Apropos 18
Advanced Properties and Processes in Optoelectronic Materials and Systems
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CENTER FOR PHYSICAL SCIENCES AND TECHNOLOGY

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

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# Outline

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

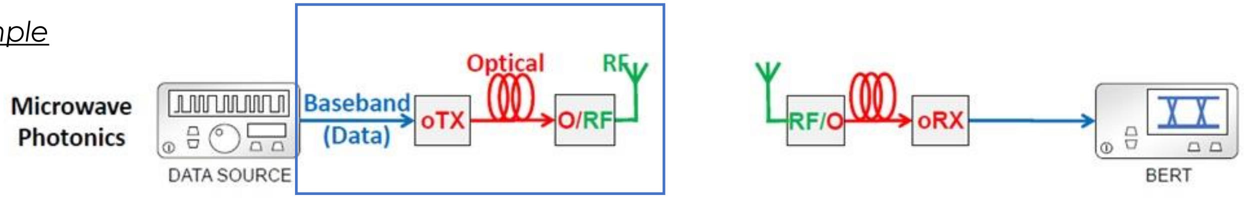
# Purpose of this work

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

***Promising solution: integrated together***

| **Photonics** | + | **Radio Frequency** |
|---|---|---|
| *Generation*<br>*Detection*<br>*Advanced modulation formats*<br>***Broadband** operation*<br>***Low transmission loss***<br>*Filtering*<br>*Beamforming*<br>*Up/down conversion* | | *High frequency carrier*<br>*Matured technology*<br>*Compact antenna arrays*<br>*Minimum wireless link loss* |

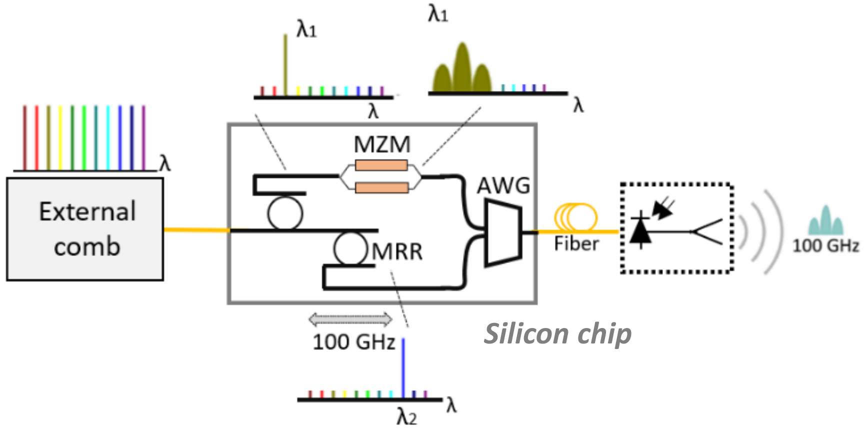
*Example*




Optical domain

RF domain

**Photonic Integration** is the key enabler of the data communications future




high-speed RF Photonics transmitter

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

# TOWER Semiconductor SiPho Platform

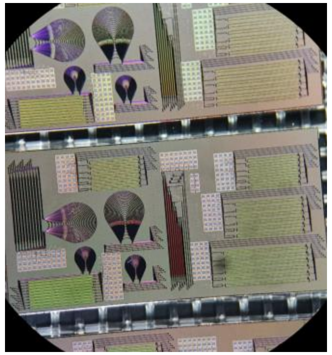
*One of the very few open-access silicon foundries!*

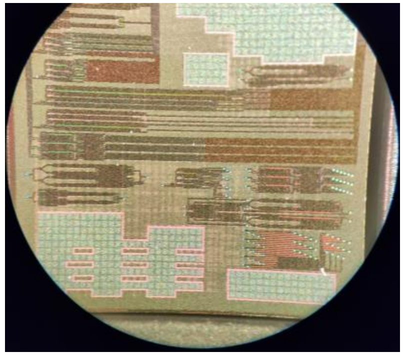
Data center Interconnects

High performance computing

Telecom

Autonomous cars



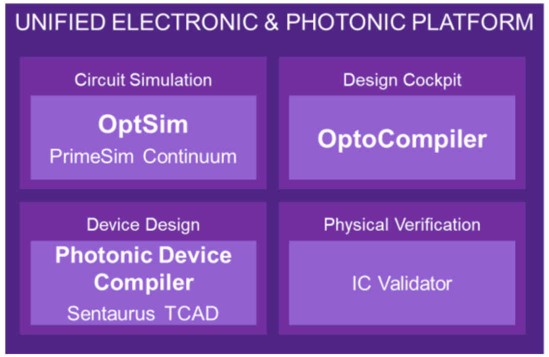


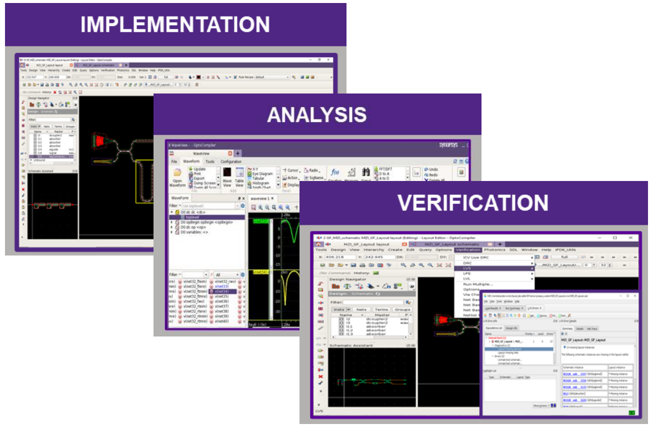
*@ towersemi.com*

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

<u>**Synopsys Photonics Solutions** offer:</u>

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



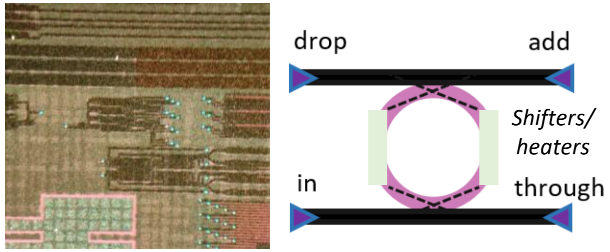




*@ synopsys.com*

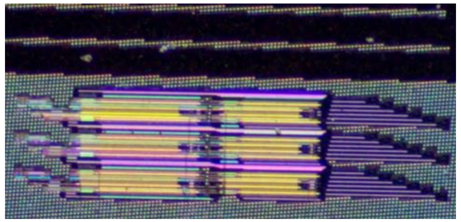
# The proposed sub-THz transmitter module

## Optical filtering

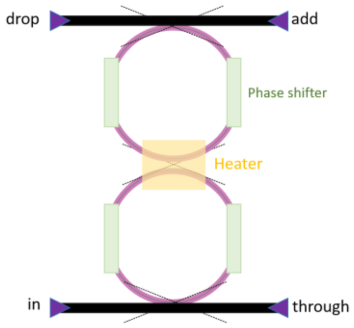
- Filters based on phase modulation
- FSR of 100 GHz
- Thermo- and electro-optic tuning
- Heater design: silicon strip waveguides (custom design)

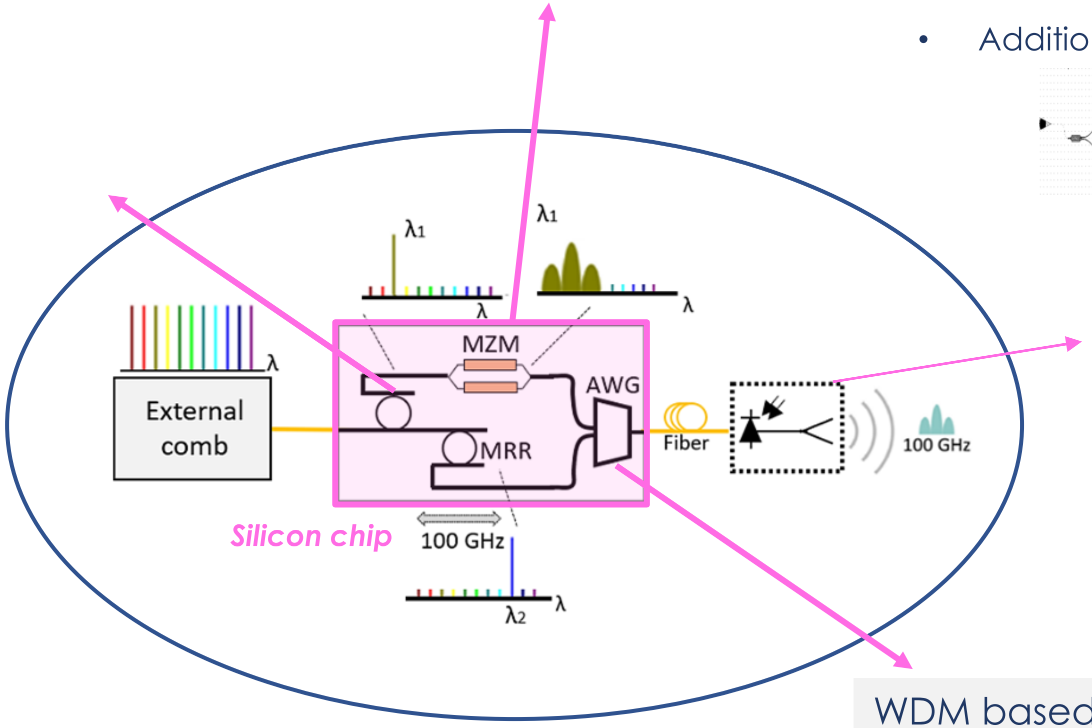



***Single-order filters***



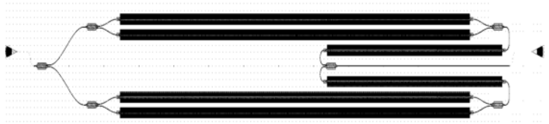
***Second-order filters***




## Optical modulation

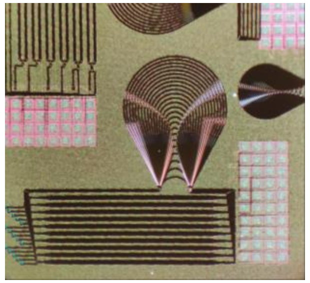
- Mach Zehnder modulators
- Offer QPSK modulation or more complex formats
- Additional shifters to ensure 90° phase shift



***Dual-parallel Mach Zehnder modulator***

## Antenna unit

## WDM based switching



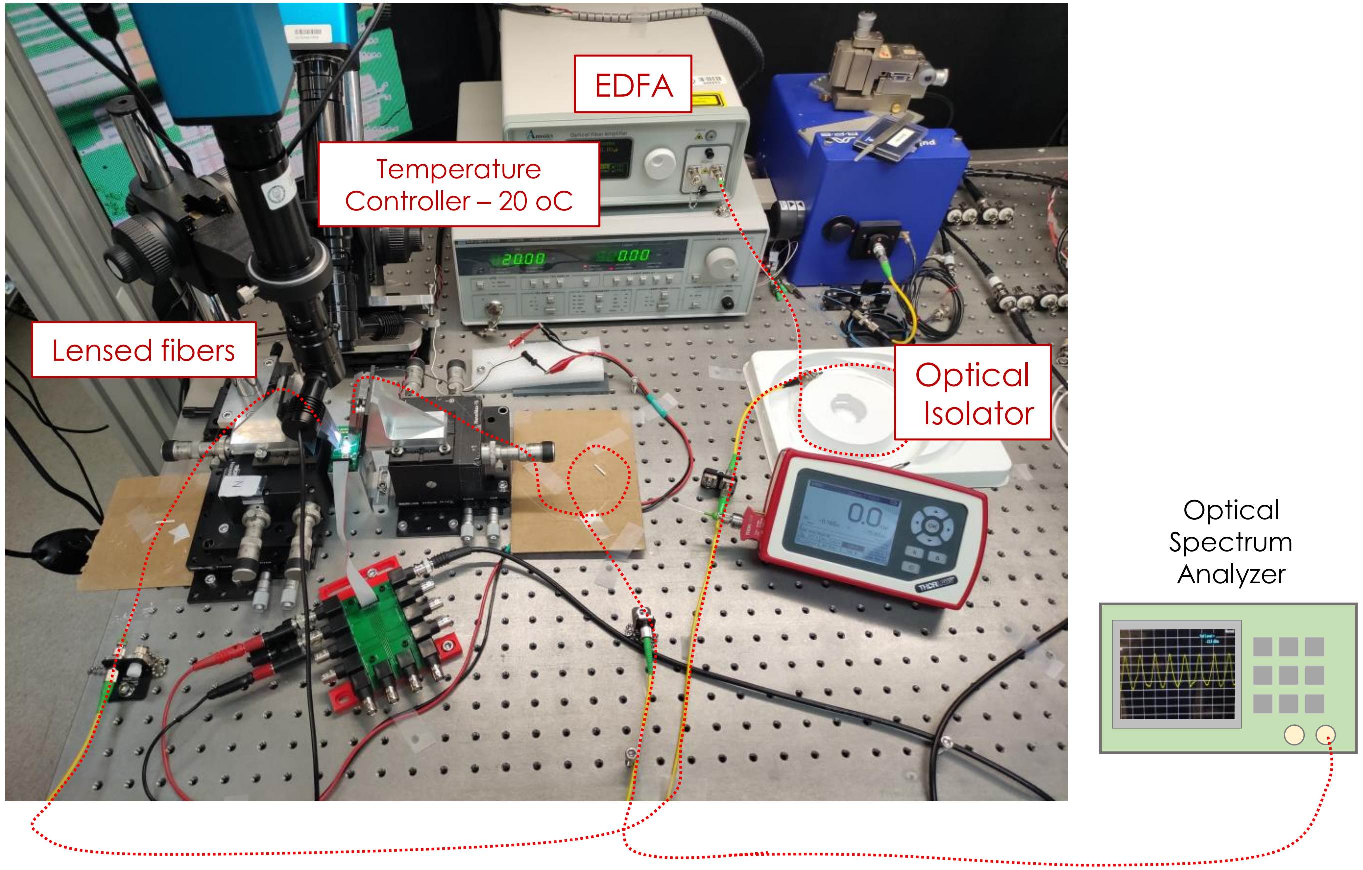
***AWG multiplexer/demultiplexer***

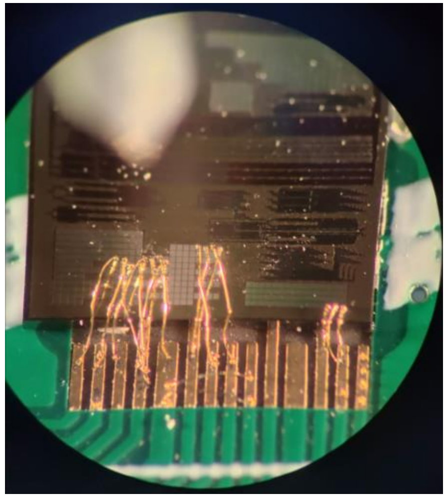
▶ Grating Coupler

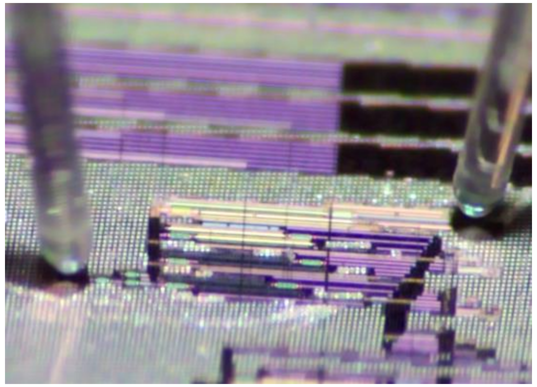
# Single order filter – Experimental setup

## Power budget

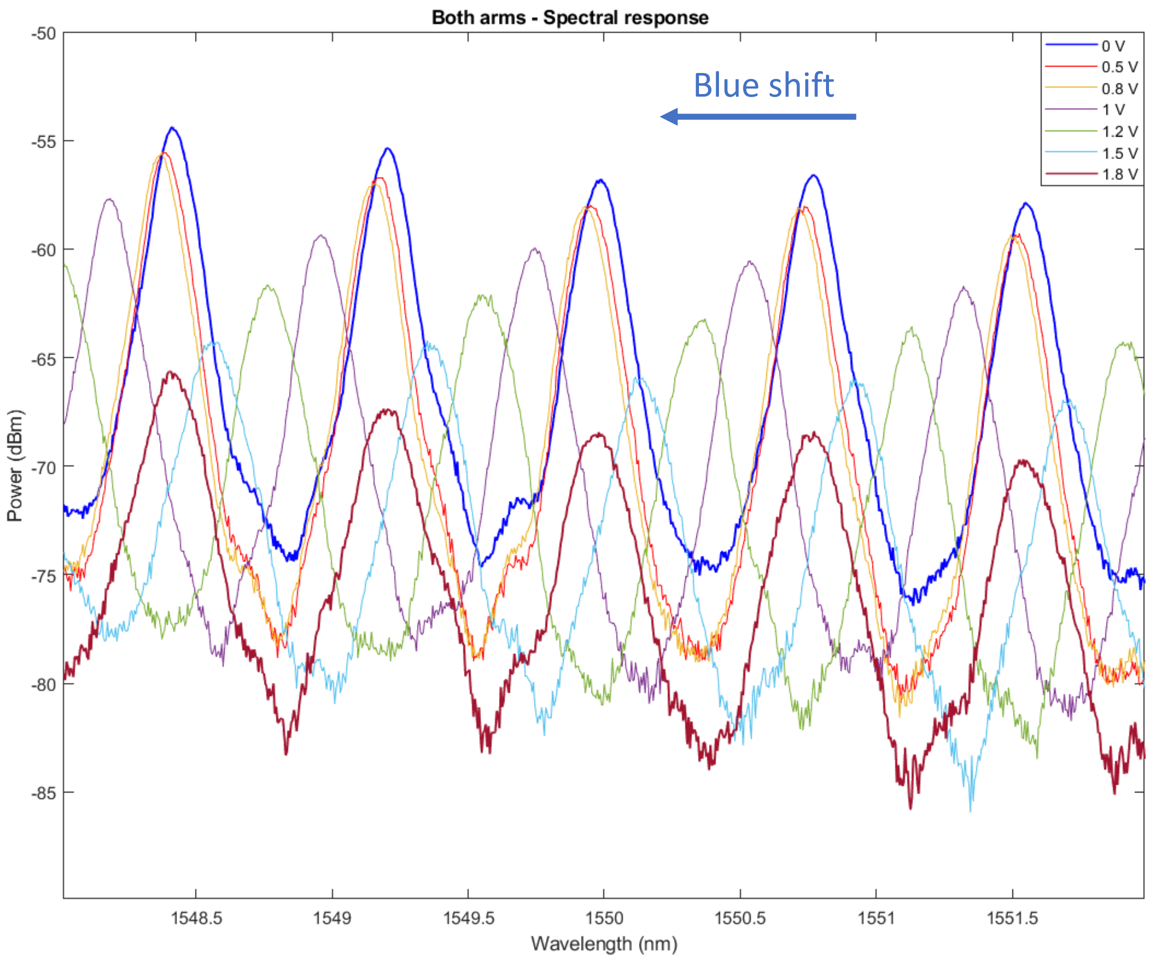
- Filter Length: 713 um
- Loss ~ 15 dBm
- Assuming 6 dB per grating coupler

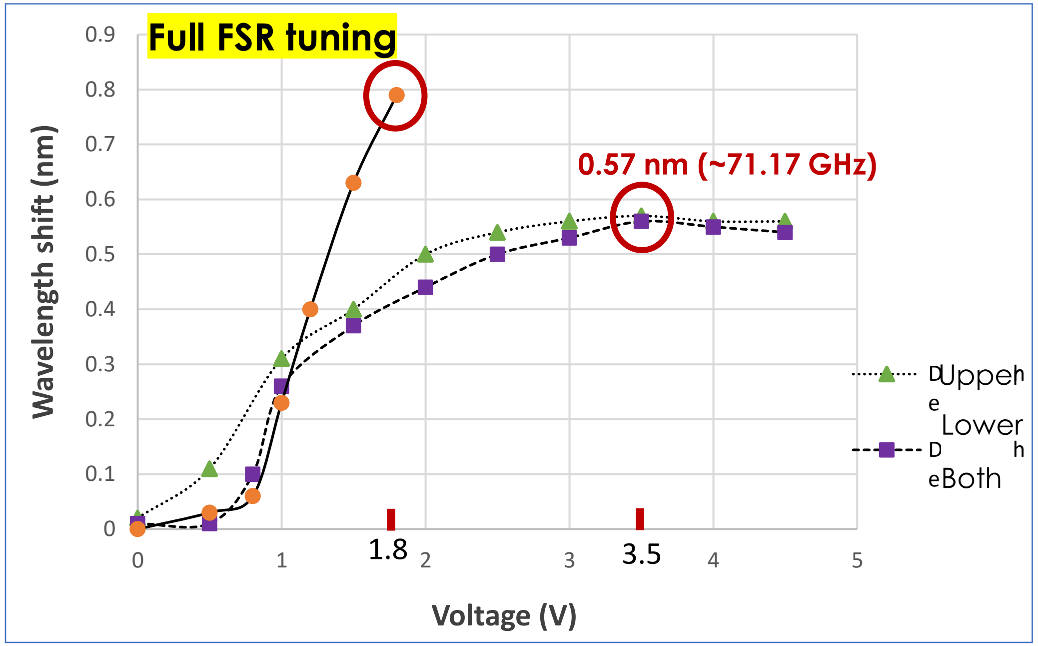




# Optical filtering ▌ Plasma dispersion effect

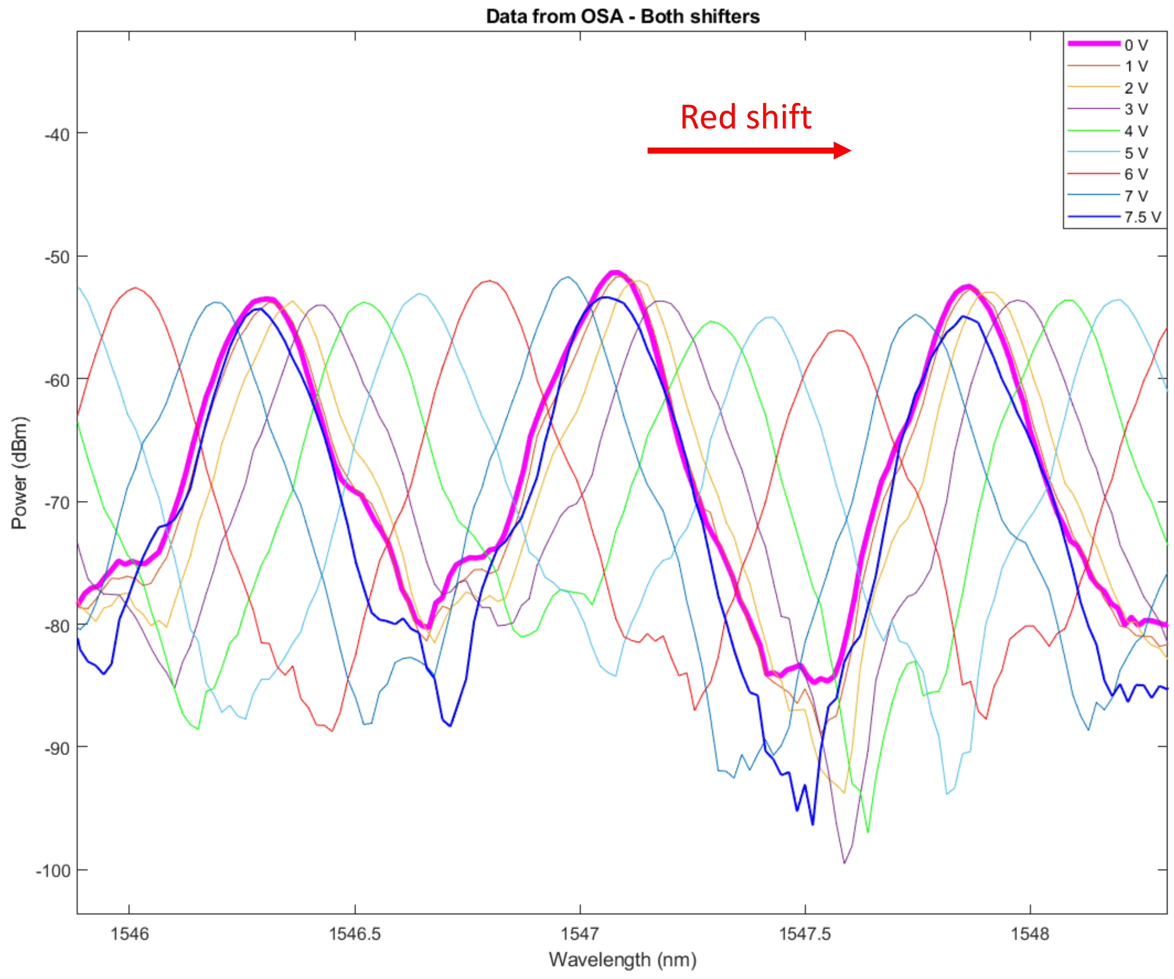


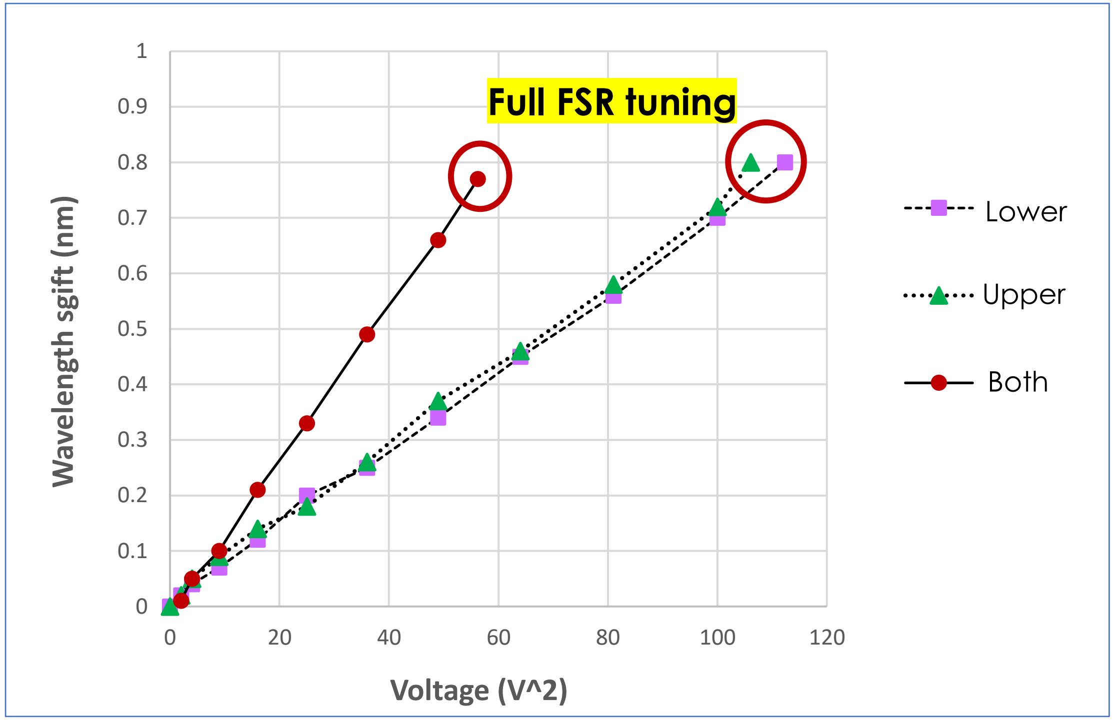




| Shifter | Shift in nm (GHz) | Power per FSR tuning (mW) | Loss (dB) |
|---|---|---|---|
| Upper | 0.57 ( ~71.17 GHz) | 3.9 | -7.3894 |
| Lower | 0.56 ( ~69.92 GHz) | 3.9 | -16.69 |
| Both | 0.79 ( ~98.64 GHz) | 0.9 | -9.9311 |

inevitable optical losses due to free-carrier absorption !!

# Optical filtering | Thermo-optic effect



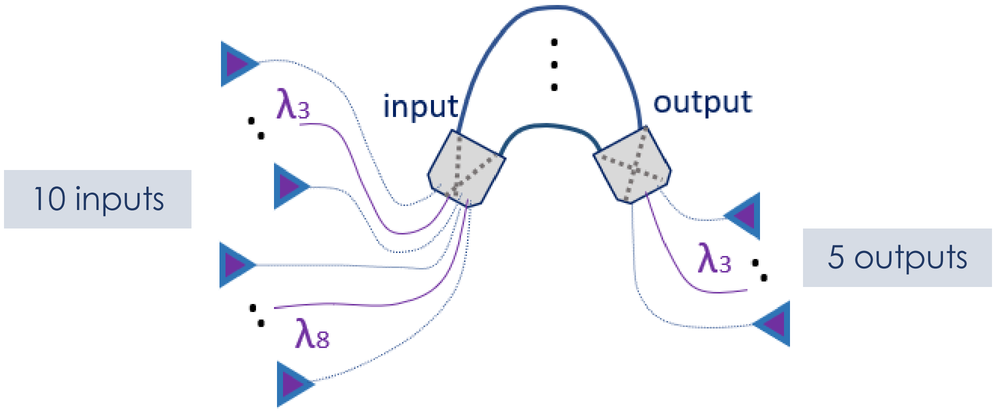




| Shifter | Shift in nm (GHz) | Power per FSR tuning (mW) | Loss (dB) | Tuning efficiency (nm/mW) |
|---|---|---|---|---|
| **Upper** | 0.8 (~99.89GHz) | 33.01 | -1.145 | 0.022 |
| **Lower** | *same* | 34.6 | -3.465 | 0.022 |
| **Both** | 0.78 (~96GHz) | 35.28 | -0.57 | 0.0439 |

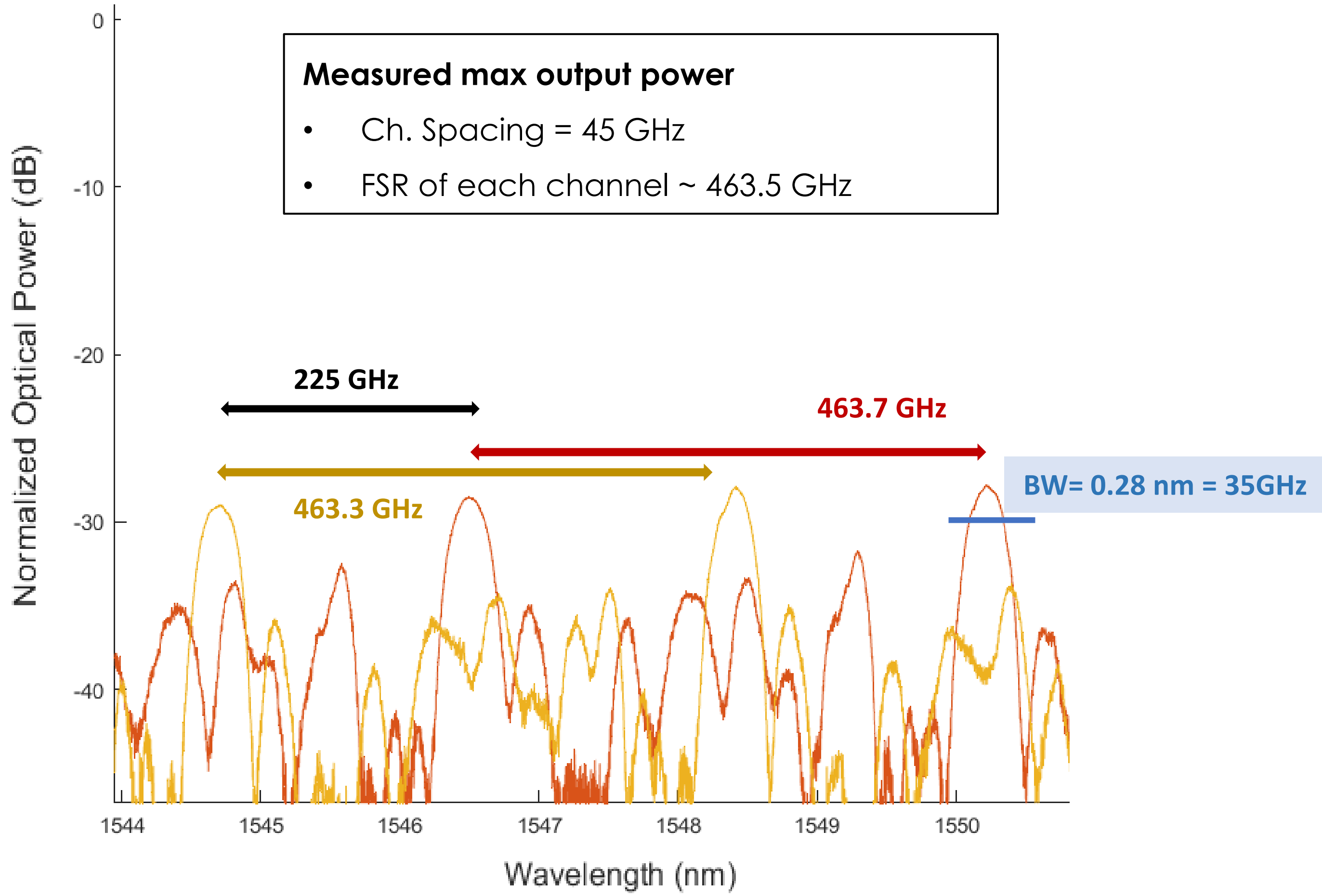
Heater: custom design

- 254 x 1 um
- Resistance: 3154 kΩ

# Optical multiplexing results




→ Measuring the centered channels

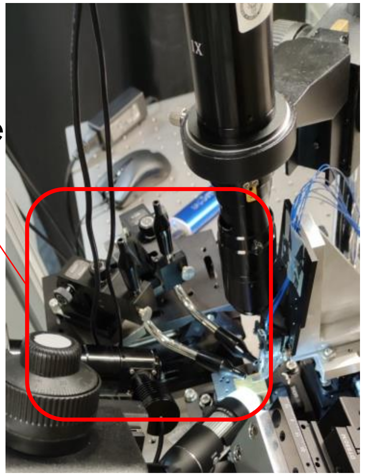


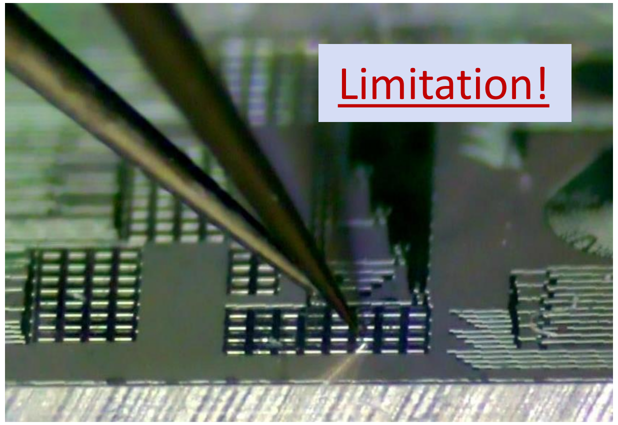

It's under investigation to define precisely the origin of the noise between the resonant responses!

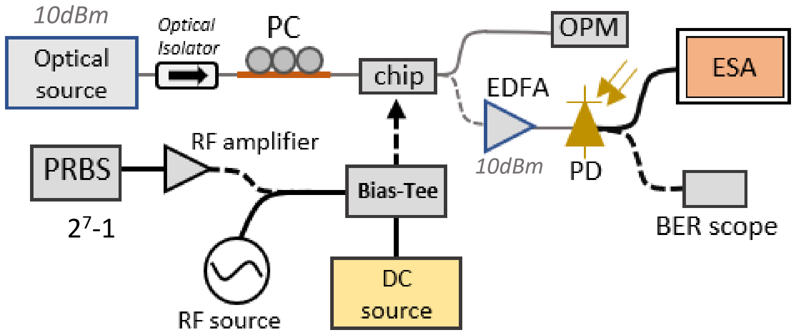
# Optical modulation results

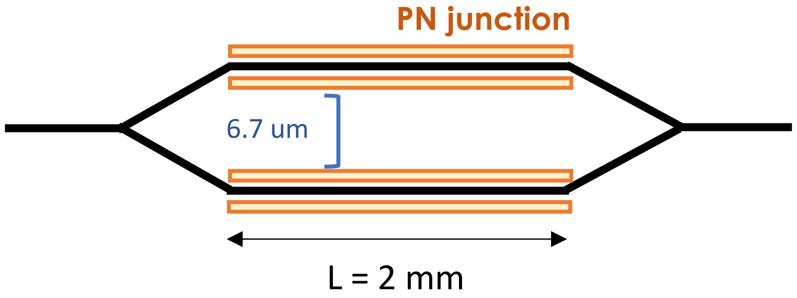
Experimental setup

DC probe Needles



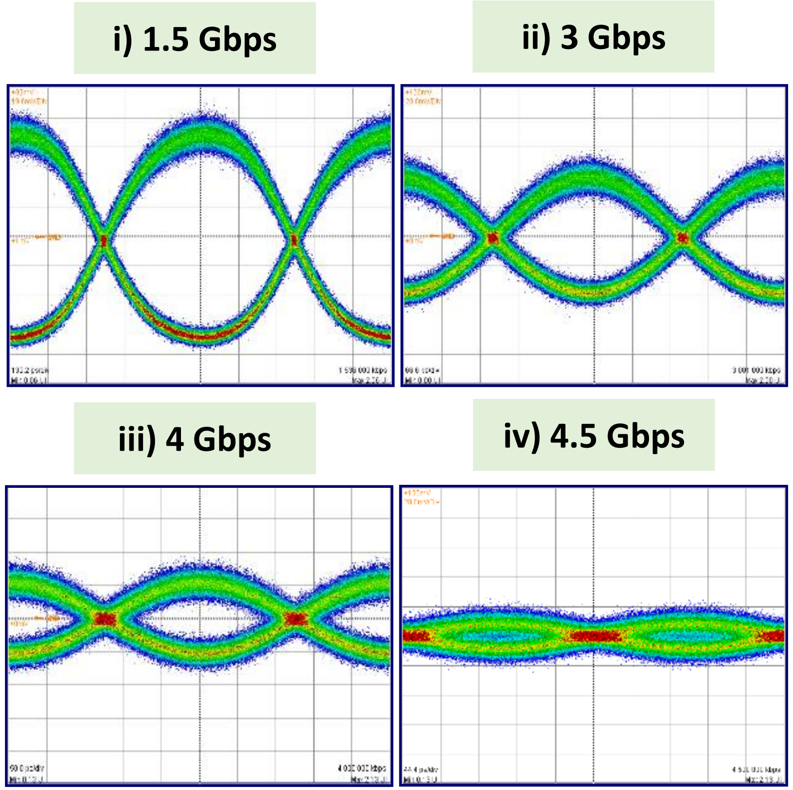



- Optical transmission response
- Intensity modulation with a direct detection in optical domain
- BER scope to record the eye diagram

**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)

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- 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

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# Thank you for your attention.

*Any questions?*

For further discussion!

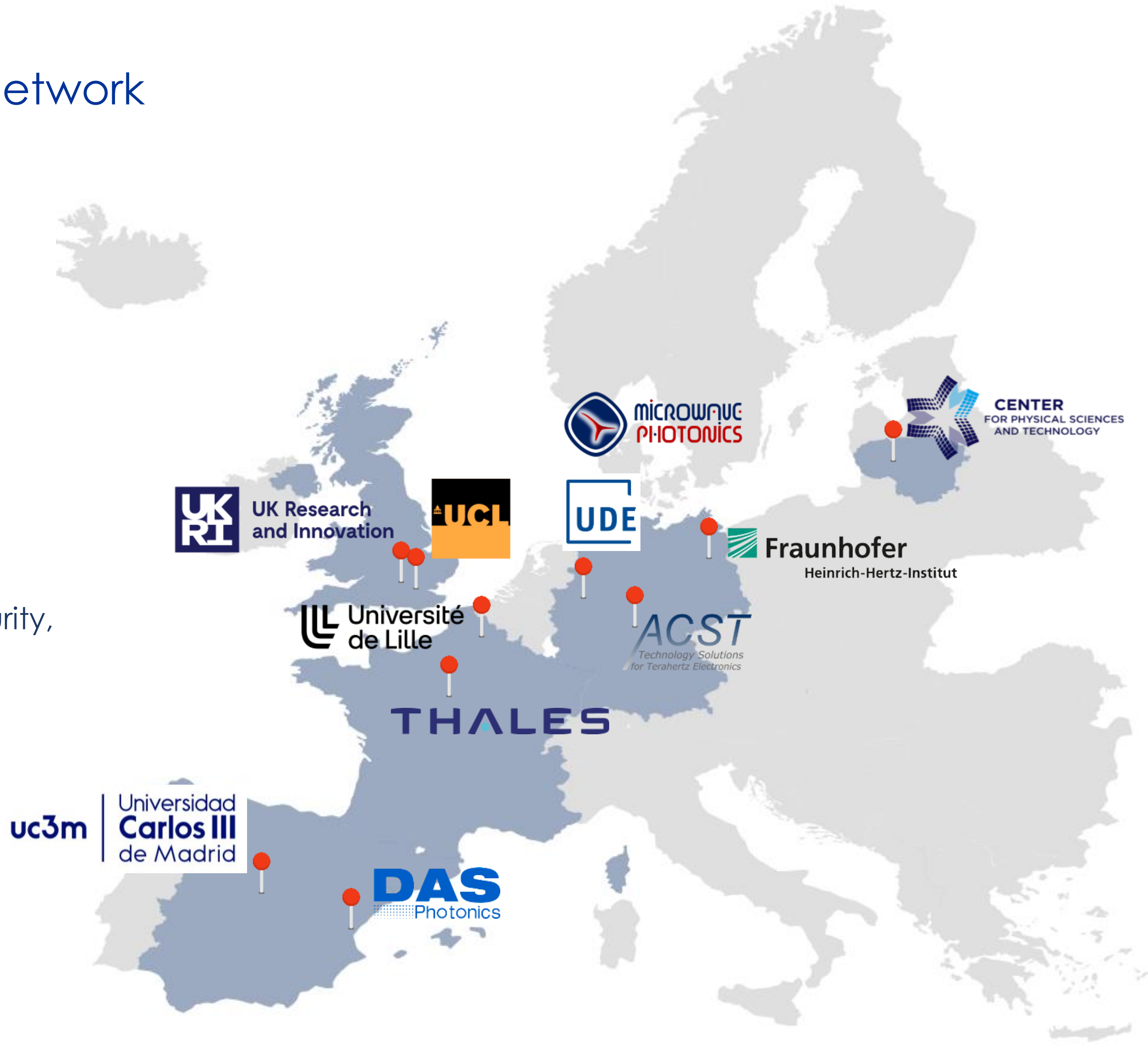
Email: kspanido@ing.uc3m.es

# 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

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