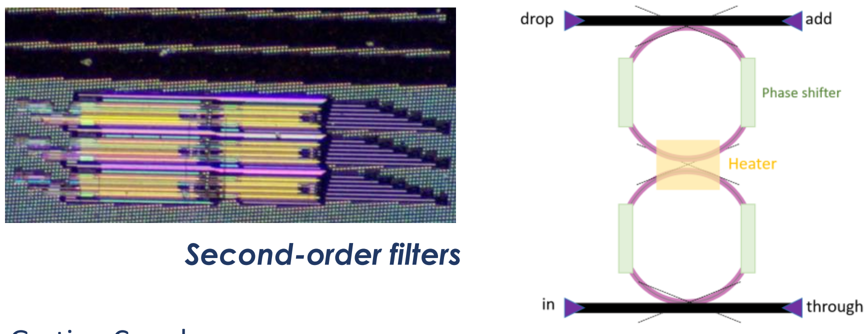
The proposed sub-THz transmitter module

Optical filtering

- Filters based on phase modulation
- FSR of 100 GHz
- Thermo- and electro-optic tuning
- Heater design: silicon strip waveguides (custom design)

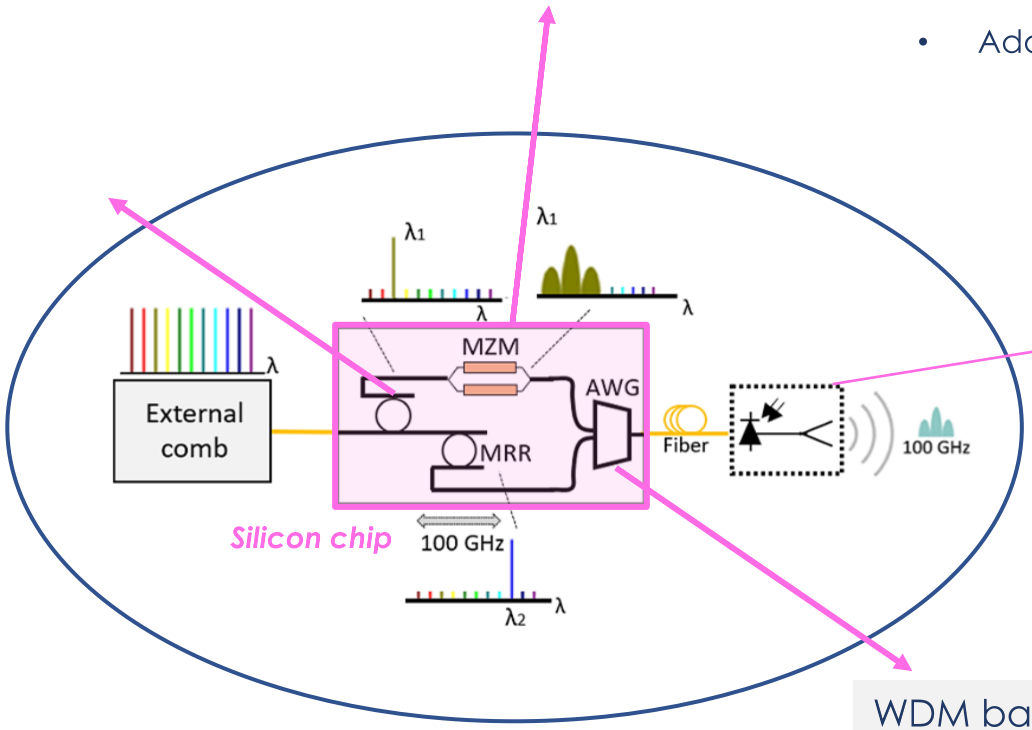


Single-order filters



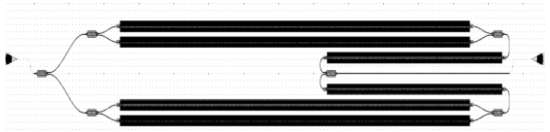
Second-order filters

Grating Coupler



Optical modulation

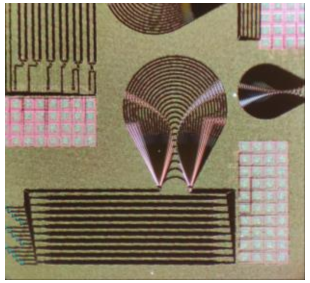
- Mach Zehnder modulators
- Offer QPSK modulation or more complex formats
- Additional shifters to ensure 90° phase shift



Dual-parallel Mach Zehnder modulator

Antenna unit

WDM based switching

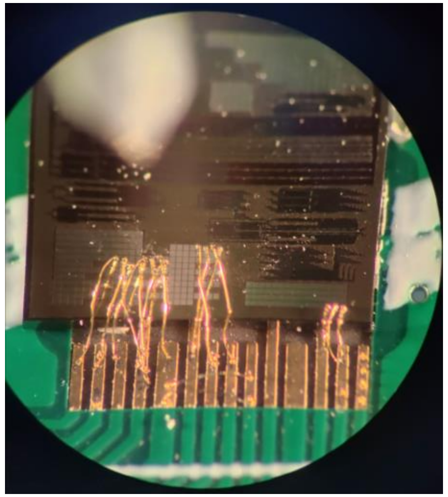


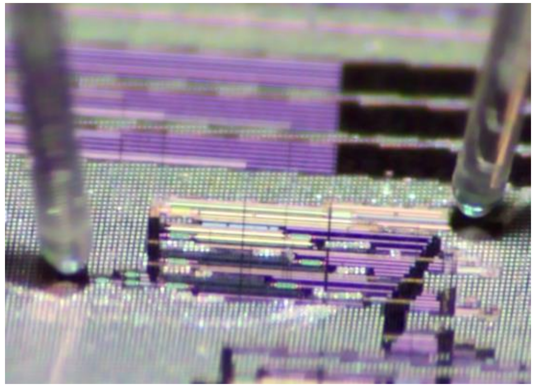
AWG multiplexer/demultiplexer

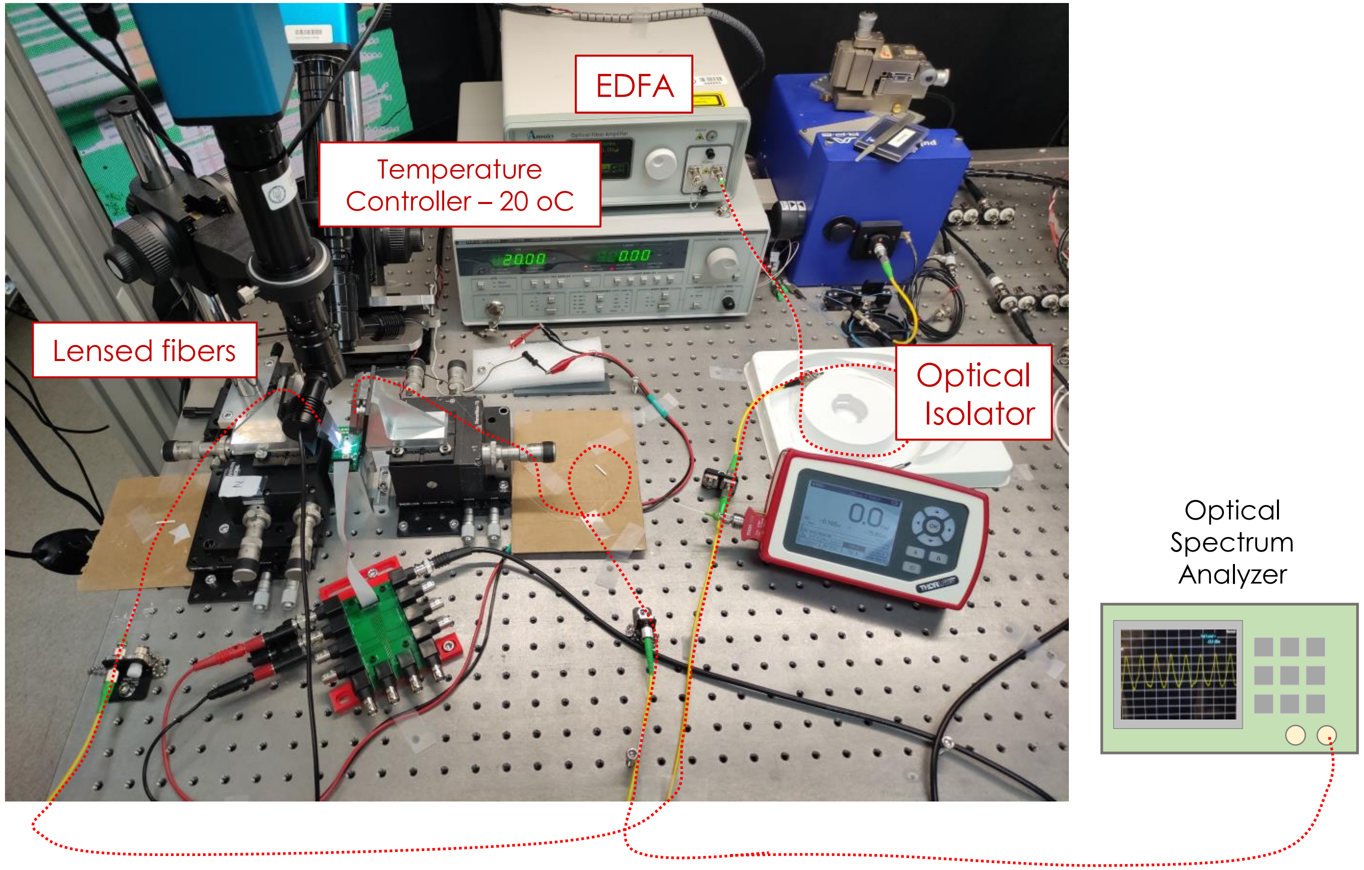
Single order filter – Experimental setup

Power budget

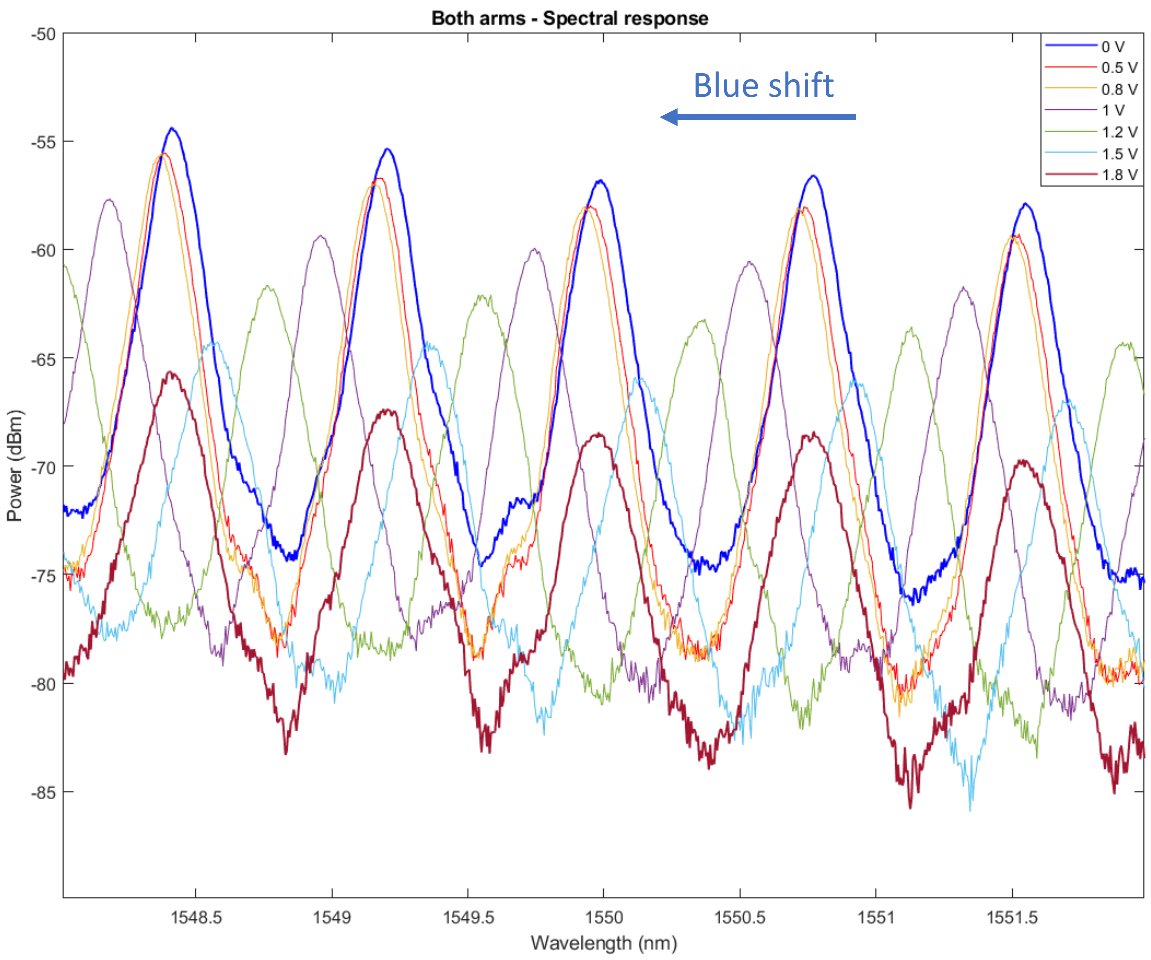
- Filter Length: 713 um
- Loss ~ 15 dBm
- Assuming 6 dB per grating coupler

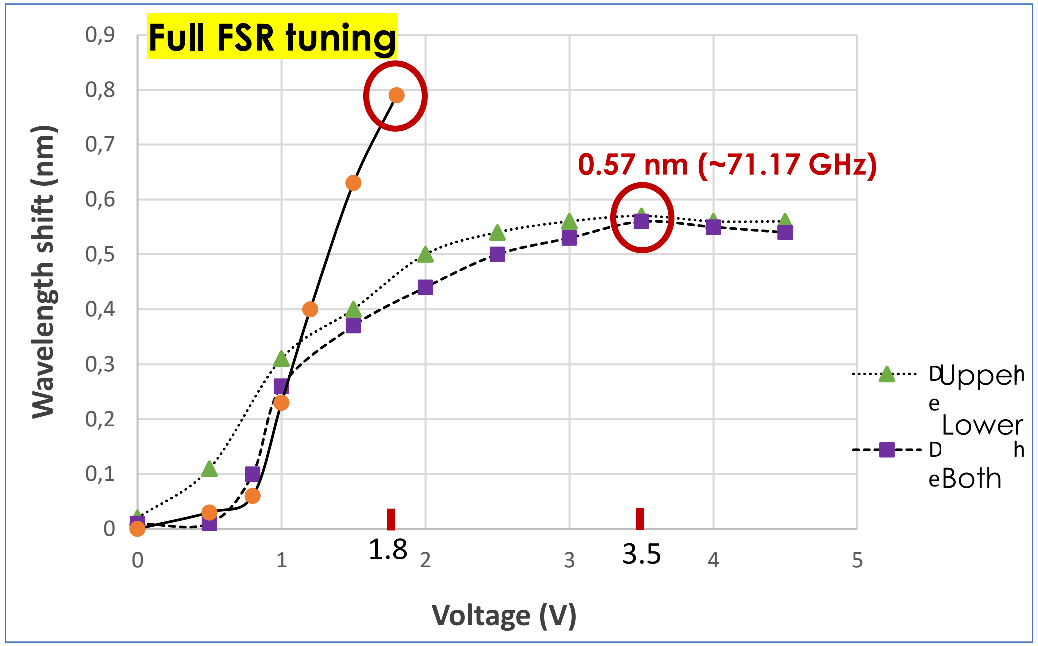






Optical filtering | Plasma dispersion effect

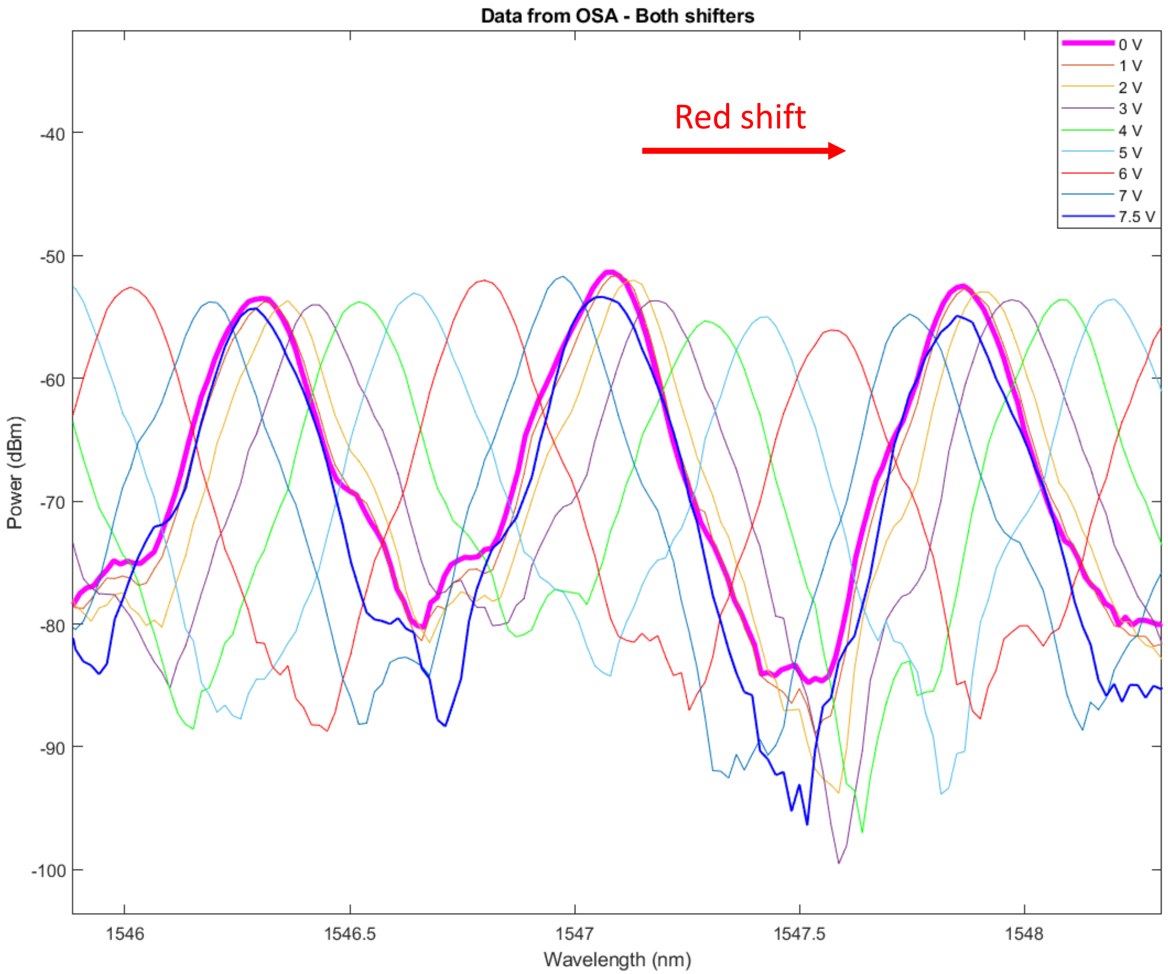


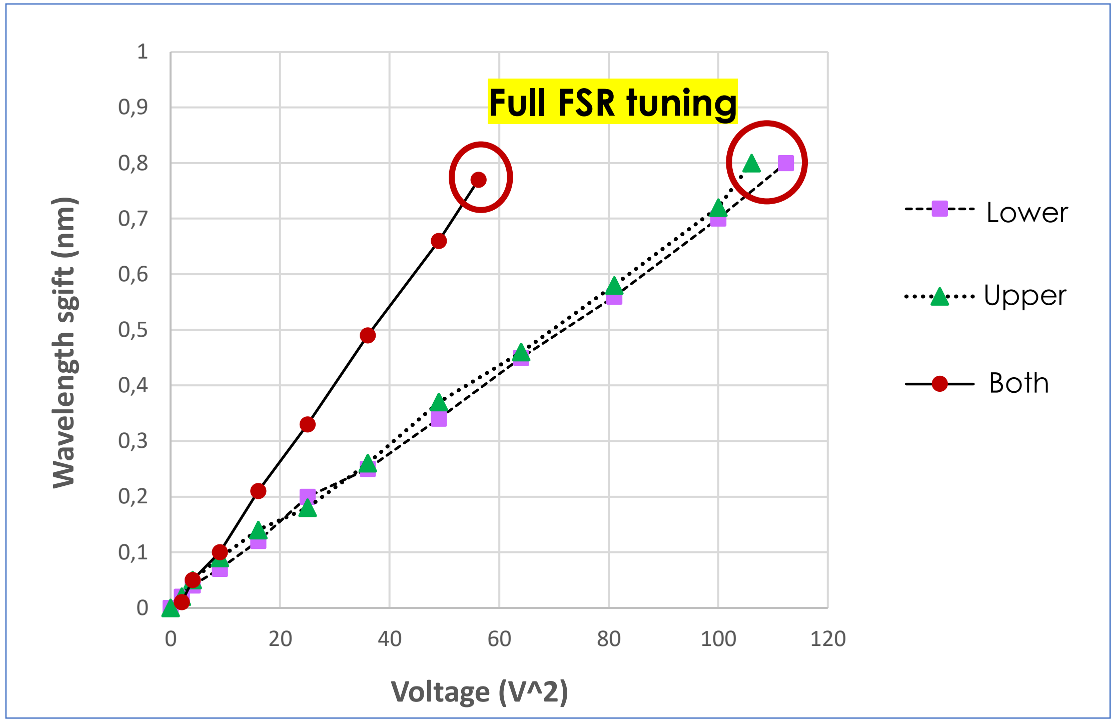


Shifter	Shift in nm (GHz)	Power per FSR tuning (mW)	Loss (dB)
Upper	0.57 (~71.17 GHz)	3.9	-7.3894
Lower	0.56 (~69.92 GHz)	3.9	-16.69
Both	0.79 (~98.64 GHz)	0.9	-9.9311

inevitable optical losses due to free-carrier absorption !!

Optical filtering ▌ Thermo-optic effect



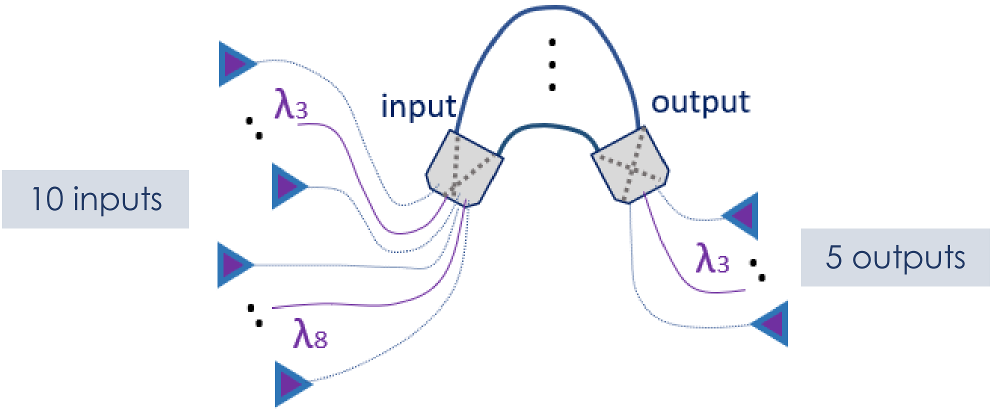


Shifter	Shift in nm (GHz)	Power per FSR tuning (mW)	Loss (dB)	Tuning efficiency (nm/mW)
Upper	0.8 (~99.89GHz)	33.01	-1.145	0.022
Lower	*same*	34.6	-3.465	0.022
Both	0.78 (~96GHz)	35.28	-0.57	0.0439

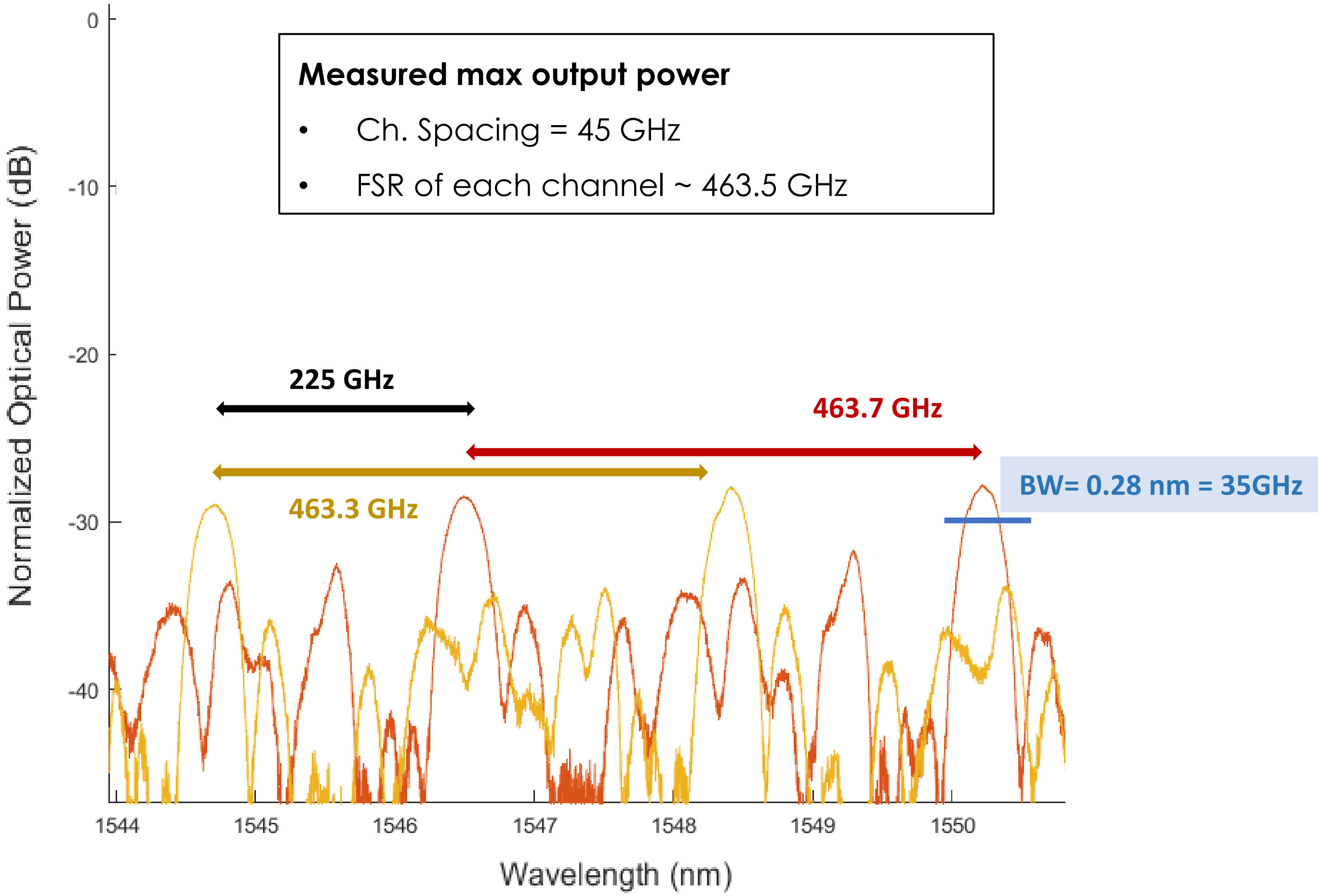
Heater: custom design

- 254 x 1 um
- Resistance: 3154 kΩ

Optical multiplexing results



→ Measuring the centered channels

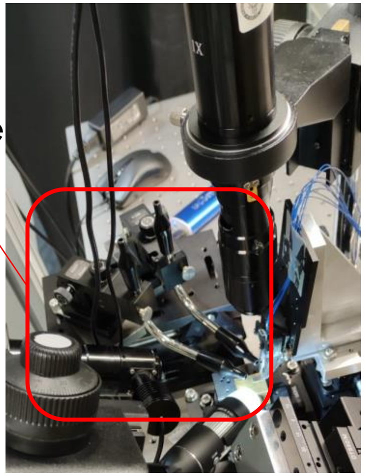


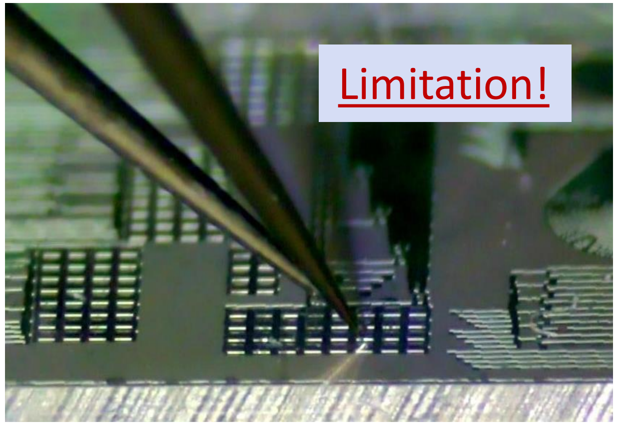
It's under investigation to define precisely the origin of the noise between the resonant responses!

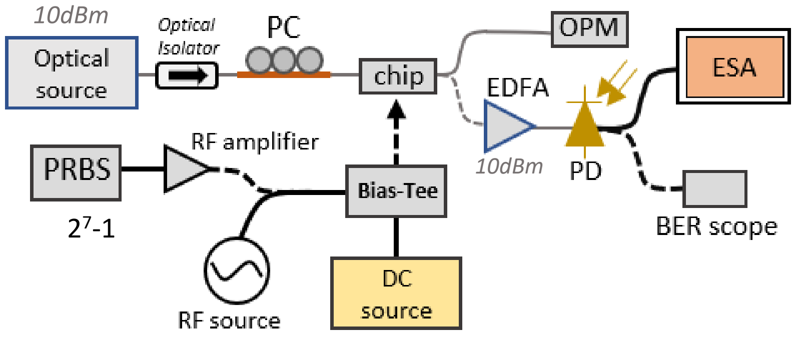
Optical modulation results

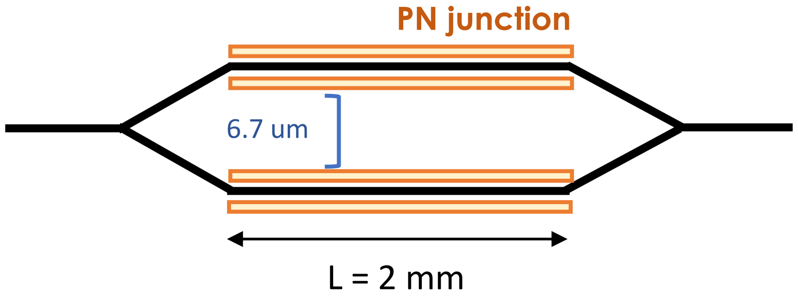
Experimental setup

DC probe Needles



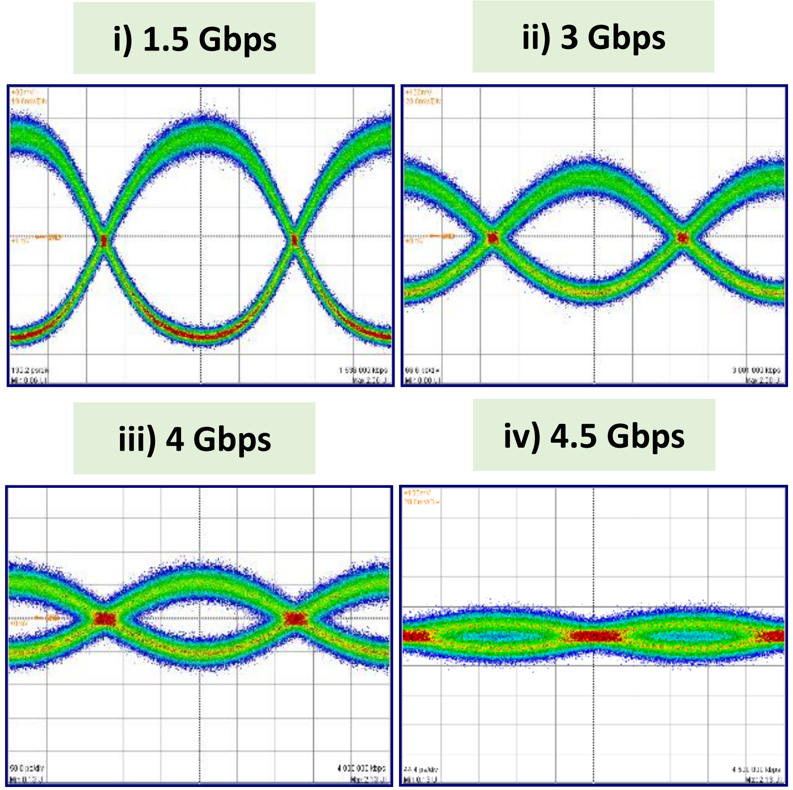






- Optical transmission response
- Intensity modulation with a direct detection in optical domain
- BER scope to record the eye diagram

Despite this limitation, data transmission was successful!



Vπ voltage (Vπ)= -9 V

Modulation efficiency: 1.8 V·cm

Quadrature point at -3.6 V

Conclusions and Future Research

First results from the Tower Semiconductor's platform

- The spectral responses of **ring-filters** and **AWG** exhibit FSR compatible to the simulation results
- Tunable filtering via plasma dispersion effect and TO effect
- AWG filtering with BW of ~0.3 nm (35 GHz)

- Complete the full characterization of the MZM
- Design different MZM electrodes types, such as traveling-wave electrodes that own higher modulation efficiency
- <u>Upcoming measurements</u>: **second-order** ring filters, nested **dual-parallel MZM** for complex modulation formats

→ There is potential of the TOWER's platform for monolithic integration of element to be combined and form a **complete**, **multi-functional.**

→ Design a complete sub-THz transmitter module integrated with a high-speed photodiode.

Hybrid integration ?

Acknowledgements

Authors acknowledges TOWER Semiconductor for the fabrication of the chips and Synopsys Photonic Solutions support through the University Program. We acknowledge financial support by the TERAOPTICS project and TERAWAY project funded from the European Union's research and innovation programs under grant agreements No. 956857 and No 871668, respectively, the CONEX-Plus project funded by UC3M and the European Union under grant agreement No. 801538 and the European Space Agency (ESA) under Contract No. 4000135351/21/NL/GLC/my.

Thank you for your attention.

Any questions?

For further discussion!

Email: kspanido@ing.uc3m.es

TERAOPTICS - A European Training Network

Consortium

15 PhD students
4 universities
2 research institutes
3 SMEs
2 industry

- Applications: Communications, Space, Security, Radio-Astronomy, and Material Science
- THz technology challenges: fundamental aspects and limits, THz generation and detention, photonic integration

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No. 956857.