Photonics-Assisted Integrated Devices Enabling Ultra-Wideband Terahertz Systems

2024 DUISBURG GeMiC German Microwave Conference

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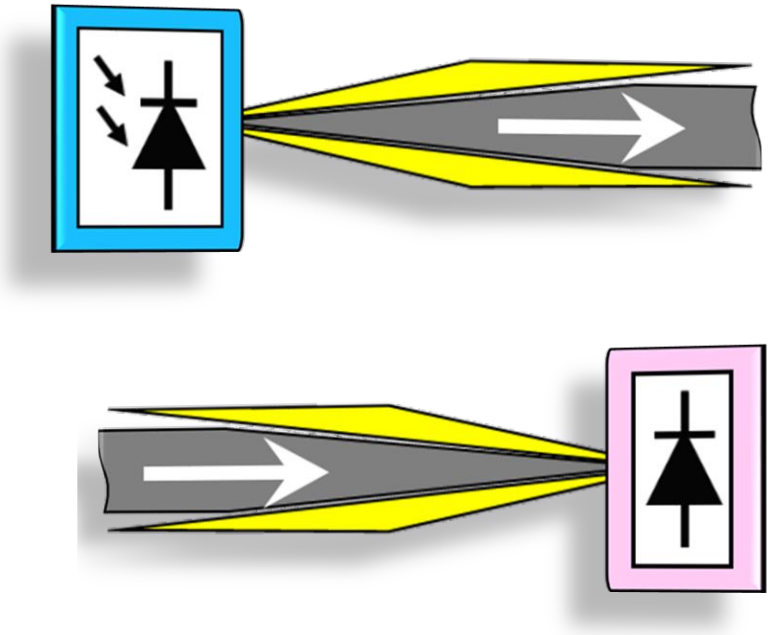
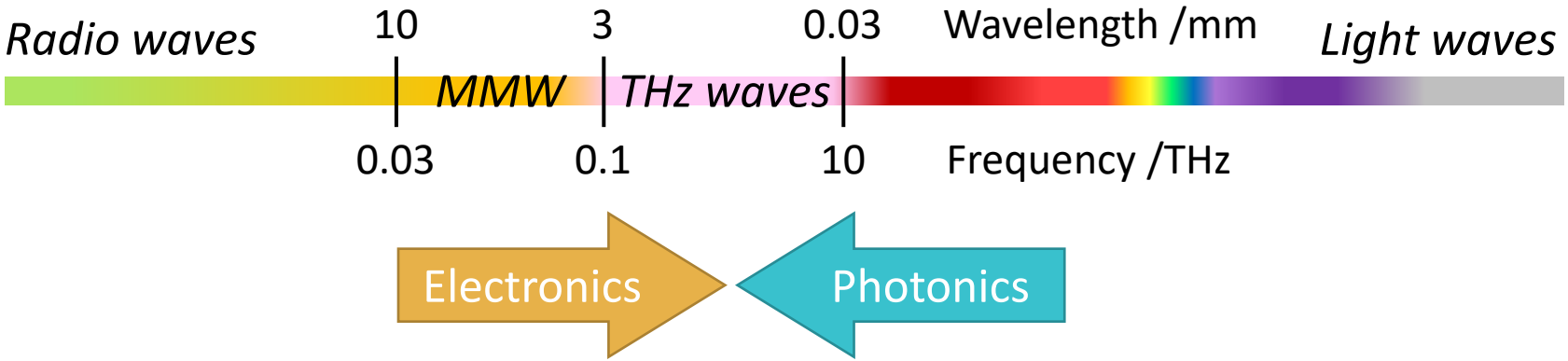
IMA e.V. MTT-S IEEE Microwave Theory & Technology Society EuMA European Microwave Association IEEE

Outline

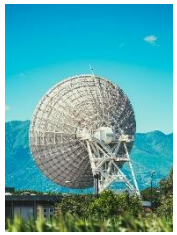
- Background
- THz silicon microphotonics
- Ultra-wideband interconnect between InP UTC-PDs and Si rod waveguides
- Summary and future perspective



Millimeter and Terahertz Waves



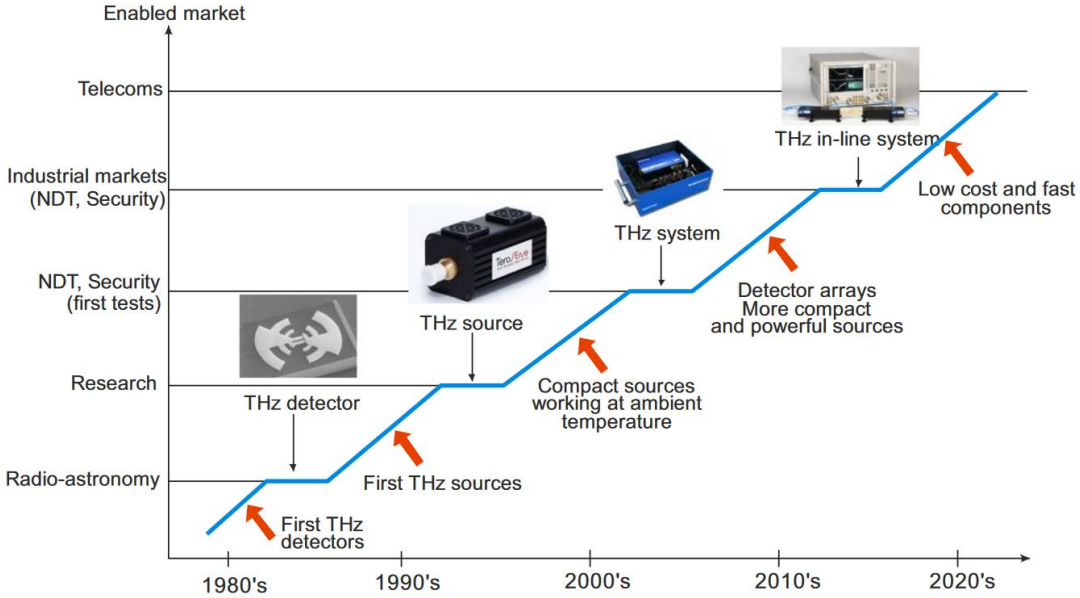




Current Mission: THz System Miniaturization

Significant advancement in THz device integration is now required

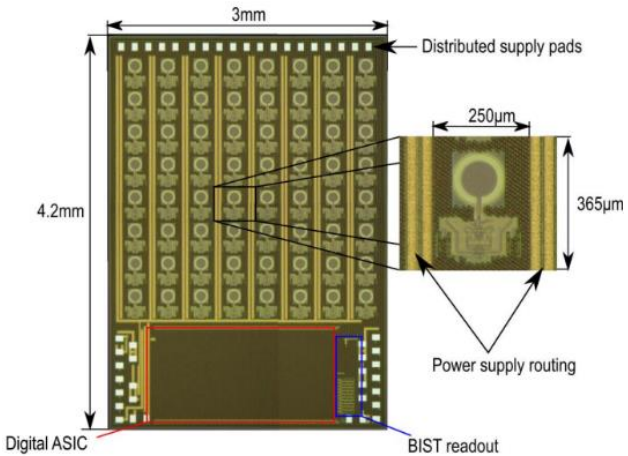


A. Rogalski, J. infrared, millimeter, and THz waves, 2022.

Electronic THz Sources

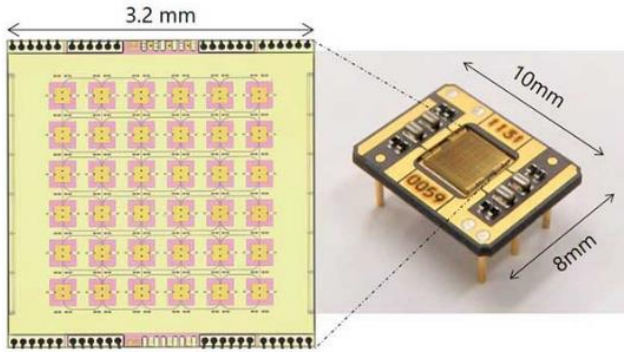
They offer high output power, but are **limited in operational bandwidth**

SiGe BiCMOS /
~10 dBm @0.45 THz



R. Jain, et al., ISSCC, 2020.

InP RTD /
>10 dBm @0.45 THz

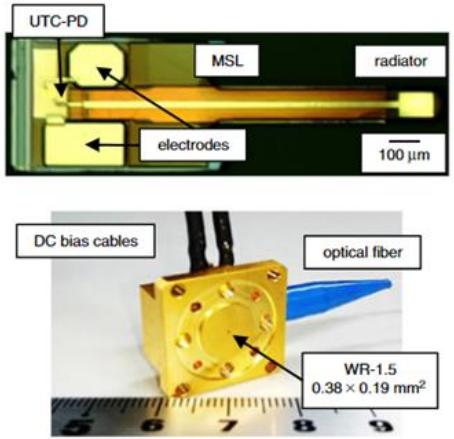


Y. Koyama, et al., IEEE Trans. THz Sci. Technol., 2022.

Photonic THz Sources

Output power needs to be increased, but **ultra-wideband operation** is possible

InP UTC-PD /
−20 dBm@0.5 THz

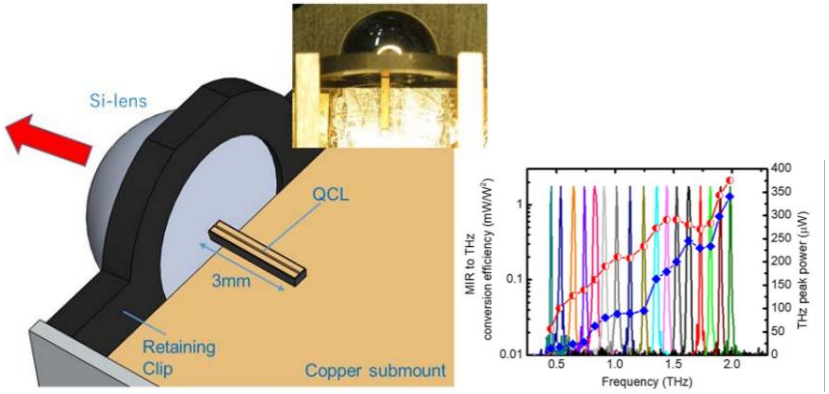


T. Kurokawa, et al., Electron. Lett., 2018.

InP MUTC-PD /
−0.6 dBm@0.24 THz

M. Grzeslo, et al., Opt. Express, 2023.

InP QCL /
−17 dBm@1.5 THz , < −20 dBm@<1 THz



K. Fujita, et al., Photon. Res., 2022.

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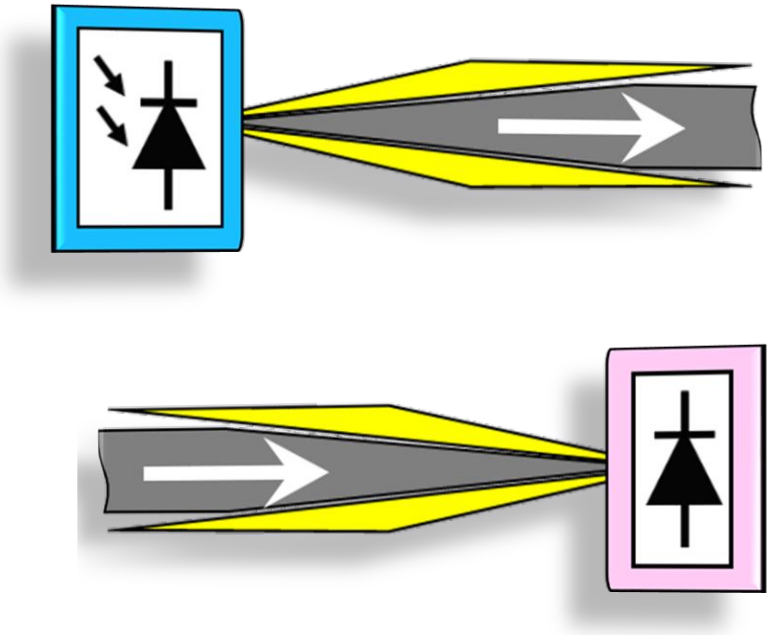
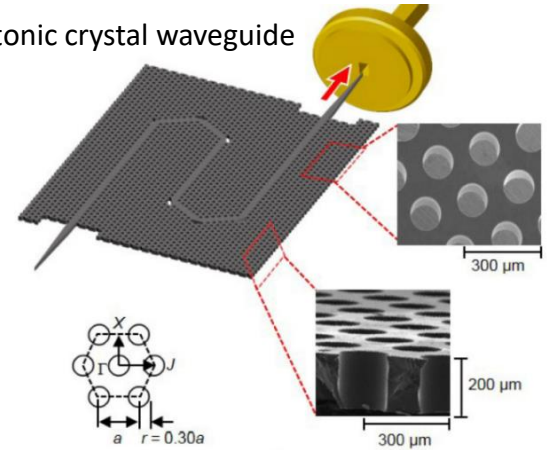


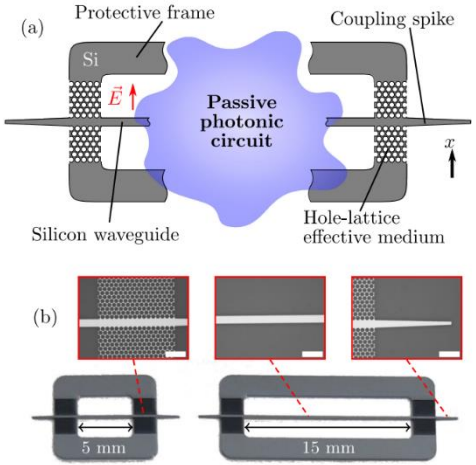
Substrateless All-Silicon microsturctures

- **Planar passive devices made of high-resistive (>10 kΩ) silicon**
- **(1) Low loss** (~0.1 dB/cm)**, (2) Low cost, (3) Broadband**

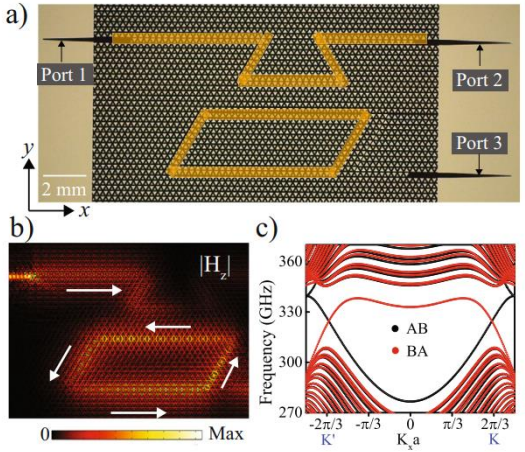
Photonic crystal waveguide



K. Tsuruda, et al., Opt. Express, 2015.



D. Headland, et al., J. Lightw. Technol., 2020.

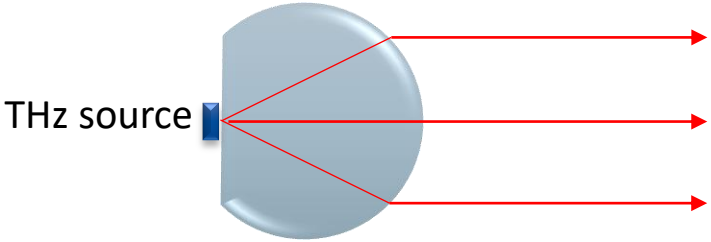


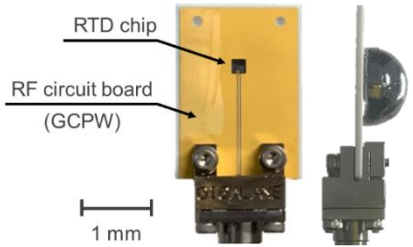
A. Kumar, et al., Nat. Comm., 2022.

Planar Photonic Circuit Integration

Quasi-optics

Si spherical lens

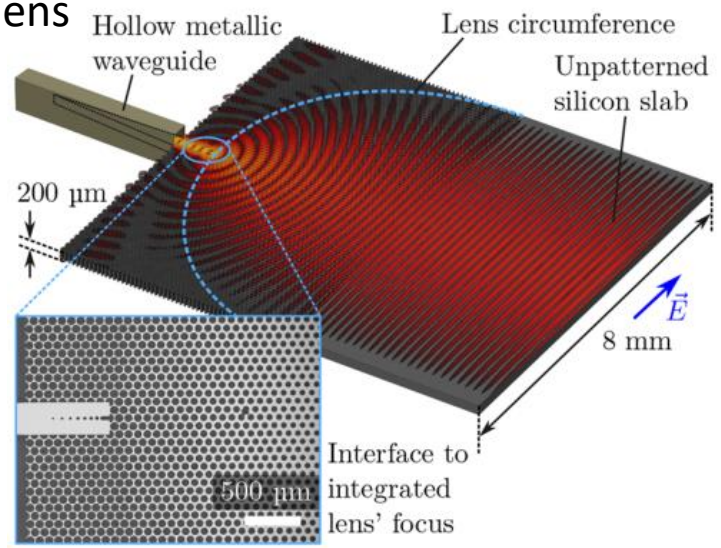




S. Iwamatsu, et al., Electron. Lett, 2021.

THz Photonic Integrated Circuit

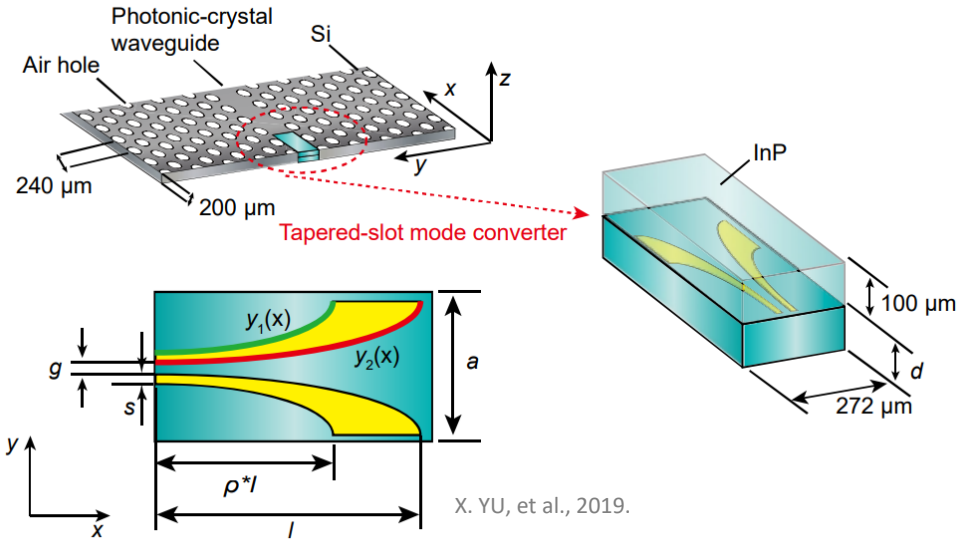
GRIN lens



D. Headland, et al., APL Photonics, 2021.

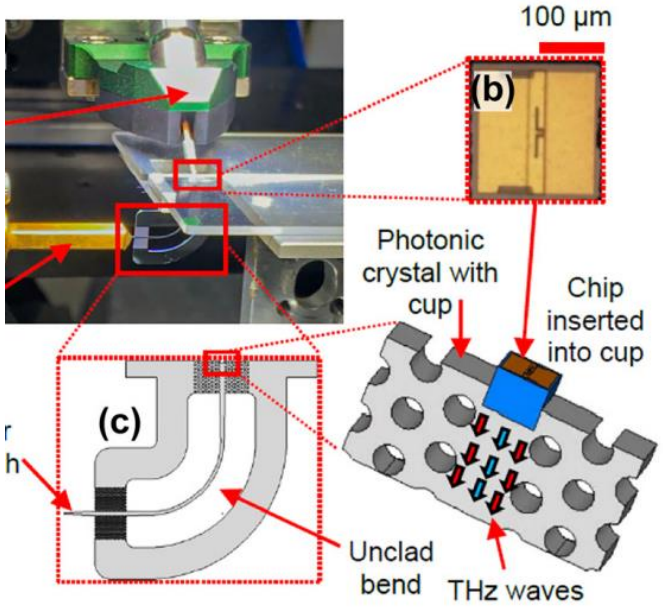
Hybrid Integration with THz Electronic Devices

End-fire coupling



X. YU, et al., 2019.

Back-side coupling



A. Koala, et al., 2021.

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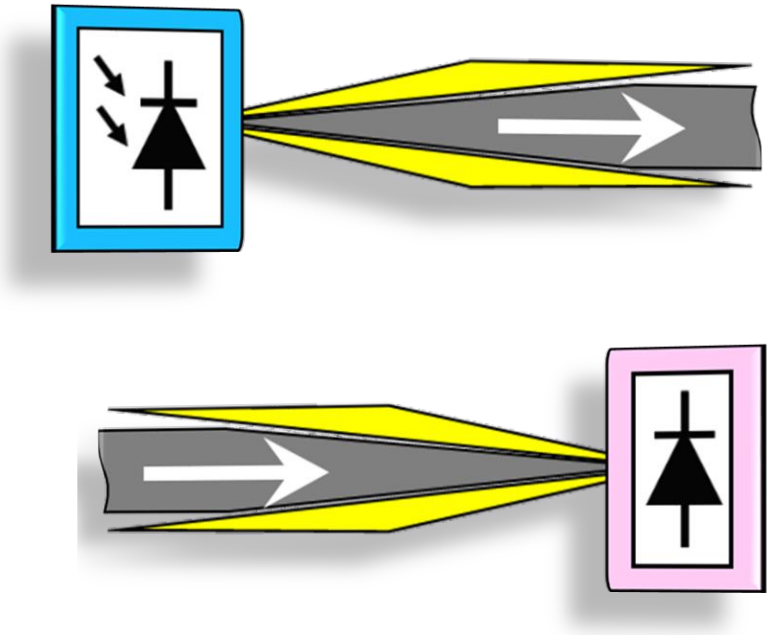
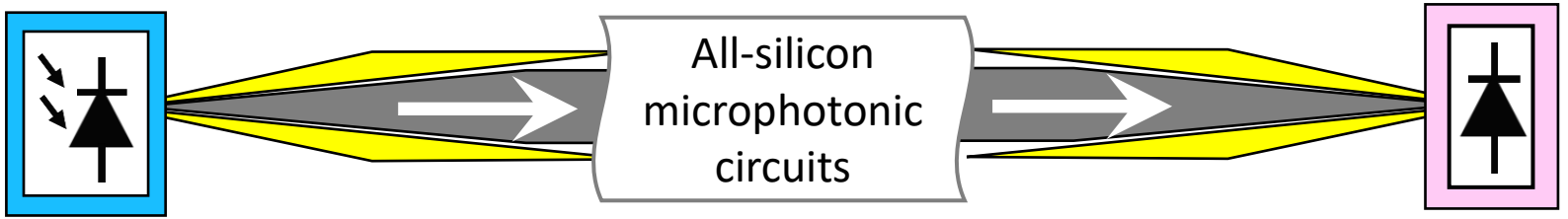


All-Si Microphotonic THz Integrated Systems



UTC-PD

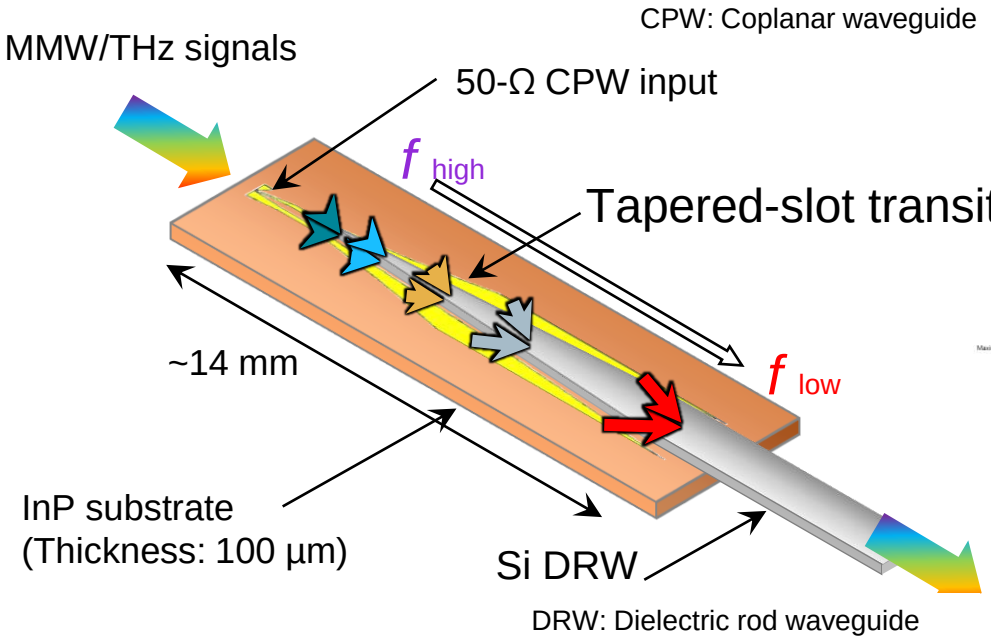
~1.0 THz

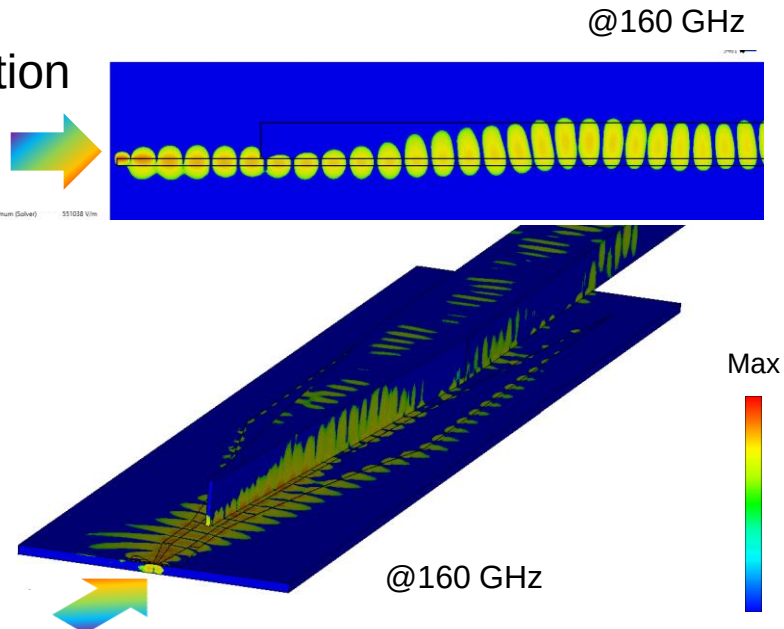
- Lens
- Mirror
- Filter
- Antenna

etc…

SBD/RTD/FMBD

InP-based Planar Tapered-Slot Transition



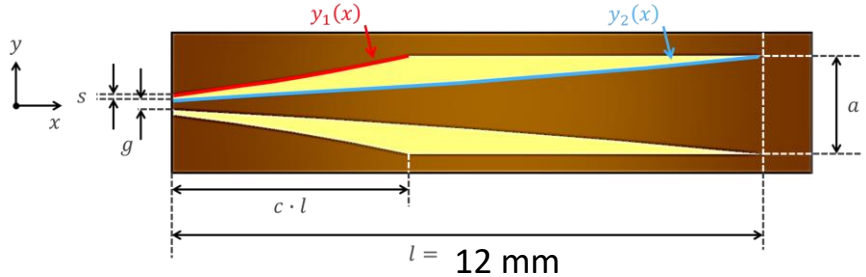


A. Rivera-Lavado, *et al., IEEE TTST.*, **13** 34, (2023).

S. Iwamatsu, *et al., J. Infrared, Millimeter, and Terahertz Waves.*, (2023).

Tapered-Slot Transition and DRW Design

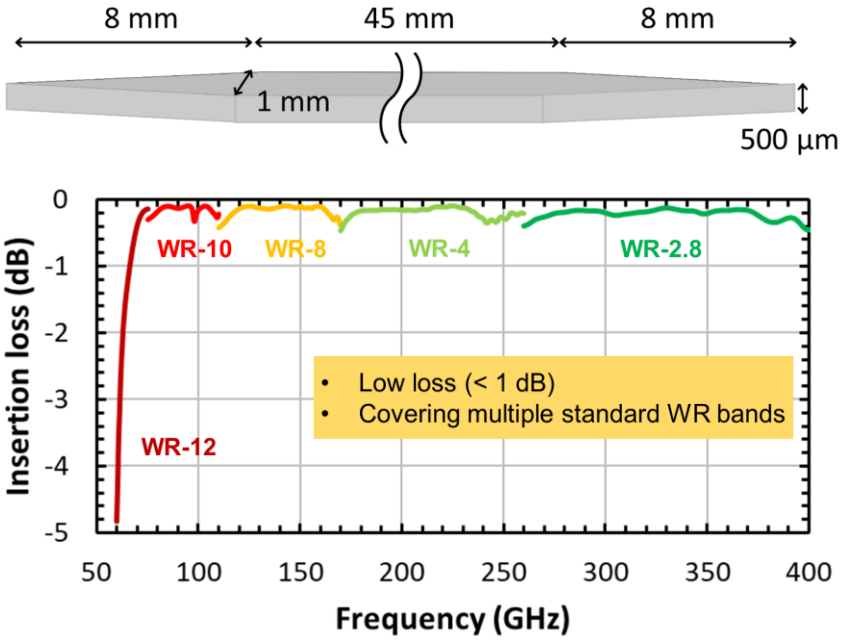
Tapered-slot transition



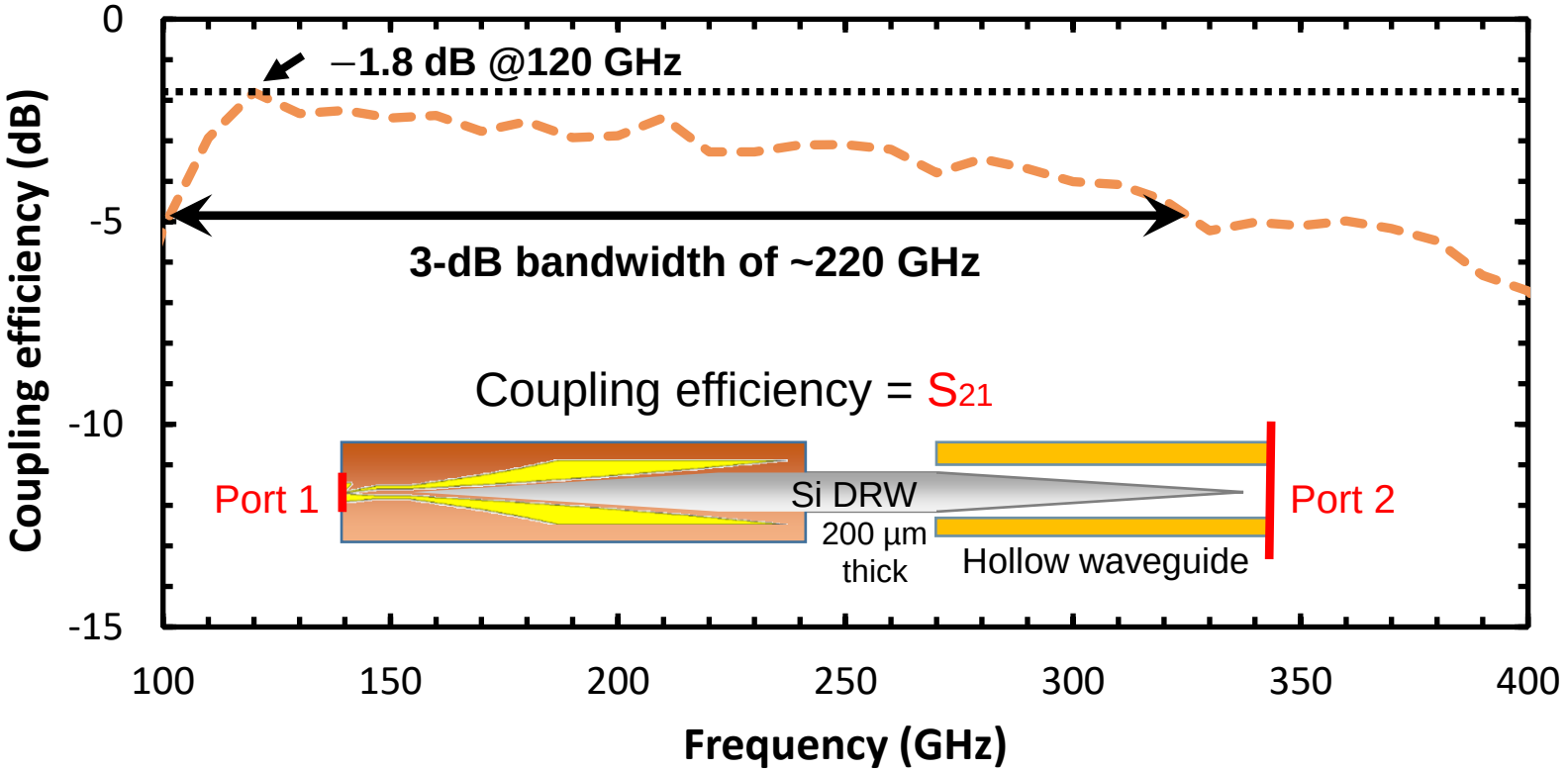
$$y_1(x) = \left(\frac{a-g-2\cdot s+2}{2}\right)^{x/c\cdot l} + \frac{g}{2} + s - 1 \qquad y_2(x) = \left(\frac{a-g+2}{2}\right)^{x/l} + s - 1$$

a	VA aperture	2 mm
c	VA curveture	0.4
l	VA length	12 mm
s	CPS width	100 µm
g	CPS gap	200 µm

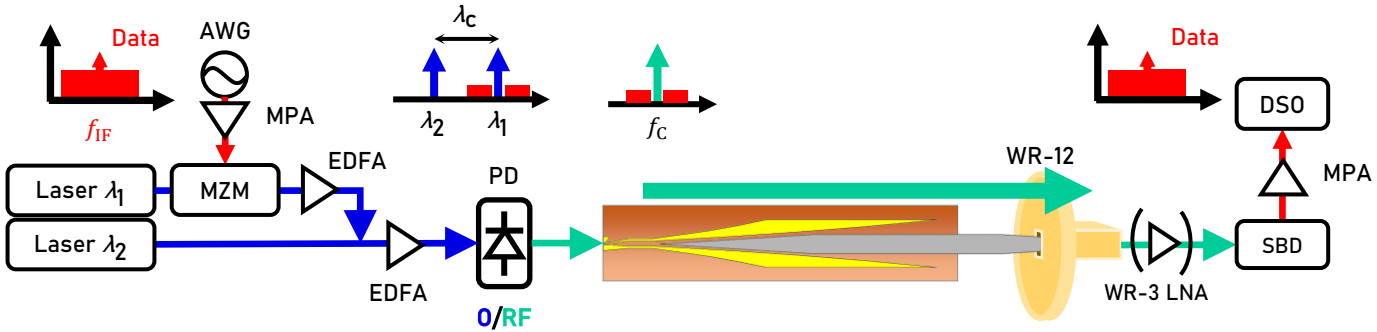
DRW



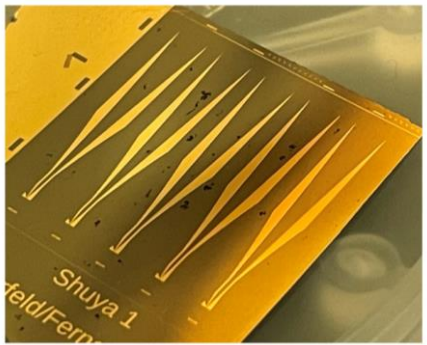
Coupling efficiency of Transition

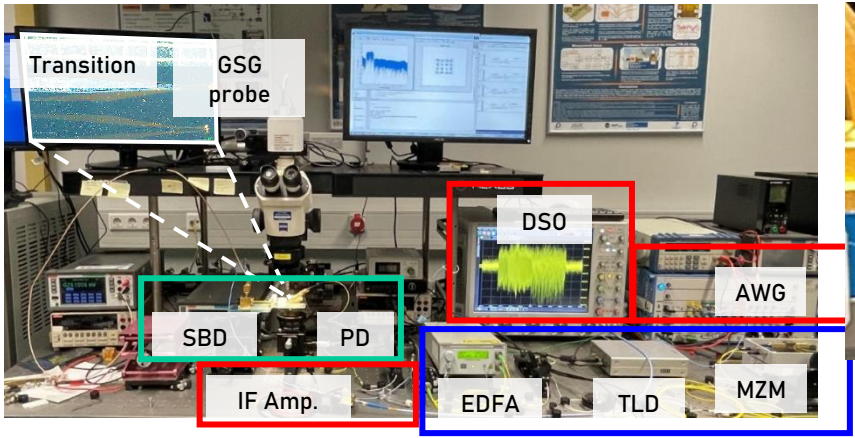


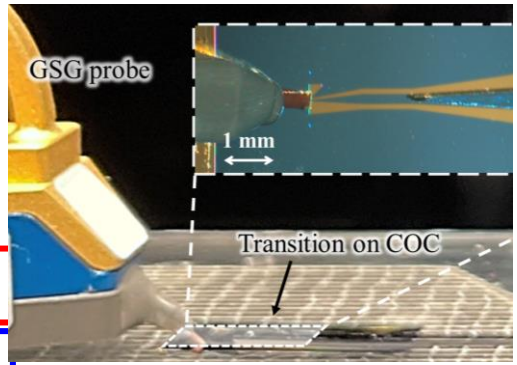
Multi-band On-Chip Communications



→ RF signal
→ Optical signal
→ Data signal



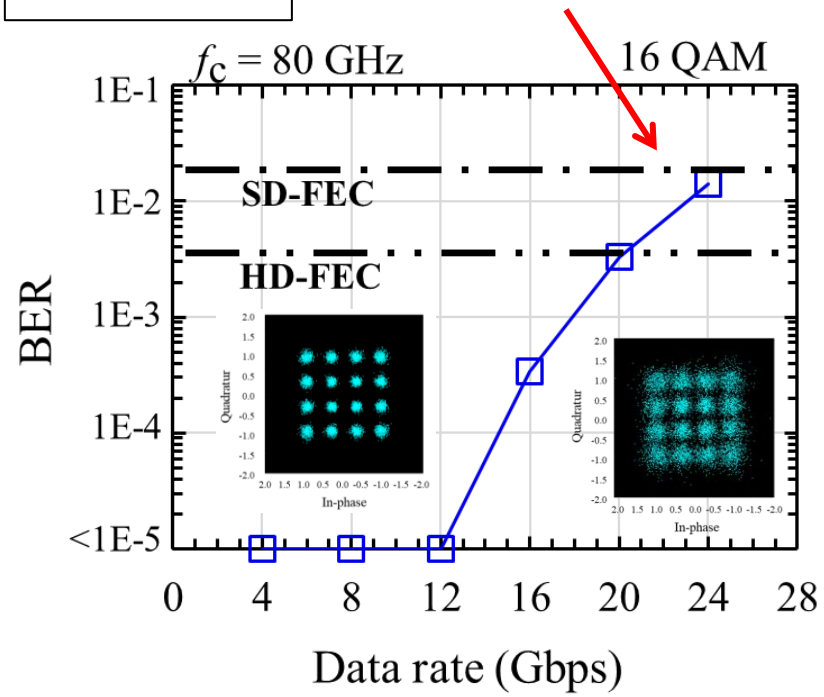




Multi-band Interconnect Capabilities

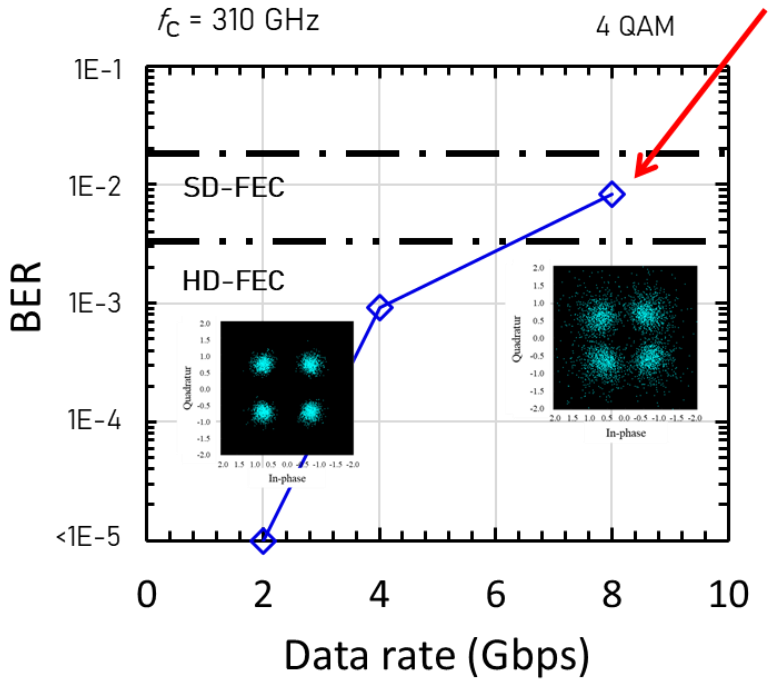
WR-12 band

Max. data rate of 24 Gbps



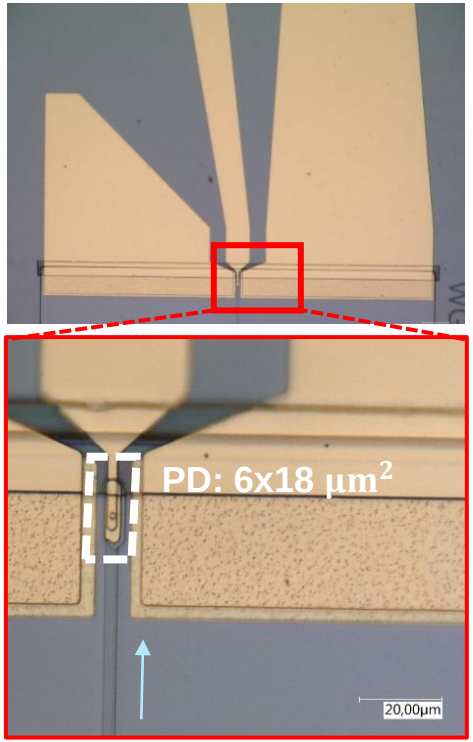
WR-3 band

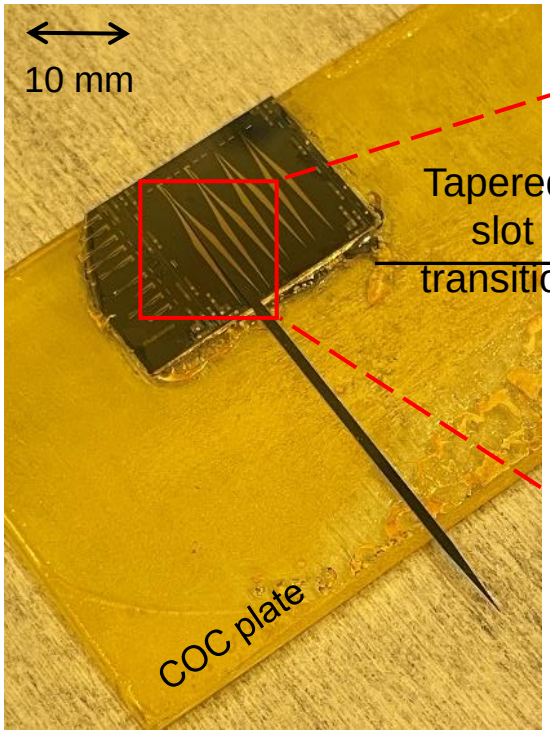
Max. data rate of 8 Gbps

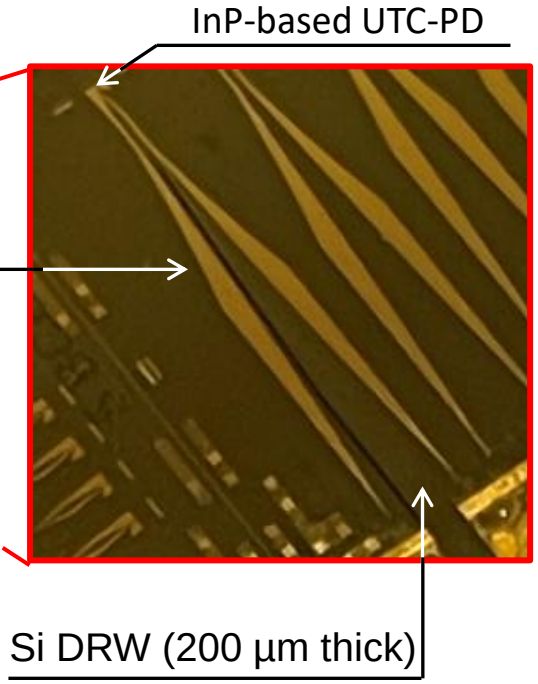


UTC-PD Fabrication

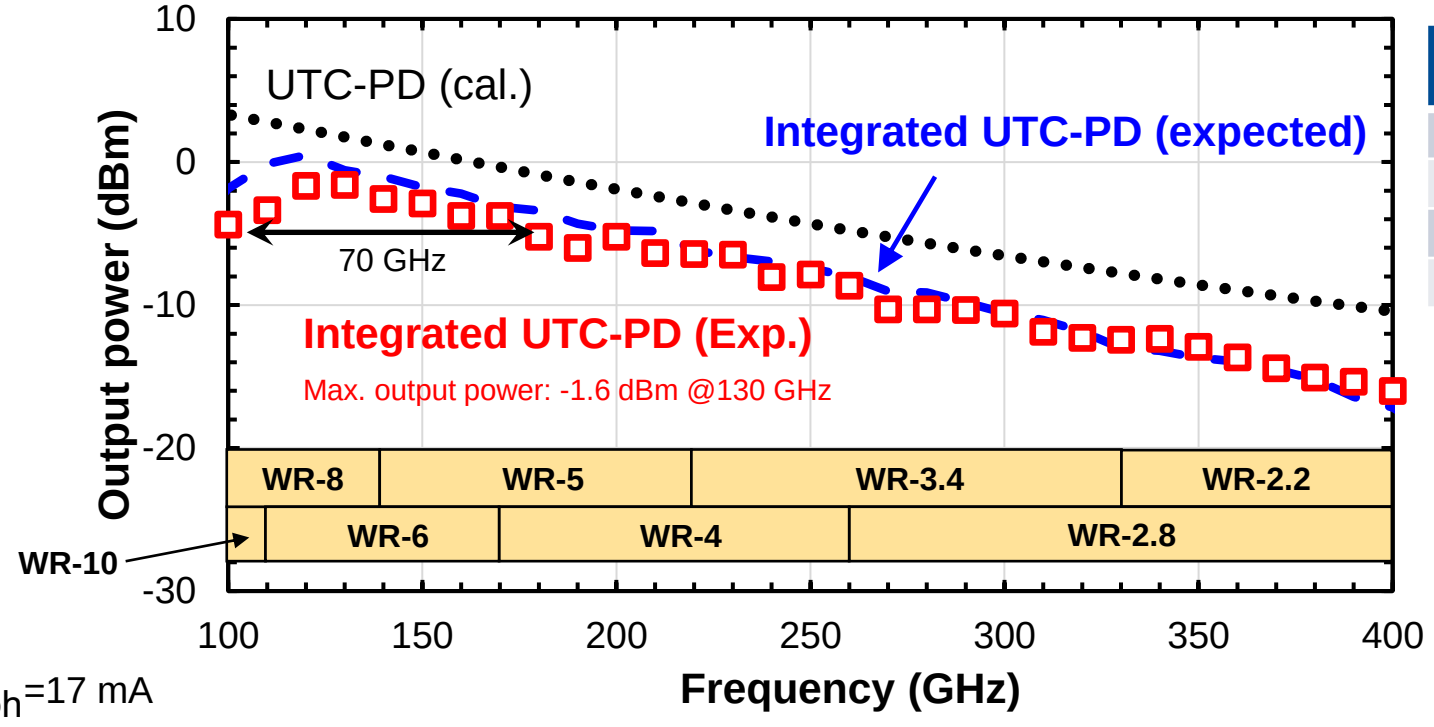
Waveguide-type UTC-PDs integrated with Si DRWs







1st demonstration of DRW-integrated Photodiodes



I_{ph}=17 mA

Freq. (GHz)	Output (dBm)
100	-4
200	-5
300	-10
400	-16

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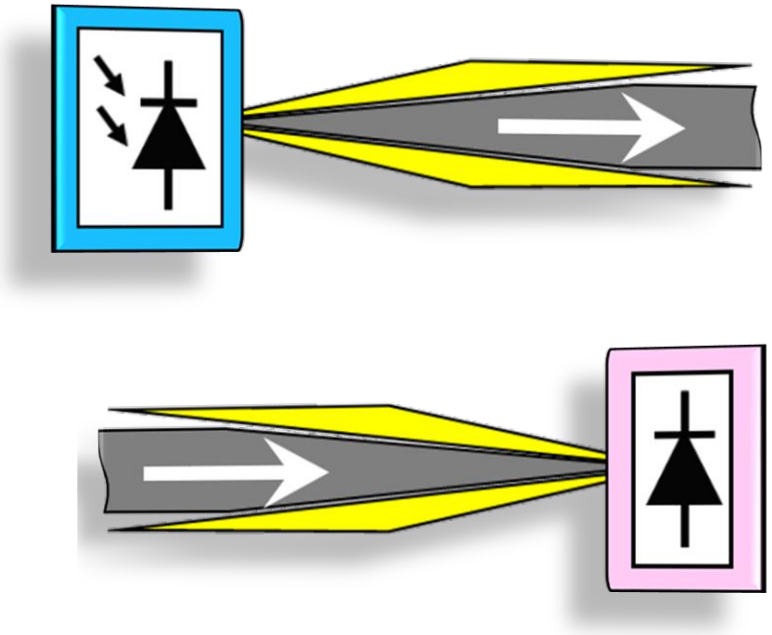
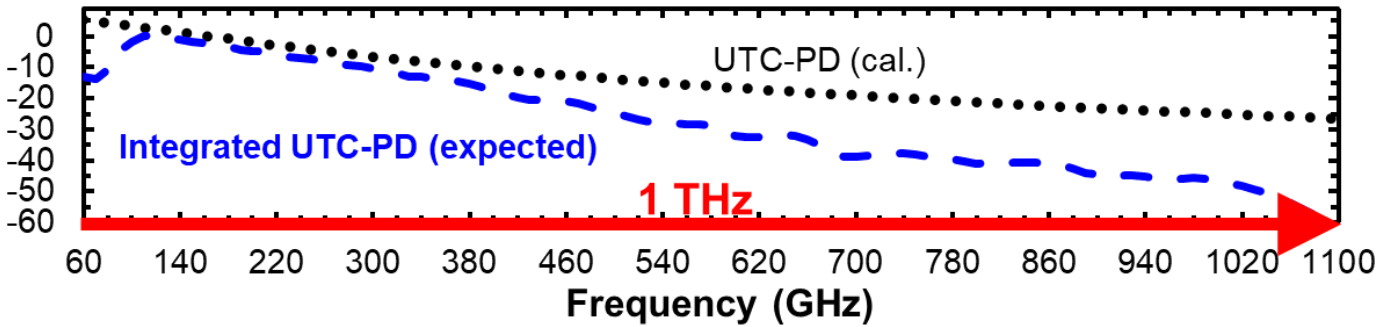


Summary

- **InP-based planar tapered-slot transition** is developed for THz photonic integrated circuits and employed for multi-band THz on-chip communications
- **UTC-PD monolitically integrated with DRW platform** shows ultra-wideband operation with measuement up to 0.4 THz and simulation up to **1.1 THz**.
- **Miniaturized ultra-wideband** communication/imaging/spectrosocpy systems



Thank you for your attention!
Vielen Dank für Ihre Aufmerksamkeit!

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TERAmeasure

THz-IZ