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Plasmonics – a Solution to THz

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- Introduction
- Devices
  - Plasmonic Detectors
  - Plasmonic Modulators
- Wireless Links

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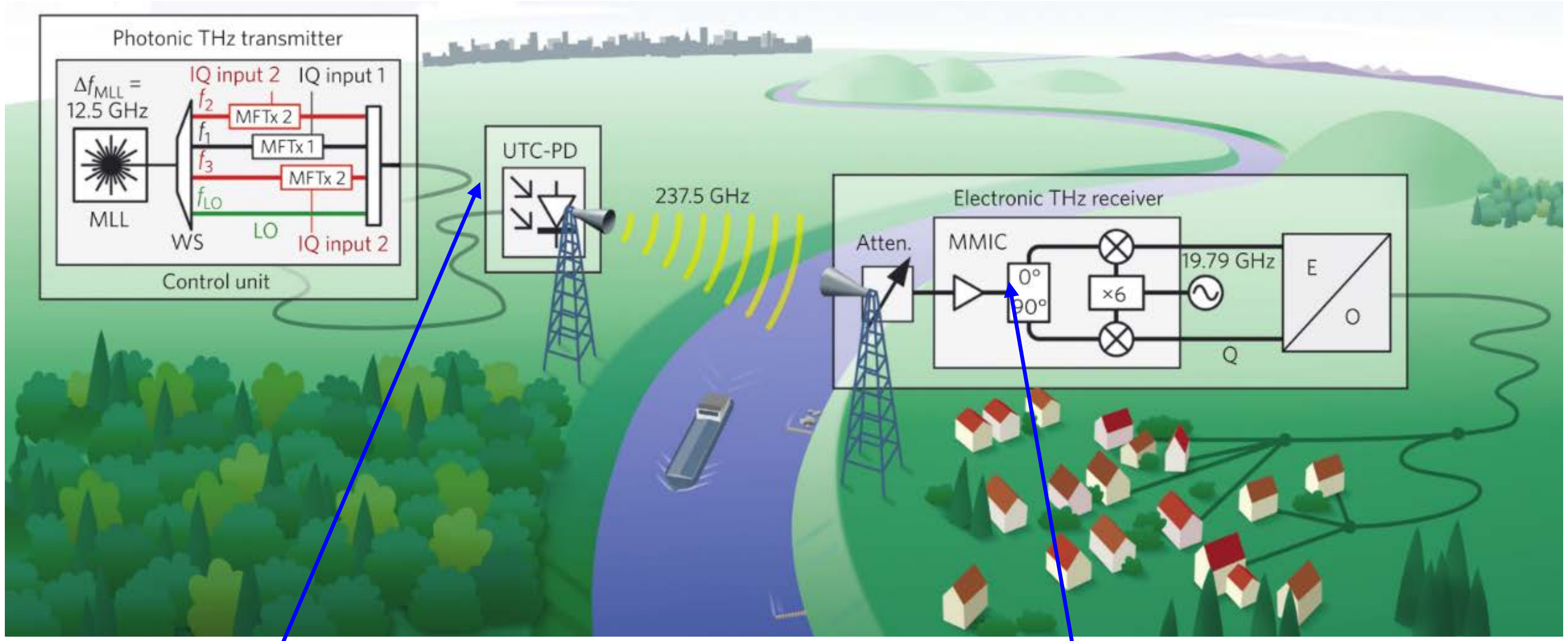
Future Optical-THz Communications Links

Optical-to-RF-conversion

RF-to-Optical Conversion

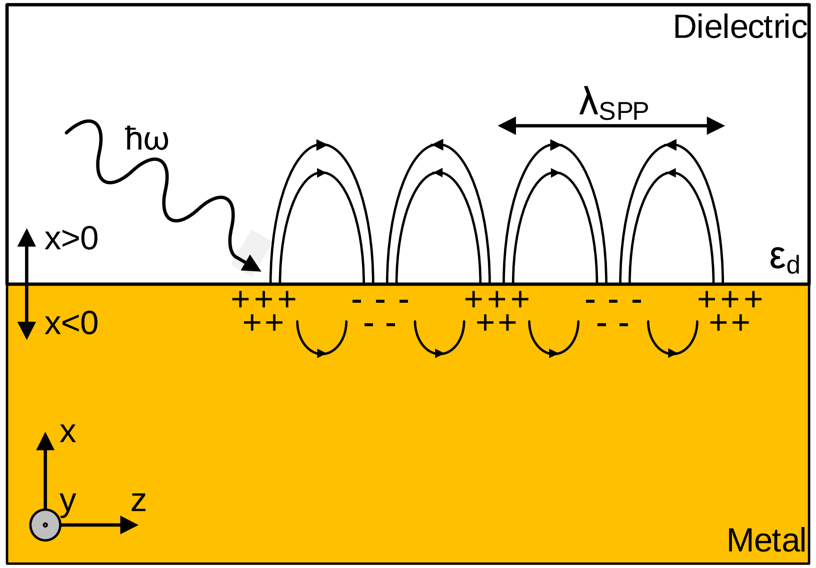


Key-element: Ultrafast PD

Key-element: RF-to-Optical Mixer

Ref.: Koenig, S., et al., "A 100 Gb/s RF Link at a 240 GHz carrier"; Nature Photonics, 2013. 7(12): p. 977-981.

Plasmonics – Surface Plasmon Polaritons (SPP)



What are Surface Plasmon Polaritons?
Photons excite an electron oscillation at a surface of a metal

The good: Plasmons are small (20 – 100 nm) and thus potentially offer a more compact footprint

The challenge: Plasmons are lossy (typically 0.4 to 1 dB per μm)

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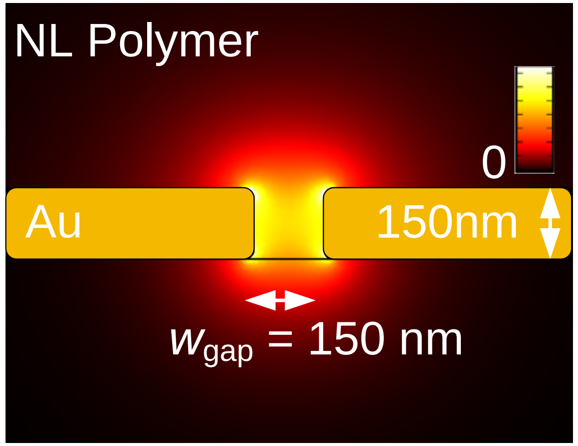
Slot-Plasmonic Waveguide

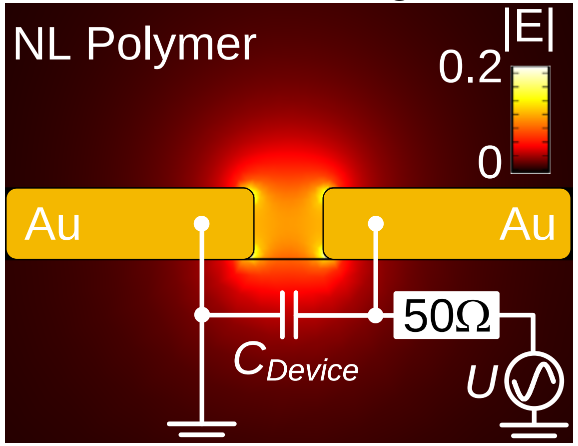
Plasmonic Waveguide

193 THz Carrier



RF-Mode

40 GHz RF Signal



Adantages:

- Plasmonwavelength is much smaller than photonic wabelength
  ➔ very compact
- Plasmonic waveguide (with optical mode) has ideal overlap with RF field
  ➔ efficient electro-optical devices
- RC-Limitations are low, as metallic waveguide have low resistance and capacity is small
  ➔ ultra-fast

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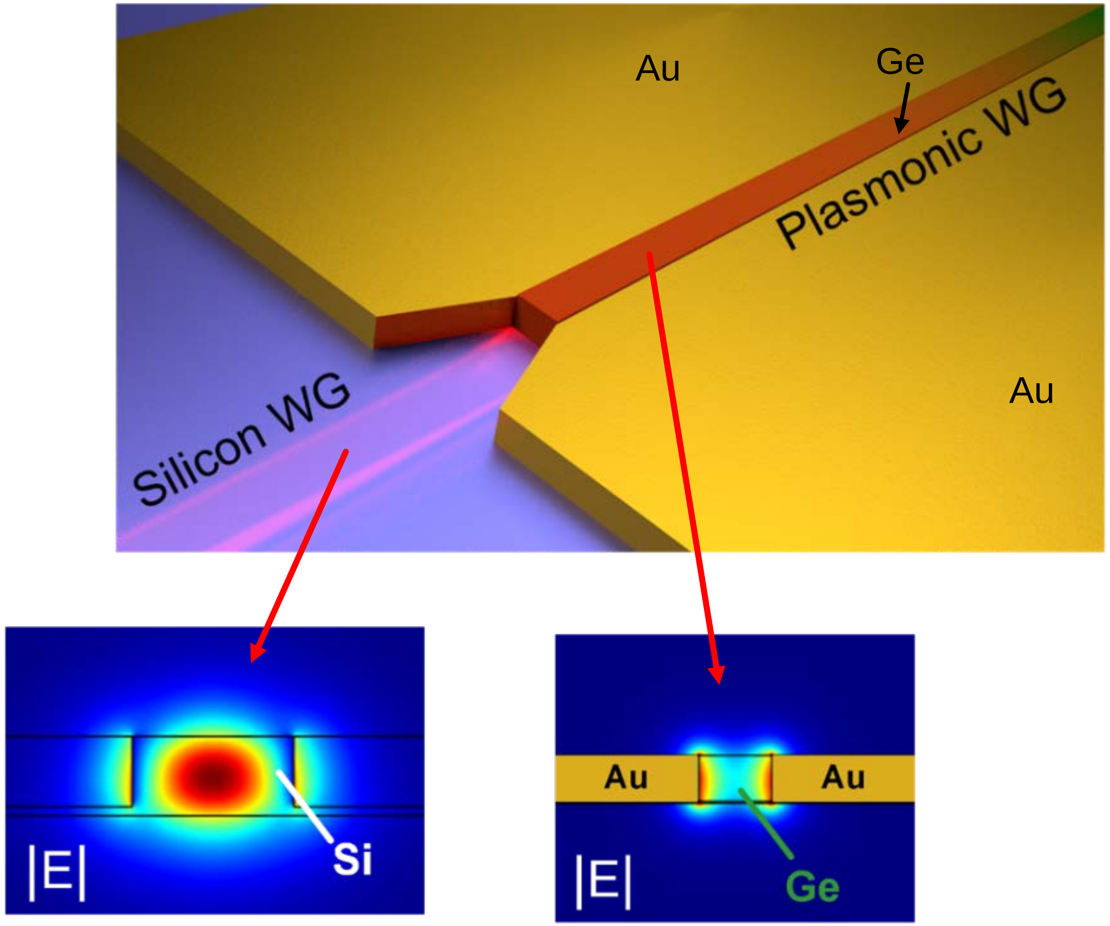
Ultrafast Plasmonic Detector: The Operation Principle



Silicon access waveguide Germanium loaded plasmonic waveguide

i) Light is converted into a plasmon in the slot
ii) Light is absorbed
iii) A current is produced by means of the photoconductive effect

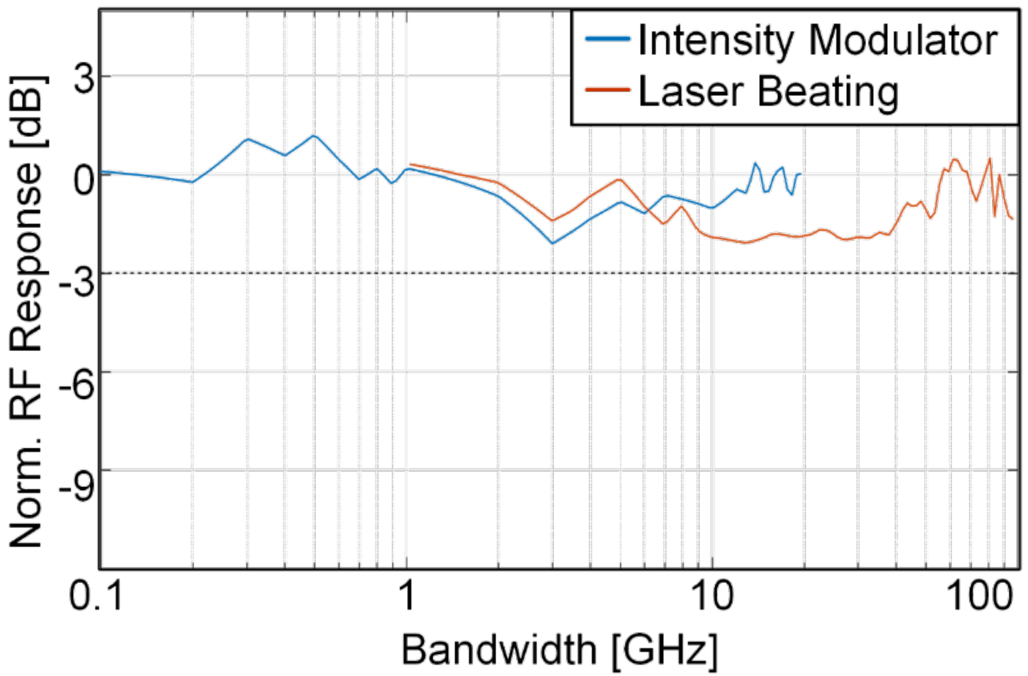
The Plasmonic advantage:

- Small dimensions → low RC limits → fast
- Small gap → short drift times → fast

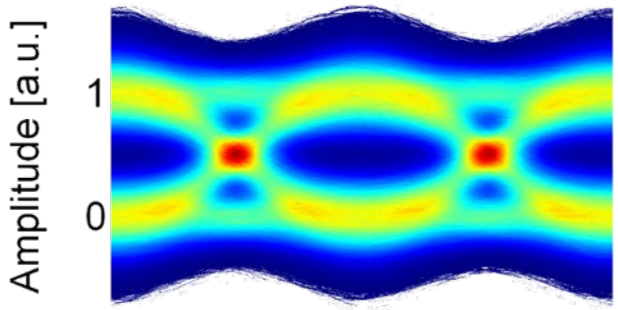
Ref.: Y. Salamin et al., and J. Leuthold, "100 GHz Plasmonic Photodetector," ACS Photonics ***5, 3291-3297 (2018).***

Ultrafast Plasmonic Detector: Frequency Response and Data Experiment

Frequency Response



Data Experiments



72 Gbit/s

Bandwidth

> 100 GHz for a 160 nm wide plasmonic detector

Internal quantum efficiency

~36% for a 3 µm long, 160 nm wide plasmonic detector @ 1310nm

Ref.: Y. Salamin et al., and J. Leuthold, "100 GHz Plasmonic Photodetector," ACS Photonics ***5, 3291-3297 (2018).***

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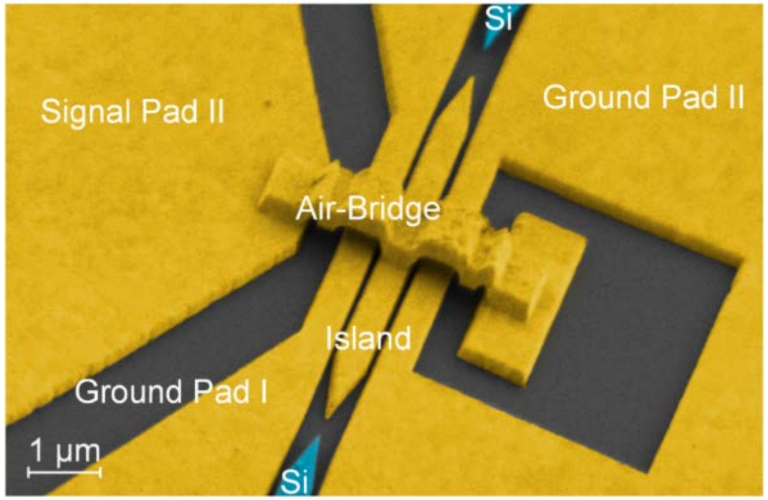
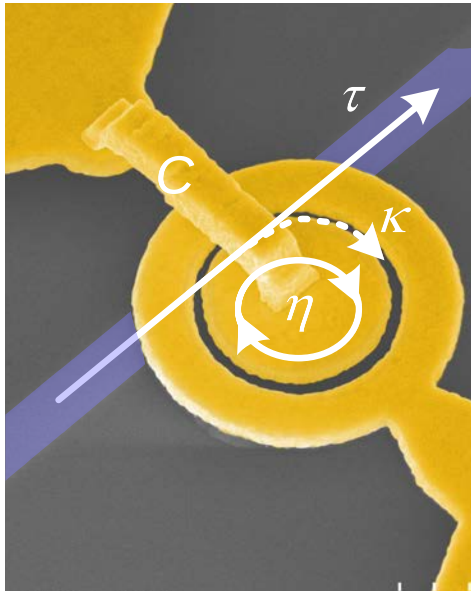
Plasmonic Modulators (>> 100 GHz BW)

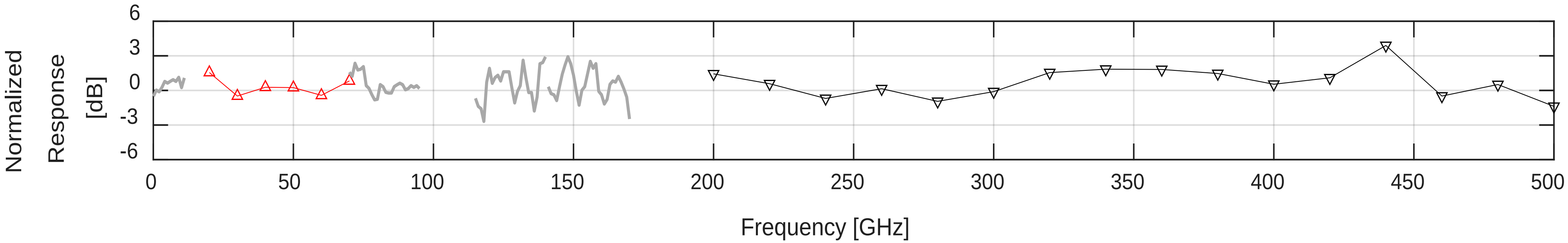


Mach-Zehnder modulator in a waveguide: **10 µm length**, 8 dB Losses
Ref.: C. Haffner *et al., Nature Photonics, pp. 525-528, Aug. 2015.*

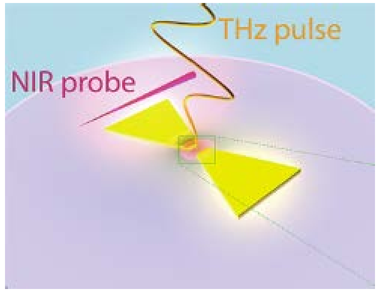


Ring modulator: **Radius 1.0 µm**; Device losses: 2.4 dB
Ref.: C. Haffner, *et al., "Low-loss plasmon-assisted electro-optic modulator," Nature, pp. 483-486, 2018.*

Plasmonic Modulators: Frequency Response



1.25 THz



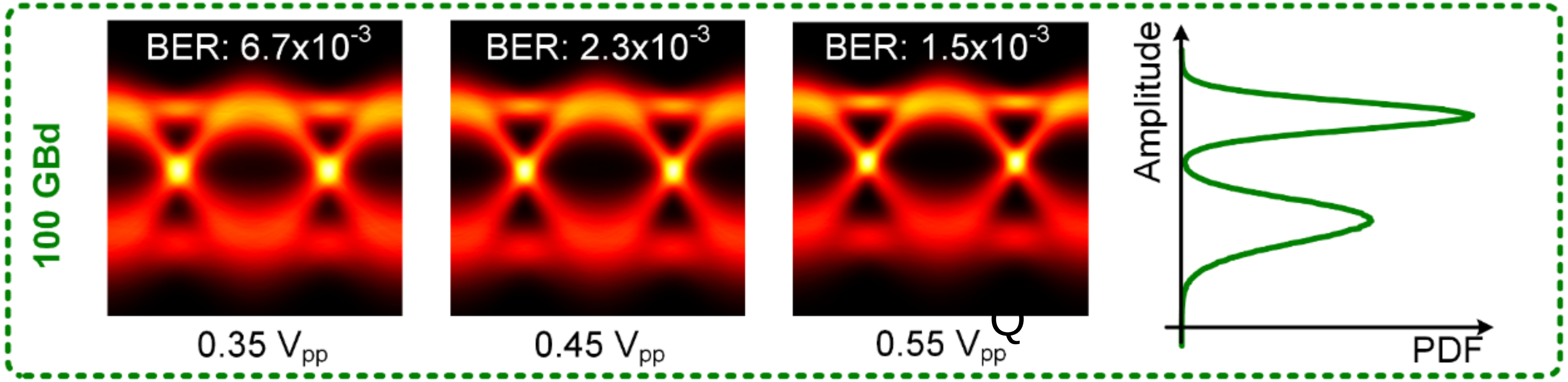
Ref.:

1. C. Hoessbacher, *et al.*, "*Plasmonic modulator with >170 GHz bandwidth demonstrated at 100 GBd NRZ," Optics Express, vol. 25, 2017*

2. M. Burla, to be submitted

3. *I.-C. Benea-Chelmus, et al., "Three-Dimensional Phase Modulator at Telecom Wavelength Acting as a Terahertz Detector with an Electro-Optic Bandwidth of 1.25 Terahertz," ACS Photonics* ***5, 1398-1403 (2018).***

Power-Efficiency: Plasmonics – the Modulator



Electrical energy consumption of **1.8 fJ/bit** and **2.8 fJ/bit**

See Ref.: Benedikt Bäuerle et al.,OFC 2018, M2I.1

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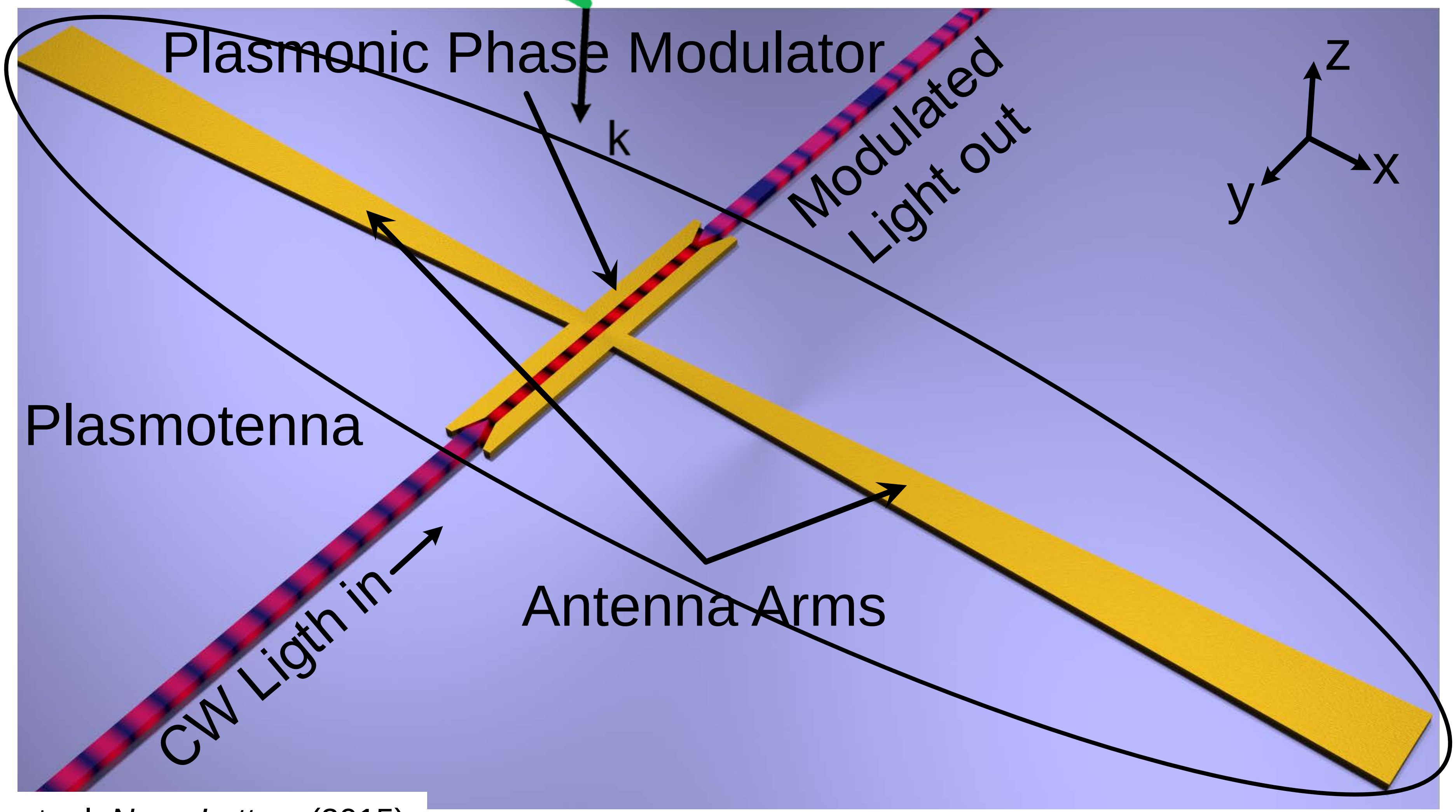
A Novel Approach - Plasmotenna

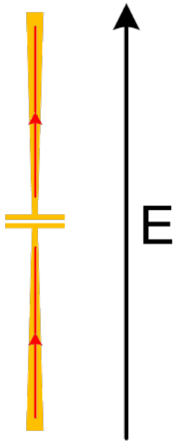
Direct mapping of an RF signal onto an optical carrier (using the modulator from before)



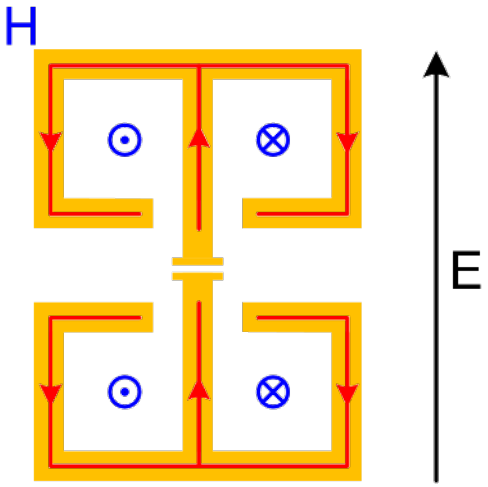
Ref.:Salamin, Y., et. al, *Nano Letters* (2015)

Plasmotenna – Four-Clover-Leaf Resonator

Dipole



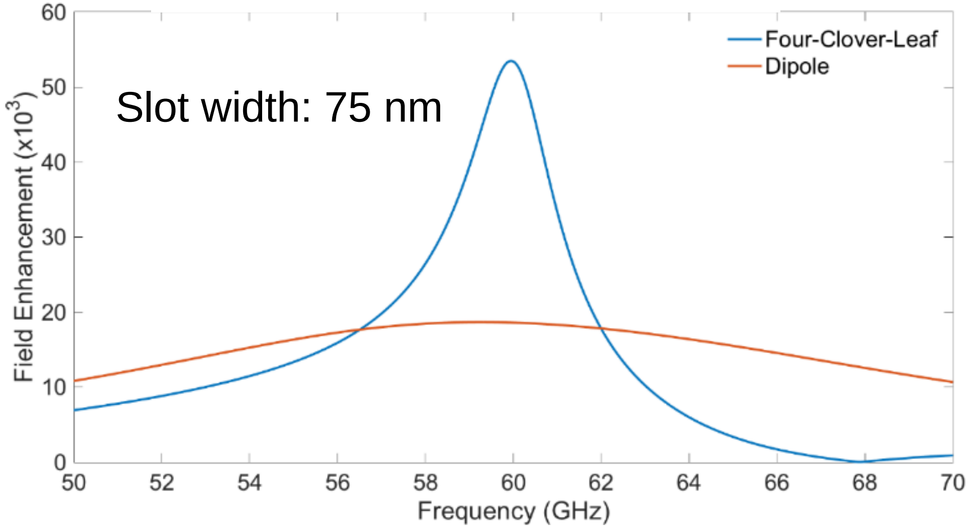
Four-Clover-Leaf Resonator



Q-Factor

$$Q = \frac{1}{R}\sqrt{\frac{L}{C}}$$

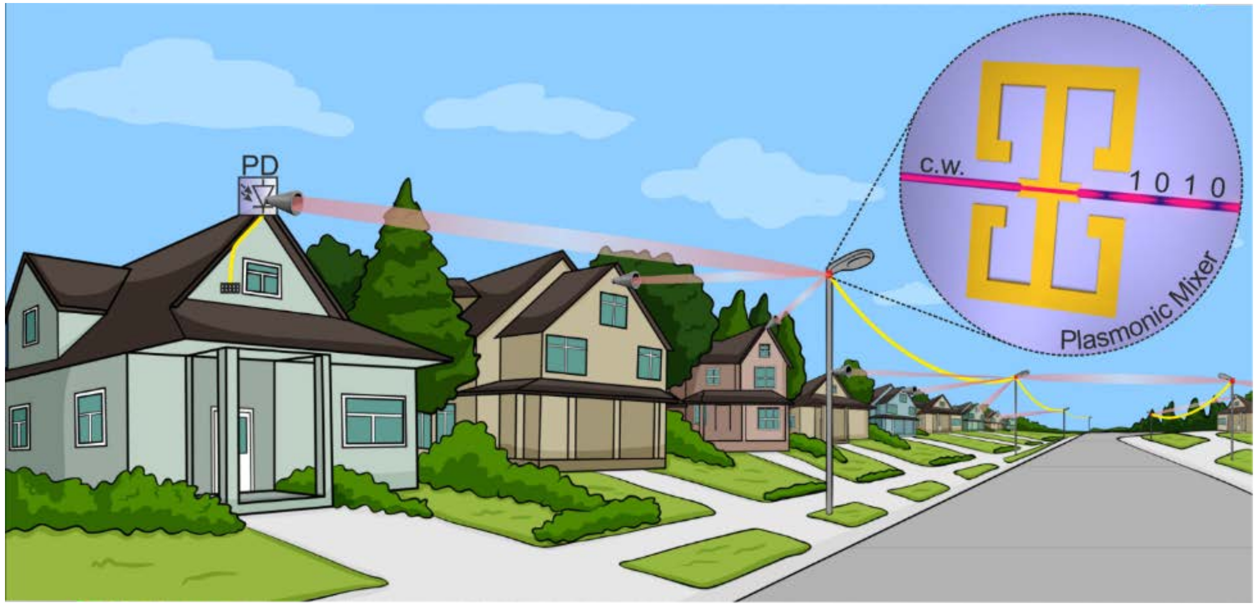
Electric Field Enhancement



- Win a factor of 3 enhancement
- Loss of bandwidth

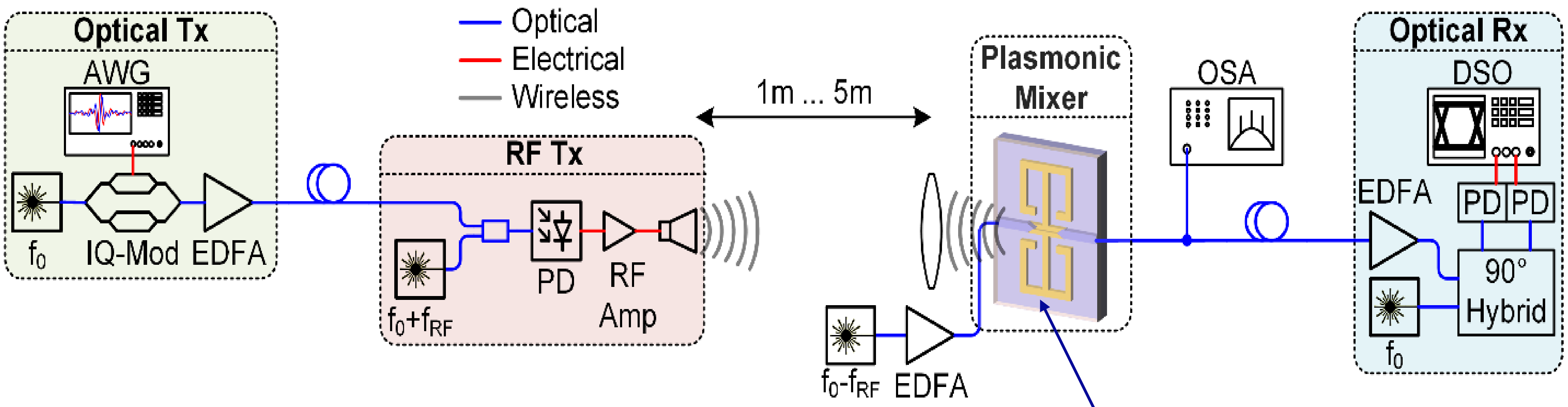
Microwave Plasmonic Wireless Link

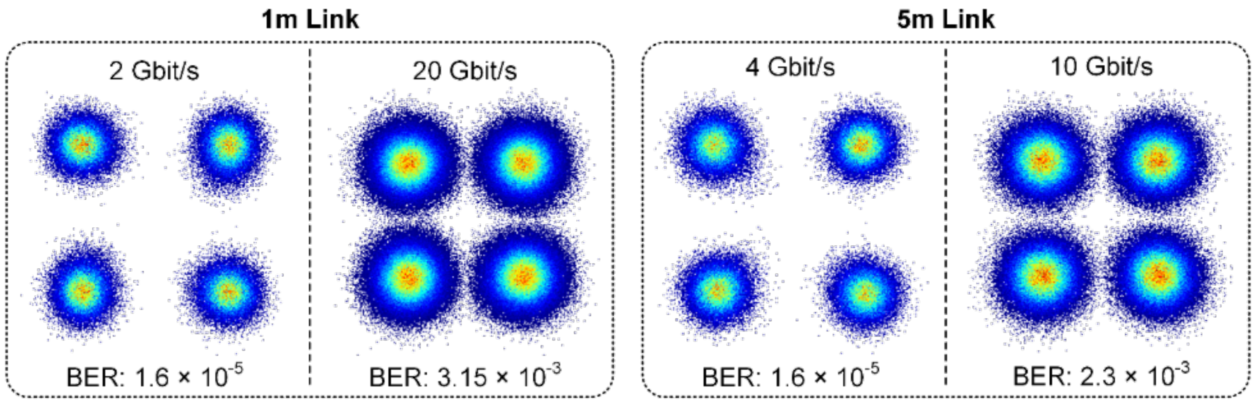
FTTH scenario: An optical network user (ONU) sends a microwave photonic signal to an antenna at the curb. At the curb, the RF signal is directly mapped onto an optical carrier and transported to the CO.



Accepted for publication

10 Gbit/s Plasmonic Optical-RF-Optical Link





The plasmonic advantage:

- Electronic replaced by Plasmonics!
- Works at any carrier frequency up to THz

Accepted for publication

Summary

Novel plasmonic devices are introduce. They offer kHz to THz bandwidth.

Key elements are emerging:

- Modulators: 500 GHz bandwith, fJ/bit operation with reasonably low losses <3 dB
- Photodetectors: 100 GHz bandwith is demonstrated

First Optical-RF-Optical Link demonstration with 10 Gbit/s data over 5 m has been demonstrated.

Key to the demonstration was a novel plasmonic antenna-modulator.