"Trends in Plasmonics and their applications"

Towards Plasmonics Communications

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Ministry of Science and Technology
28-10-2021

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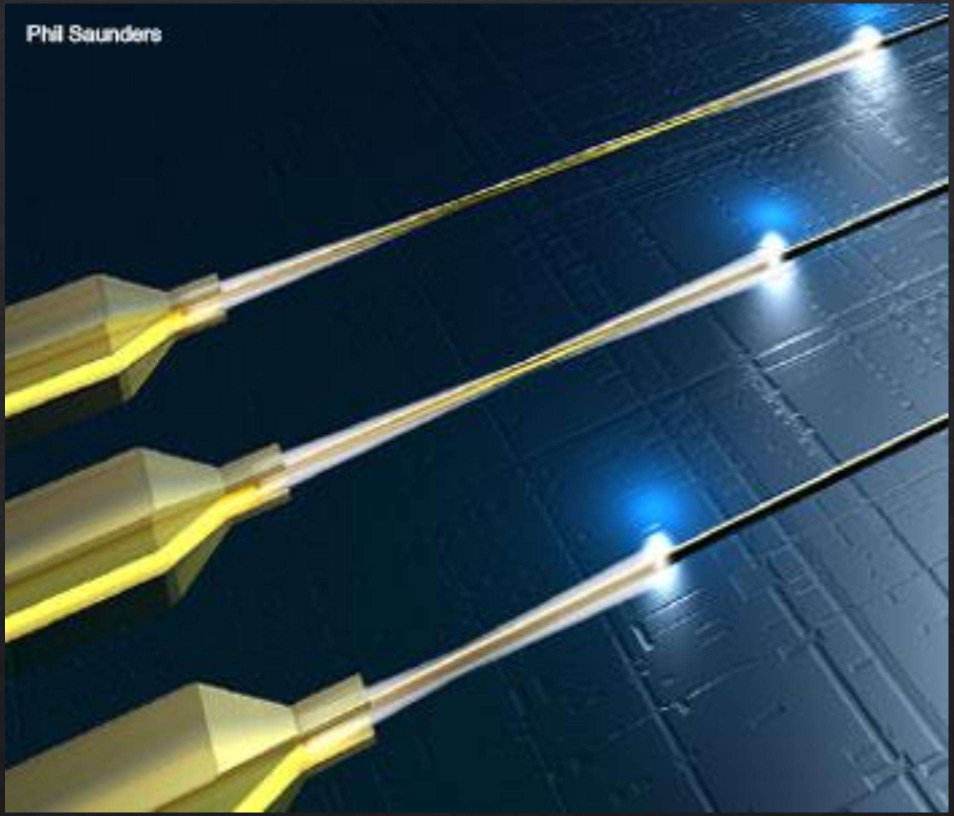
Statement

Plasmonics Communications

is

Light on a Wire

By coupling light to the charges at metal interfaces, photons will be manipulated in a way that have been never done before: **at the subwavelength level.**



Contents

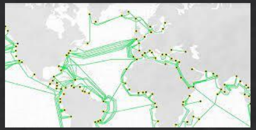
- Introduction
- Optical fibers and waveguides
- Current Solution: Silicon Photonics
- Plasmonics: A Most Compact Solution
- Physics of Plasmonics
- Plasmonics Communications System
- Applications

Introduction

1000 km
10 km
100 m
1 m
0.1 m
0.01 m

Interconnect Distance

Long Haul network



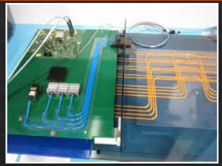
LAN

Optics since 90's

Rack Level

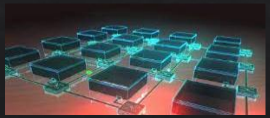
Optics since 2000

Board level



Optics current and near future

Chip level



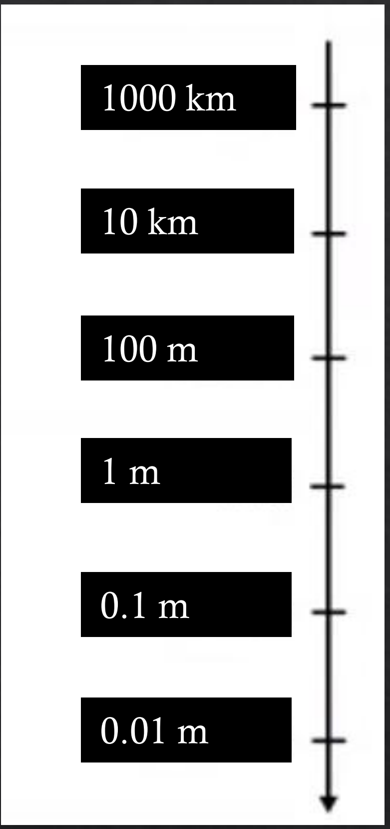
On chip ICs

Optics 2020+

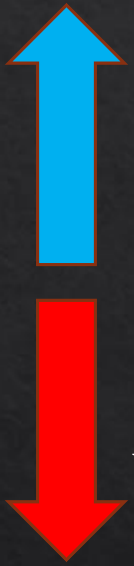
1000 um
100 um
10 um
1 um
0.10 um
0.01 um

Integrated Lines

Optical fibers and waveguides

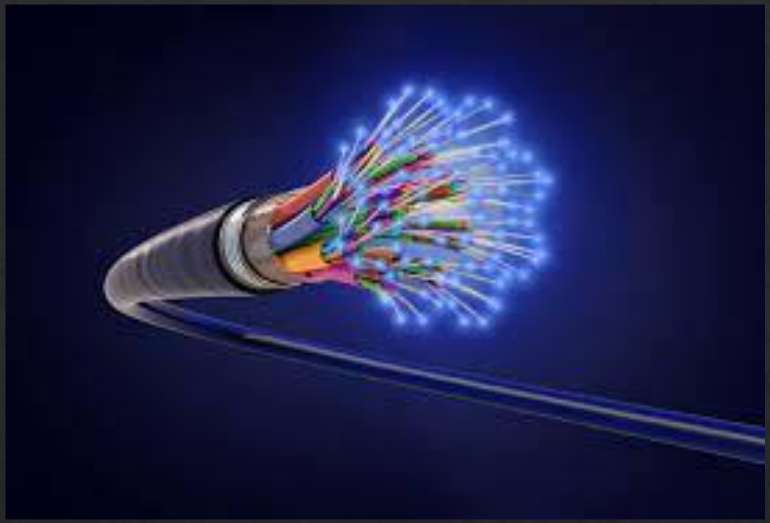


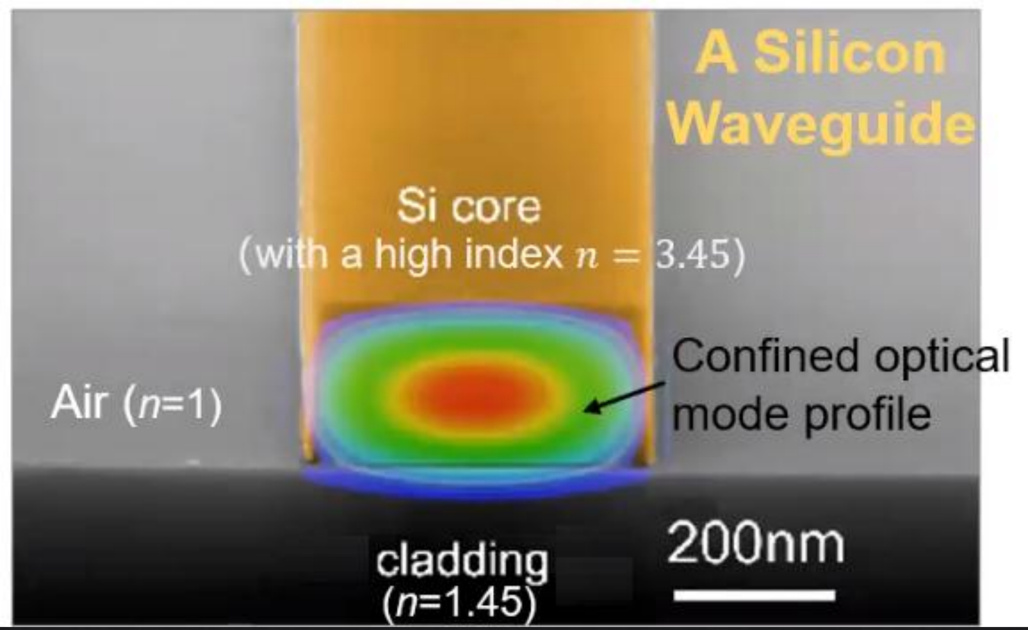
Interconnect Distance

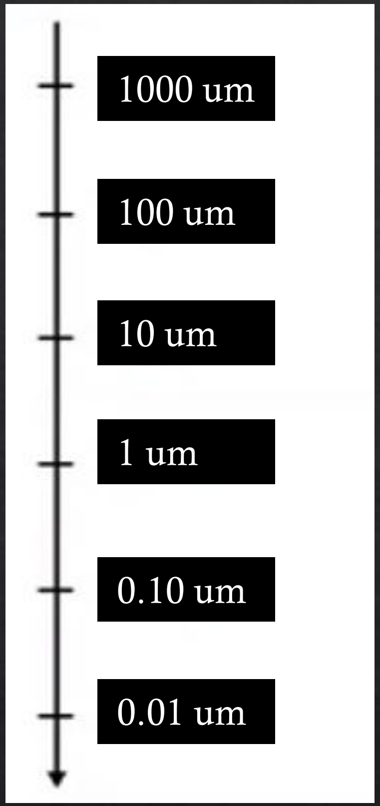


Optical Fibers

Silicon Waveguides

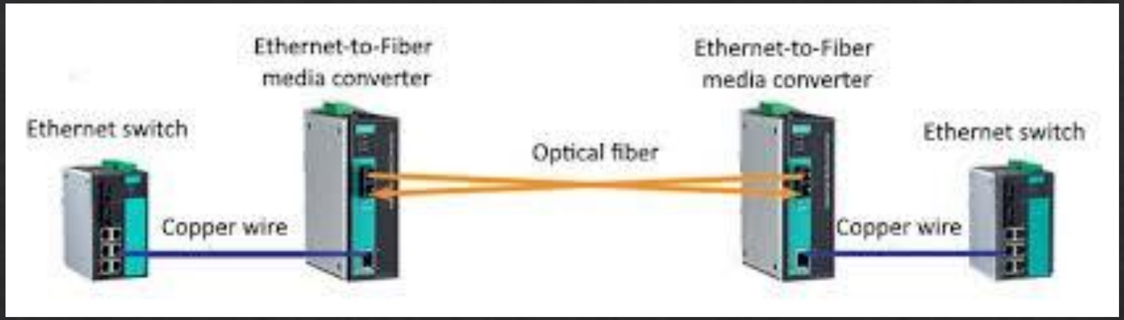






Integrated Lines

Conventional optical communications



Transmitter
Electrical System

- Processing Unit
- Memory Unit

Tx

- E/O convertor
- Laser source
- Modulator
- Multiplexer
- Switch

Rx

- O/E convertor
- Laser Detector
- Demodulator
- Demultiplexer
- Switch

Receiver
Electrical System

- Processing Unit
- Memory Unit

Bottleneck **Bottleneck**

The Challenges

- Speed limitation
- Dense integration
- Energy Consumption

The Missions

- Faster speed
- Smaller Footprint
- Lower power Consumption

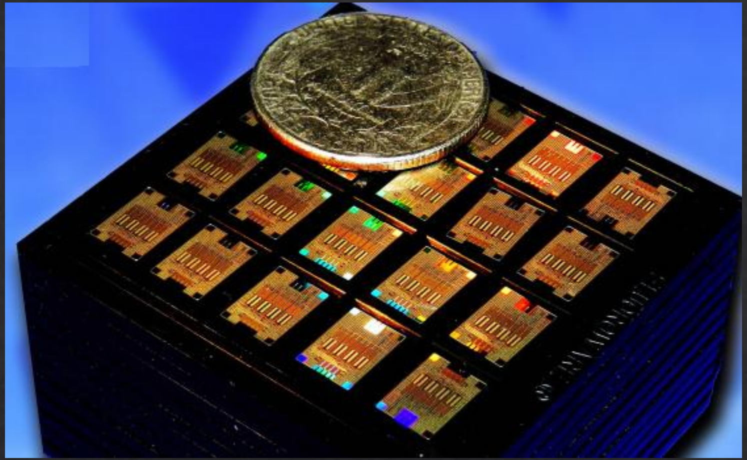
Current Solution: Silicon Photonics

Advantages:

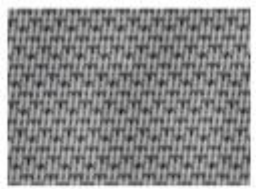
- Low cost mass production.
- good mode confinement.
- Can be integrated with electronics IC in the same printed circuit board (PCB).

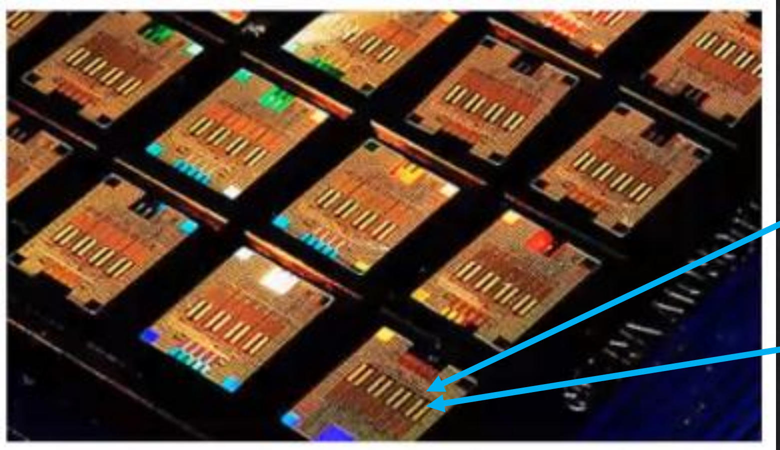
Disadvantages:

- Large footprint.
- Limited bandwidth.
- Diffraction limit.



Silicon Photonics Circuit





Each **1** mm^2 can have about **100M** Transistors

An optical modulator with area about mm^2

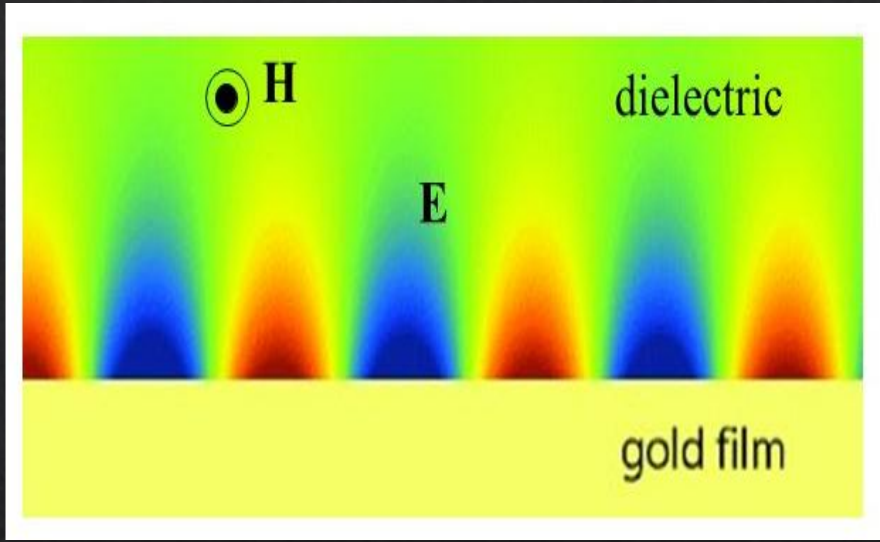
So that :

To achieve faster information transport

Overcome the disadvantages

Size mismatch between photonic and electronic components

Silicon photonics are limited in size by the fundamental laws of diffraction to about half a wavelength of light



Solution

Plasmonics Technology

Physics of Plasmonics

Plasmonics is the study of interaction of light (photon) and metal under precise circumstances and the term "PLASMONICS" is derived from plasmons.

Plasmon is a quantum quasi-particle representing the elementary excitations, or modes, of the charge density oscillations in a plasma.

Photon → quantum particle representing the elementary excitations, or modes, of the free electromagnetic field oscillations → real particle.

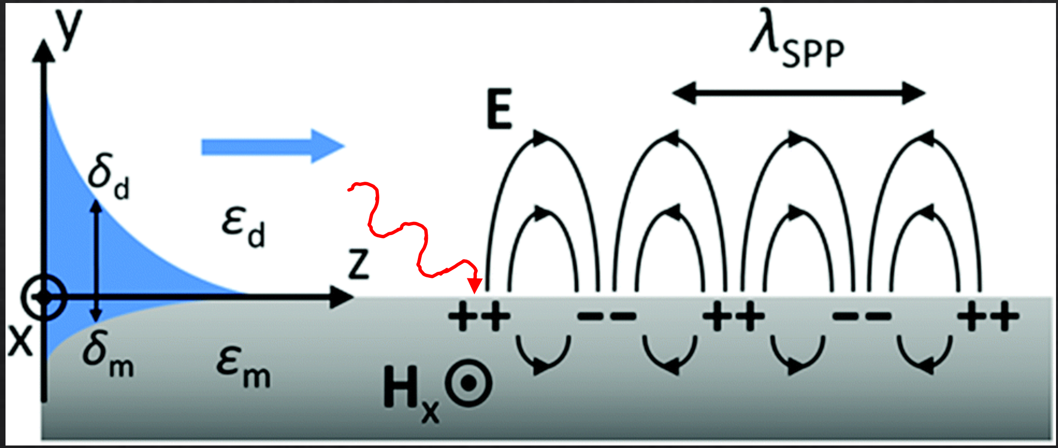
Polaritons are quasi-paticles resulting from strong coupling of electromagnetic waves with an electric or magnetic dipole-carrying excitation.

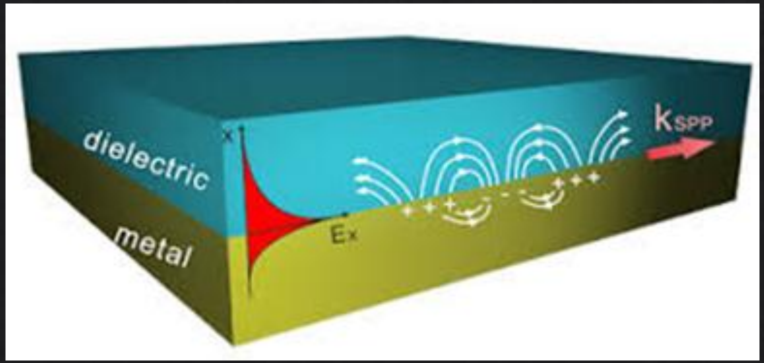
↓

→ a mixed mode → the energy is shared between:
the charge density wave (**plasmon**) + electromagnetic wave (**photon**),

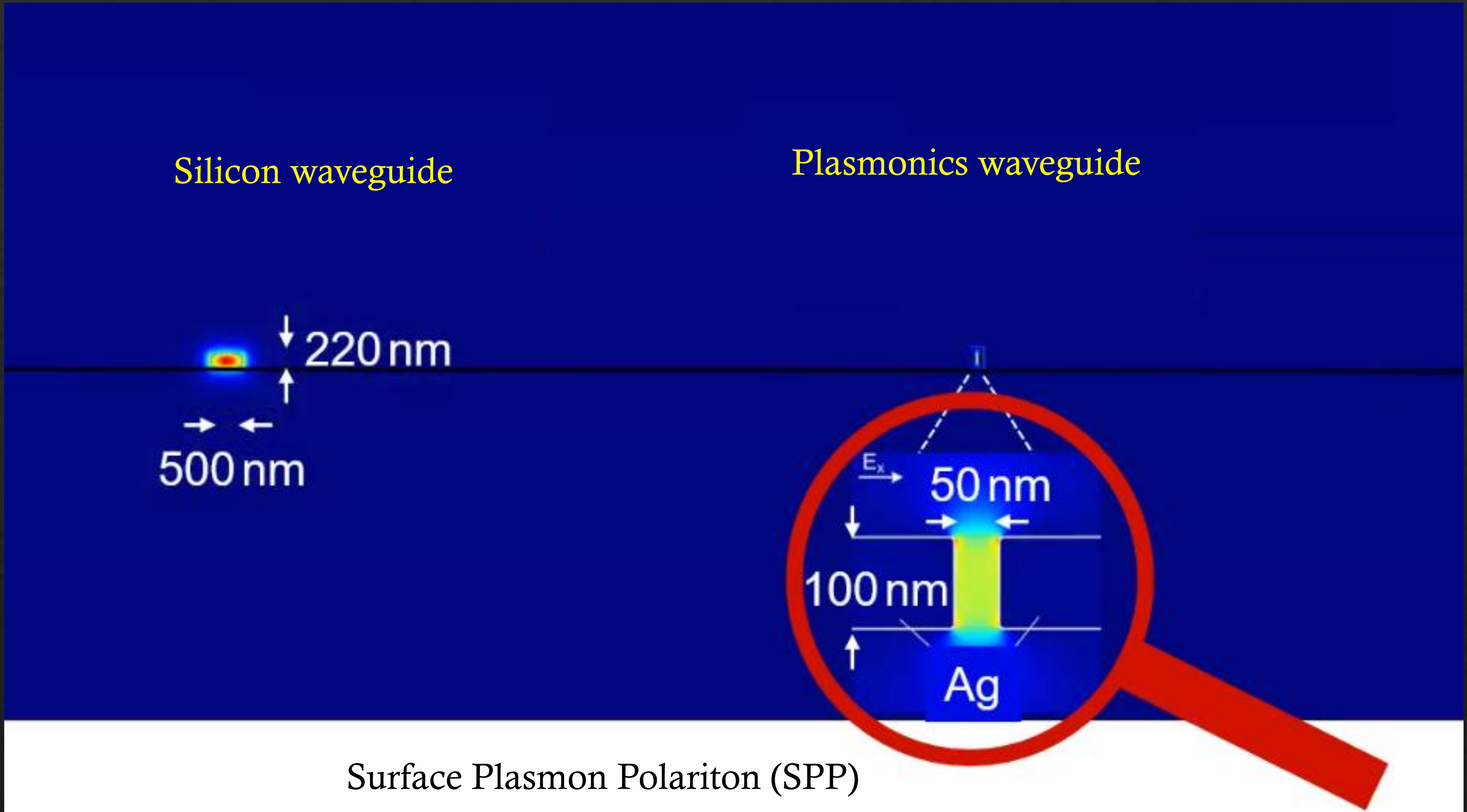
↓

Surface Plasmon Polaritons



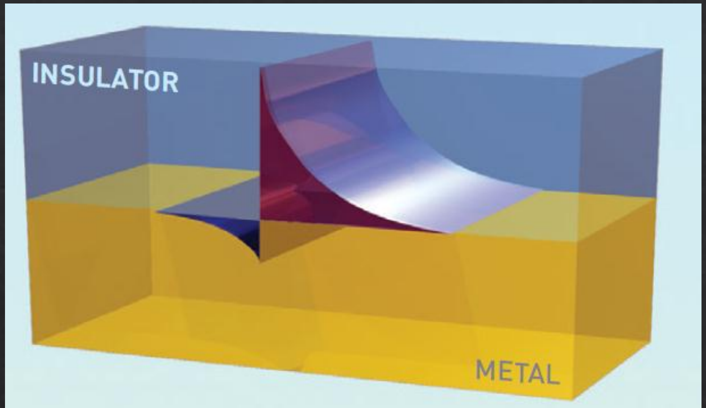


Plasmonics: A Most Compact Solution

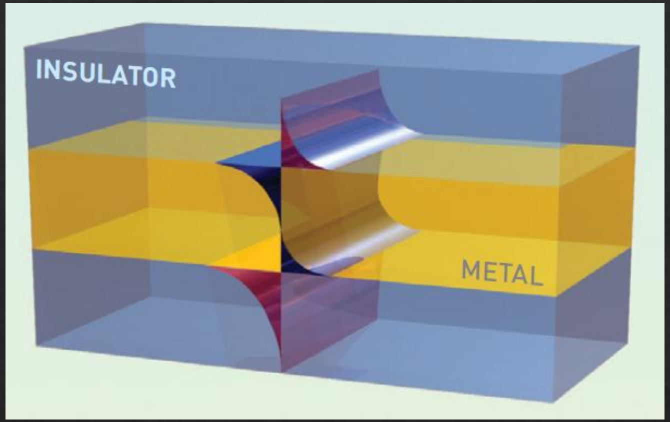


Surface Plasmon Polariton (SPP)

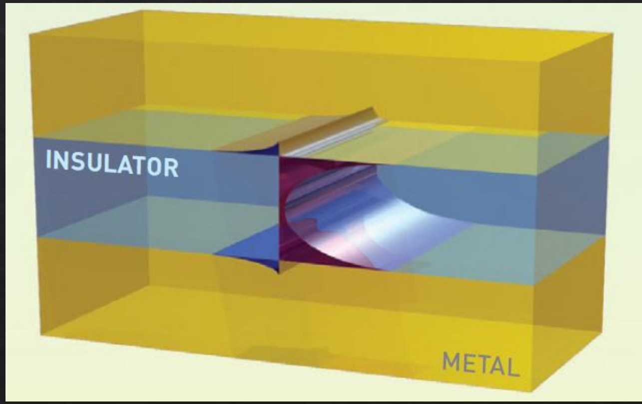
Plasmonics waveguide structures



Metal-insulator interface is
the simplest plasmonic waveguide

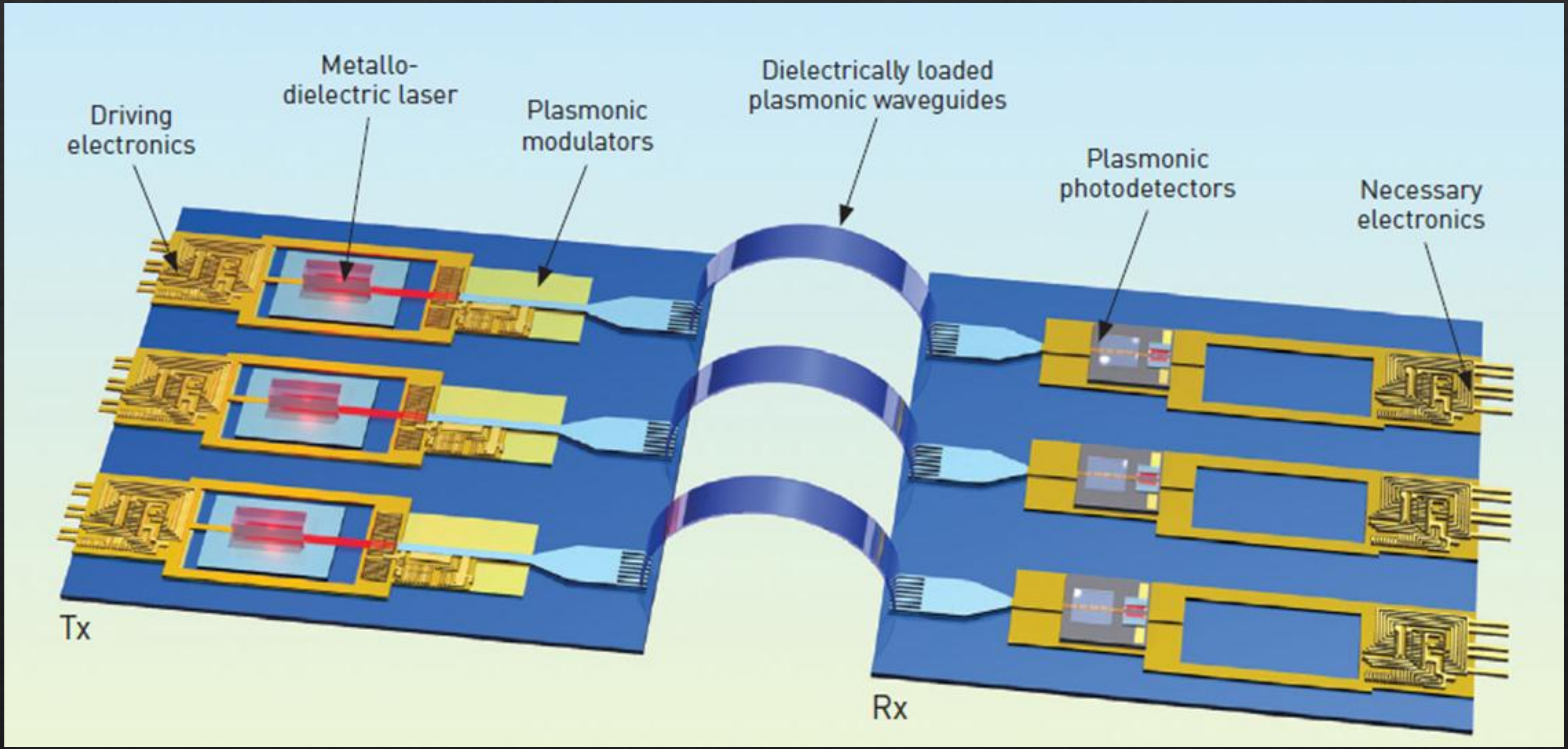


Insulator-metal-insulator waveguide
offers long propagation lengths



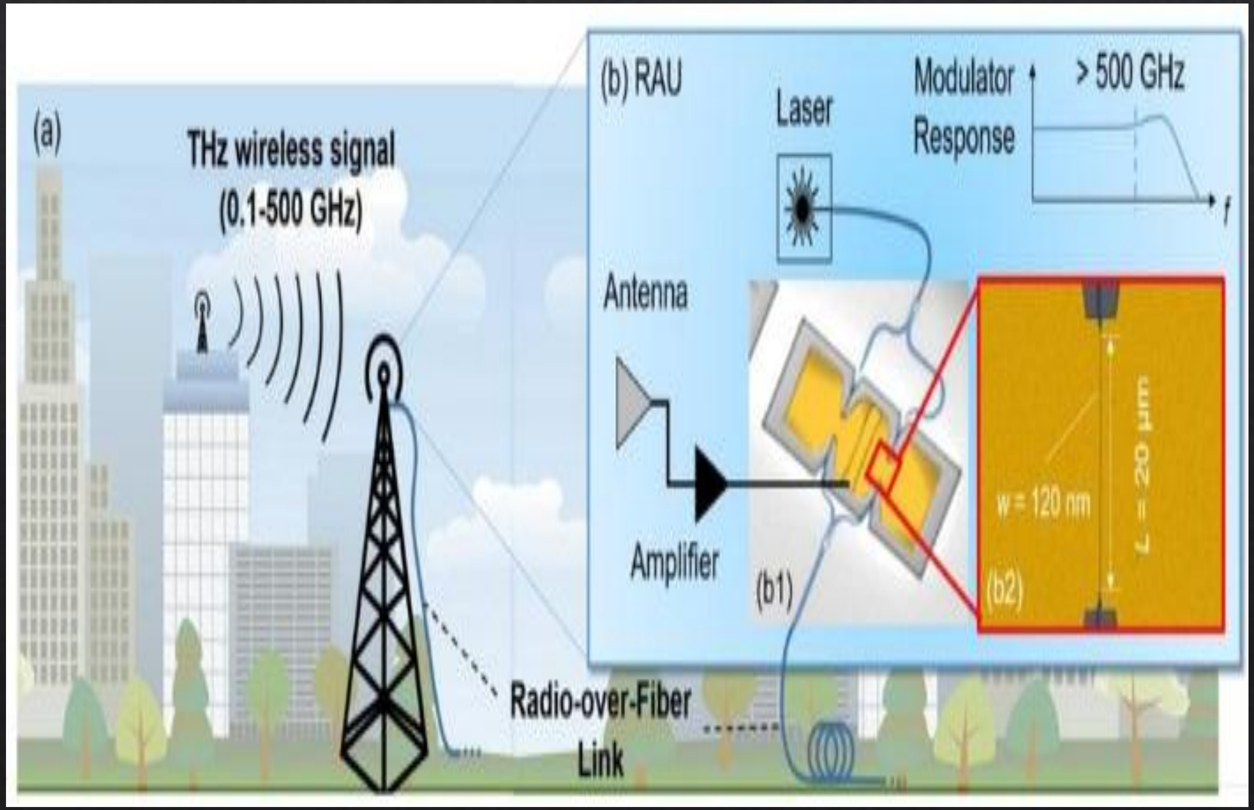
Metal-insulator-metal waveguide allows
for very small transverse dimensions

Plasmonics communications system



Applications

- Detector
- Switch
- Modulator
- Multiplexer
- Memory
- Directional Coupler



Detector

Guo et al. *Light: Science & Applications* (2020)9:29
https://doi.org/10.1038/s41377-020-0263-6

Official journal of the CIOMP 2047-7538
www.nature.com/lsa

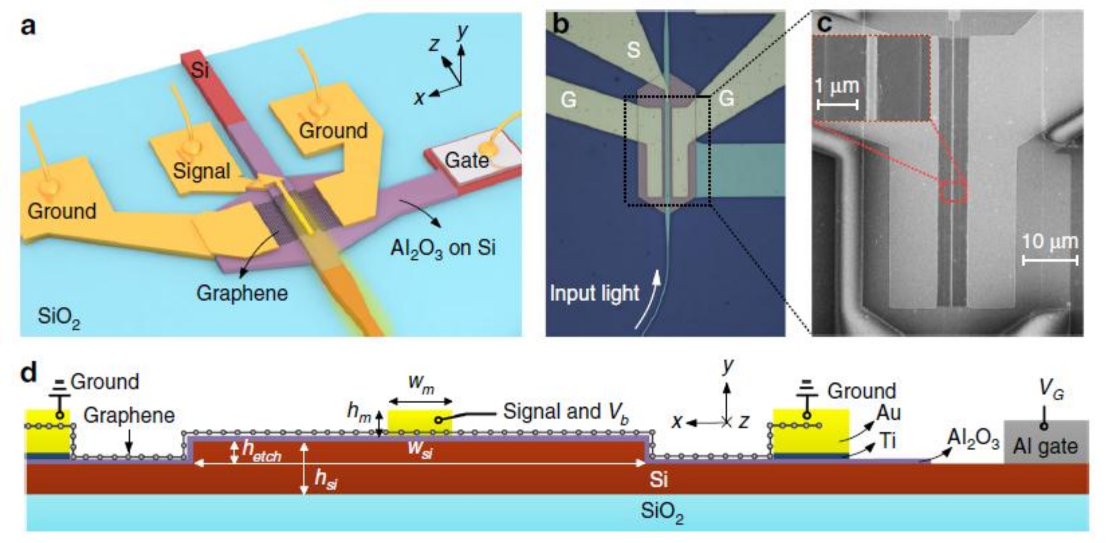
ARTICLE **Open Access**

High-performance silicon–graphene hybrid plasmonic waveguide photodetectors beyond 1.55 μm

Jingshu Guo[1,2], Jiang Li[1], Chaoyue Liu[1], Yanlong Yin[1], Wenhui Wang[3], Zhenhua Ni[3], Zhilei Fu[4], Hui Yu[4], Yang Xu[2,4], Yaocheng Shi[1,2], Yungui Ma[1], Shiming Gao[1,2], Limin Tong[1] and Daoxin Dai[1,2]

Conclusion:

When operating at 2 um, the photodetector has a responsivity of ~70 mA/W and a setup-limited 3 dB bandwidth of >20 GHz. When operating at 1.55 μm, the present photodetector also works very well with a broad 3 dB bandwidth of >40 GHz (setup-limited) and a high responsivity of ~0.4 A/W even with a low bias voltage of −0.3 V.



Structures of the silicon–graphene hybrid plasmonic waveguide photodetector. a Schematic configuration. b Optical microscopy image. c SEM images. d Cross-section of the present silicon–graphene hybrid plasmonic waveguide.

602 Vol. 38, No. 2 / February 2021 / Journal of the Optical Society of America B **Research Article**

Journal of the Optical Society of America B

OPTICAL PHYSICS

Plasmon-enhanced graphene photodetector with CMOS-compatible titanium nitride

MOHAMMED ALALOUL* AND MAHMOUD RASRAS

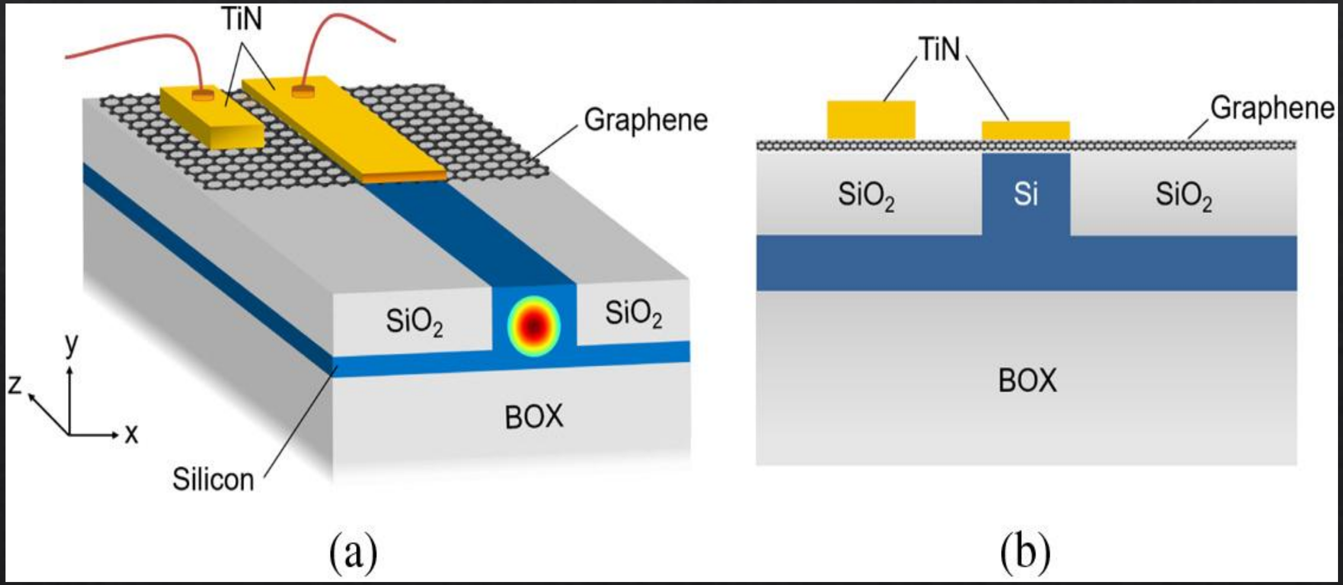
Photonics Research Lab, Department of Electrical and Computer Engineering, New York University Abu Dhabi, Abu Dhabi, United Arab Emirates

**Corresponding author: maa9328@nyu.edu*

Received 1 December 2020; revised 20 December 2020; accepted 26 December 2020; posted 5 January 2021 (Doc. ID 416520); published 1 February 2021

Conclusion:

The device performance is quantified by its responsivity, operation speed, and noise equivalent power. Its bandwidth exceeds 100 GHz, and it exhibits a nearly flat photo response across the telecom C-band. The photodetector responsivity is as high as 1.4 A/W (1.1 A/W external) at an ultra-compact length of 3.5 um, which is the most compact footprint reported for a graphene-based waveguide photodetector.



On-chip photodetector structure. (b) Front view of the photodetector device.

Switch

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Article | Open Access | Published: 22 September 2021

Integrated non-volatile plasmonic switches based on phase-change-materials and their application to plasmonic logic circuits

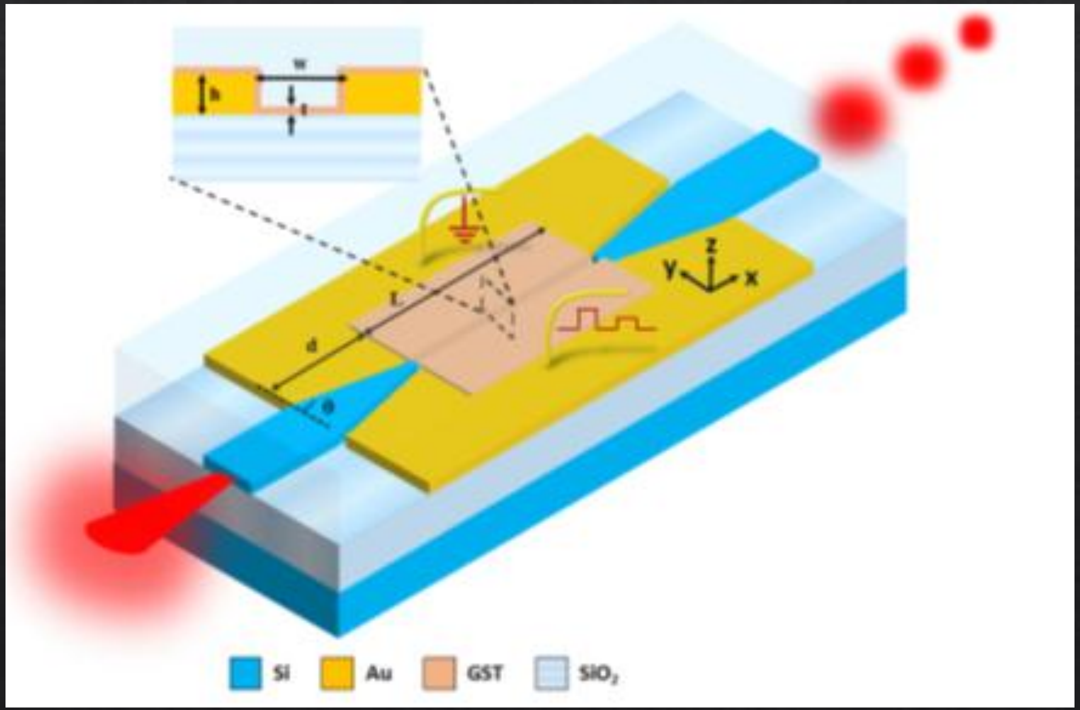
Rajib Ratan Ghosh & Anuj Dhawan

Scientific Reports **11**, Article number: 18811 (2021) | Cite this article

Scientific Reports | (2021) 11:18811 | https://doi.org/10.1038/s41598-021-98418-6

Conclusion:

The proposed switch exhibits excellent performance in several important categories, including large extinction ratio (> 28 dB), high bandwidth (BW > 400 nm), low power consumption, and low footprint



Schematic of the proposed broadband non-volatile hybrid electro-optic plasmonic switch

Modulator

nanomaterials

MDPI

Article

Design of an On-Chip Plasmonic Modulator Based on Hybrid Orthogonal Junctions Using Vanadium Dioxide

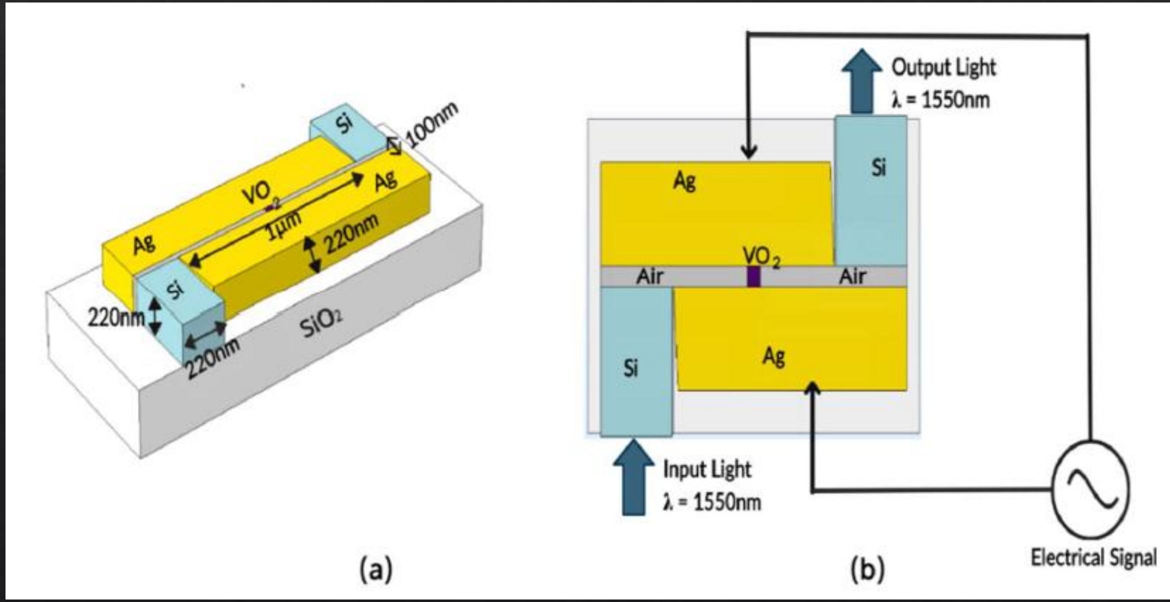
Gregory Beti Tanyi *, Miao Sun, Christina Lim and Ranjith Rajasekharan Unnithan *

Department of Electrical and Electronic Engineering, Faculty of Engineering and Information Technology, The University of Melbourne, Melbourne, VIC 3010, Australia; aussunnysun@gmail.com (M.S.); chrislim@unimelb.edu.au (C.L.)
* Correspondence: gtanyi@student.unimelb.edu.au (G.B.T.); r.ranjith@unimelb.edu.au (R.R.U.); Tel.: +61-3-8344-4733 (R.R.U.)

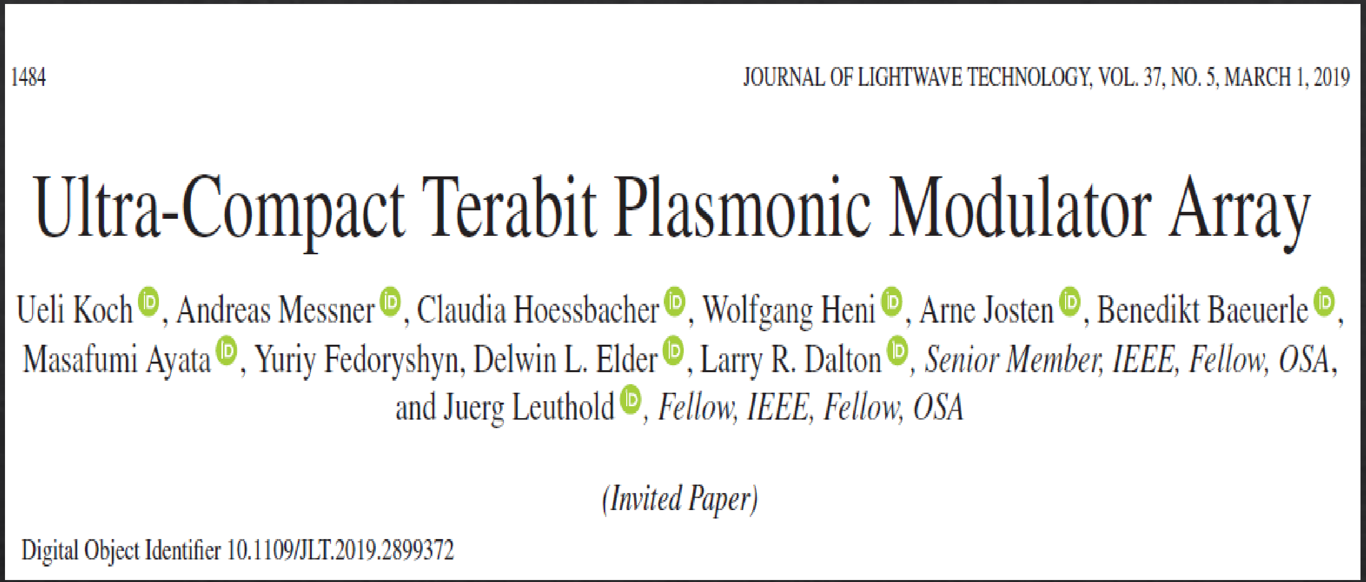
Nanomaterials **2021**, *11*, 2507. https://doi.org/10.3390/nano11102507

Received: 6 September 2021
Accepted: 22 September 2021
Published: 26 September 2021

Conclusion:
The modulator has an footprint of 1.8 um x 1 um with a 100 nm x 100 nm modulating section based on the hybrid orthogonal geometry.



(**a**) Three-dimensional geometry of the plasmonic modulator. (**b**) Two-dimensional geometry of the plasmonic modulator.



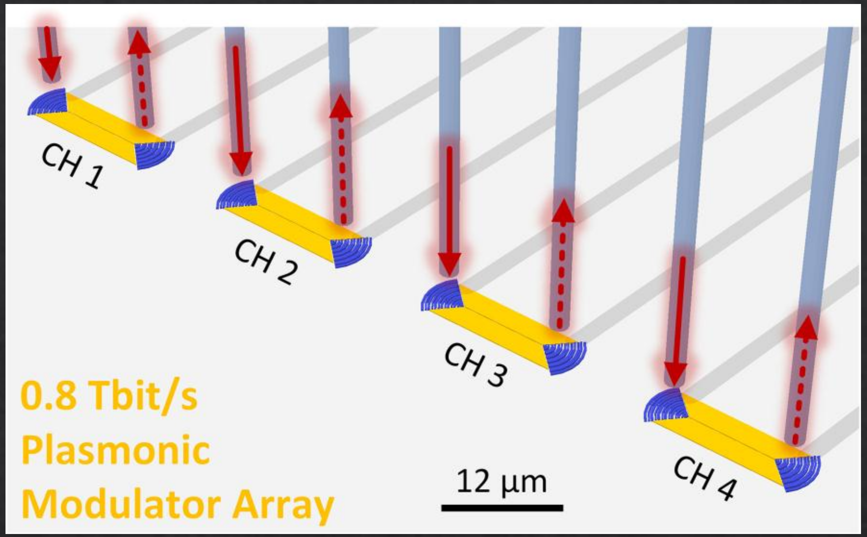
1484 JOURNAL OF LIGHTWAVE TECHNOLOGY, VOL. 37, NO. 5, MARCH 1, 2019

Ultra-Compact Terabit Plasmonic Modulator Array

Ueli Koch, Andreas Messner, Claudia Hoessbacher, Wolfgang Heni, Arne Josten, Benedikt Baeuerle, Masafumi Ayata, Yuriy Fedoryshyn, Delwin L. Elder, Larry R. Dalton, *Senior Member, IEEE, Fellow, OSA*, and Juerg Leuthold, *Fellow, IEEE, Fellow, OSA*

(Invited Paper)

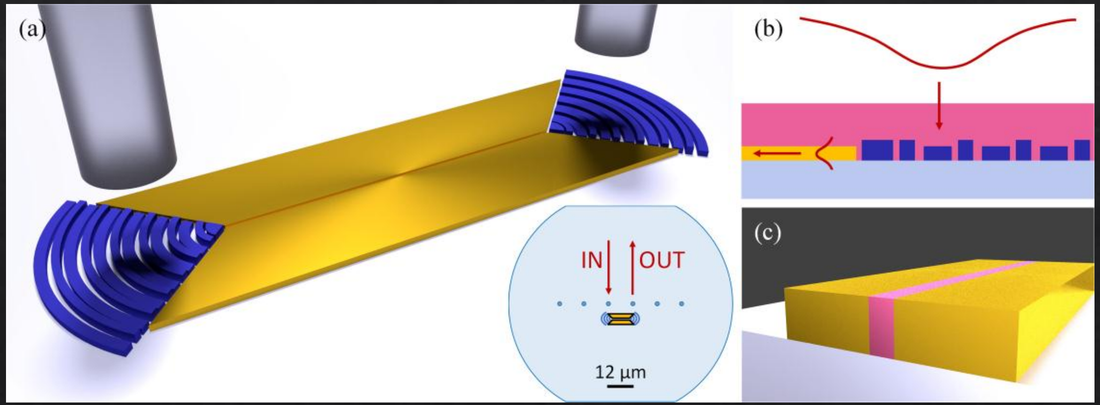
Digital Object Identifier 10.1109/JLT.2019.2899372



3-dimensional rendering of the 4-channel plasmonic modulator array.

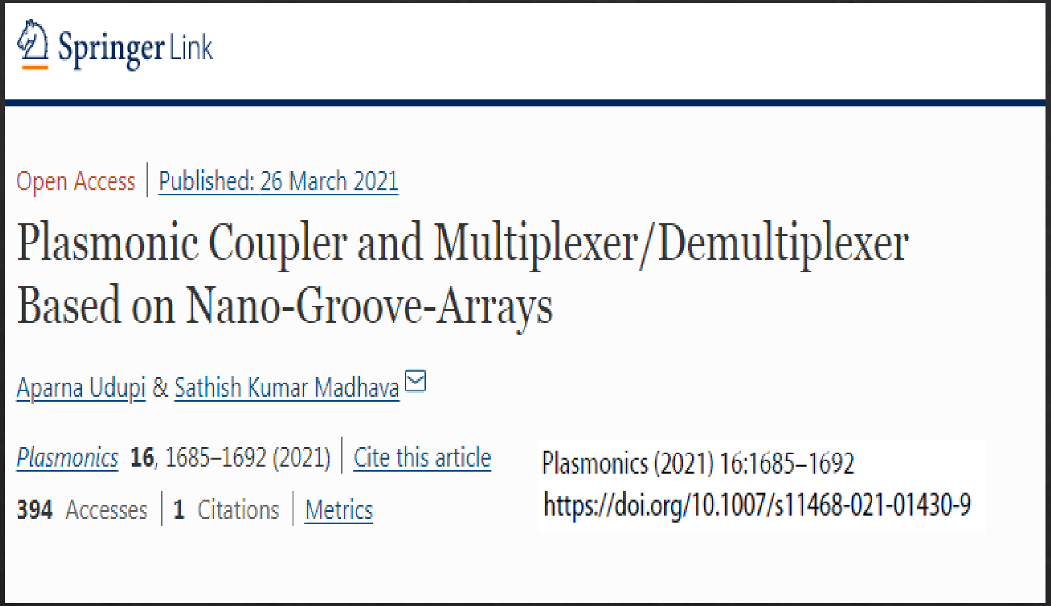
Conclusion:

A new plasmonic transmitter solution offering 0.8 Tbit/s on an ultra-compact 90 um × 5.5 um footprint is introduced. The individual devices achieve data rates of 200 Gbit/s.



(a) 3-dimensional rendering of the plasmonic phase modulator. (b) Cross-section along the device. (c) Cross-section across the plasmonic slot waveguide.

Multiplexer and Demultiplexer



Springer Link

Open Access | Published: 26 March 2021

Plasmonic Coupler and Multiplexer/Demultiplexer Based on Nano-Groove-Arrays

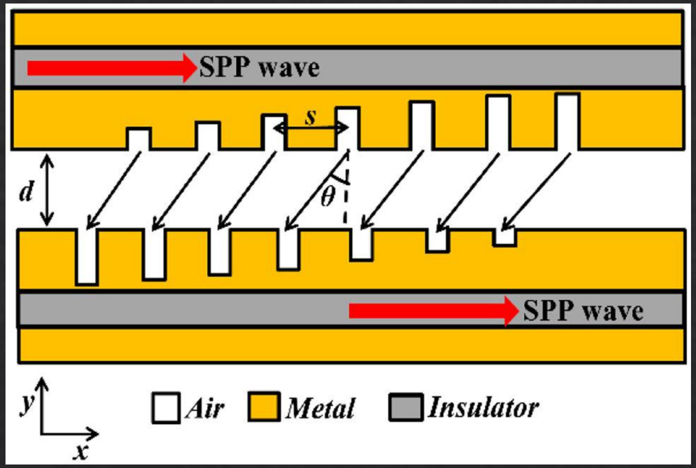
Aparna Udupi & Sathish Kumar Madhava

Plasmonics 16, 1685–1692 (2021) | Cite this article

394 Accesses | 1 Citations | Metrics

Plasmonics (2021) 16:1685–1692

https://doi.org/10.1007/s11468-021-01430-9

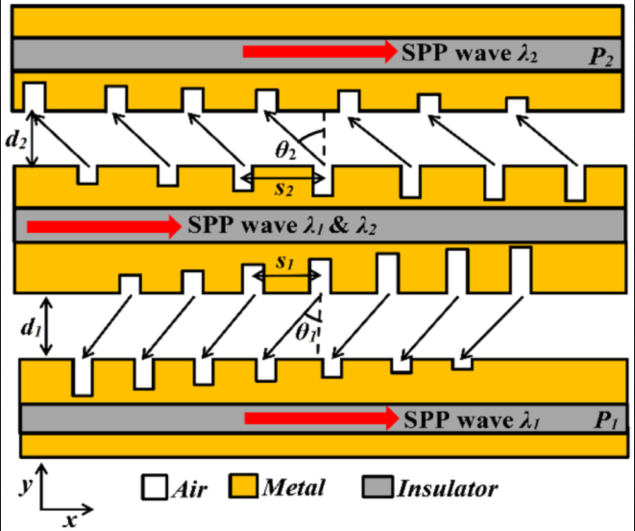


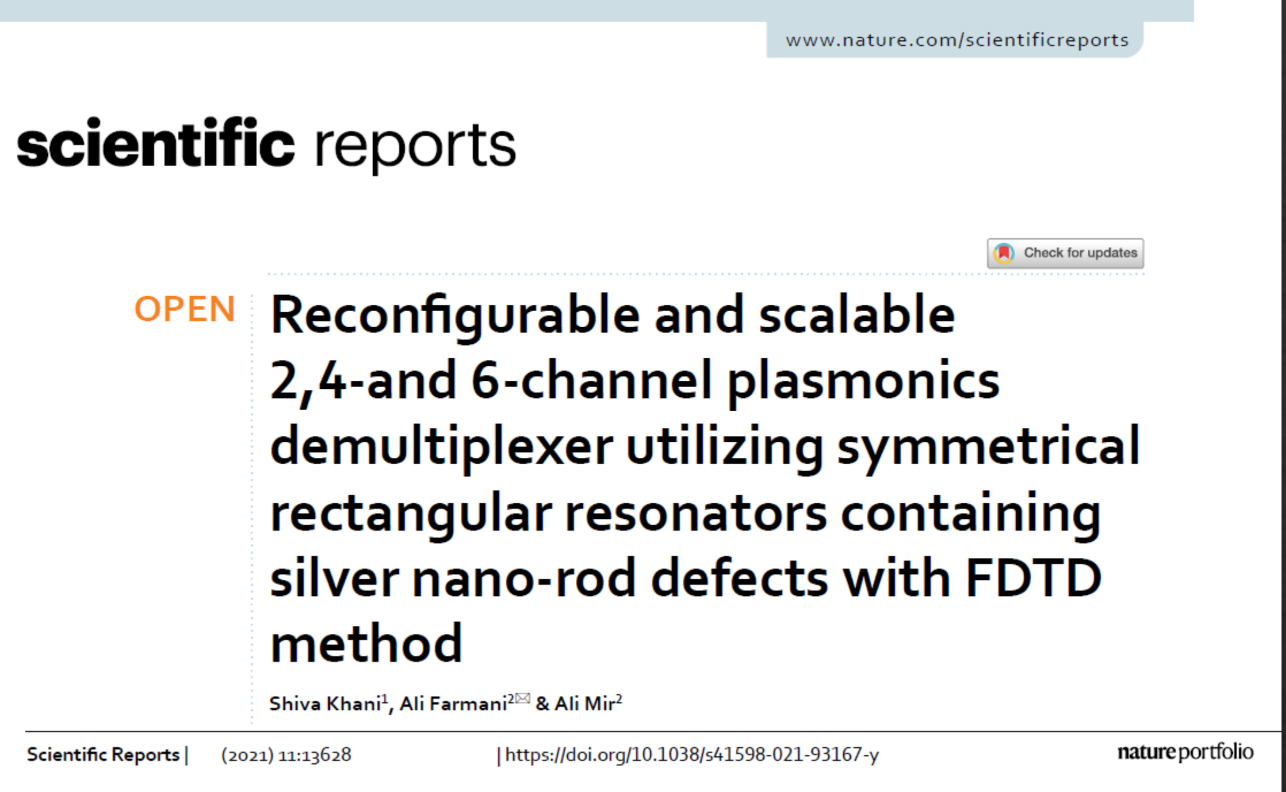
Schematic of the proposed unidirectional coupler

Conclusion:

The 1 × 2 multiplexer/ demultiplexer was simulated for wavelengths of 650 nm and 850 nm. ER > 11 dB at operating wavelength of 650 nm. crosstalk of – 19 dB for a wavelength of 650 nm, and – 18 dB for a wavelength of 850 nm.

Schematic of the proposed multiplexer/demultiplexer





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OPEN

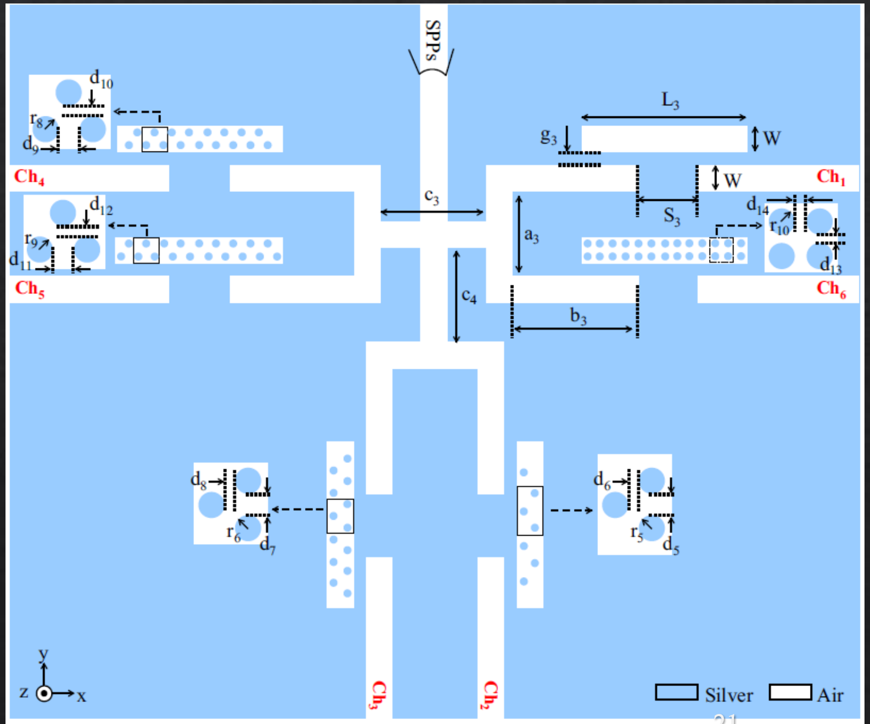
Reconfigurable and scalable 2,4-and 6-channel plasmonics demultiplexer utilizing symmetrical rectangular resonators containing silver nano-rod defects with FDTD method

Shiva Khani[1], Ali Farmani[2]✉ & Ali Mir[2]

Scientific Reports | (2021) 11:13628 | https://doi.org/10.1038/s41598-021-93167-y nature portfolio

Conclusion:

The simulation results, for two, four, and six channel demultiplexer, the maximum transmission values of 56.7%, 54.13%, and 49.62% and the average channel spacing values of 233, 137.33, and 99.6 nm have been obtained, respectively. The simple and compact designed demultiplexer structures are promised for integrated optical circuits.



Schematic of the proposed six-channel demultiplexer.

Memory

Journal of Applied Physics | PERSPECTIVE | scitation.org/journal/jap

A plasmonically enhanced route to faster and more energy-efficient phase-change integrated photonic memory and computing devices

Cite as: J. Appl. Phys. **129**, 110902 (2021); doi: 10.1063/5.0042962
Submitted: 5 January 2021 · Accepted: 28 February 2021 ·
Published Online: 16 March 2021

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E. Gemo,[1] J. Faneca,[1] S. G.-C. Carrillo,[1] A. Baldycheva,[1] W. H. P. Pernice,[2] H. Bhaskaran,[3] and C. D. Wright[1,a)]

AFFILIATIONS

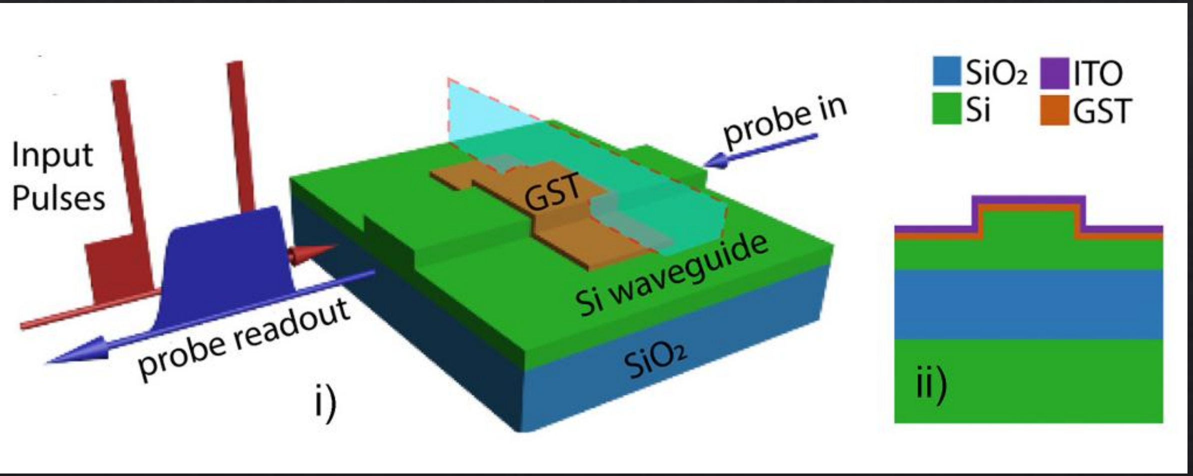
[1]Department of Engineering, University of Exeter, Exeter EX4 4QF, United Kingdom
[2]Department of Physics, University of Münster, Heisenbergstr 11, Münster 48149, Germany
[3]Department of Materials, University of Oxford, Parks Road, Oxford OX1 3PH, United Kingdom

Note: This paper is part of the Special Topic on Plasmonics: Enabling Functionalities with Novel Materials.

[a)]**Author to whom correspondence should be addressed:** david.wright@exeter.ac.uk

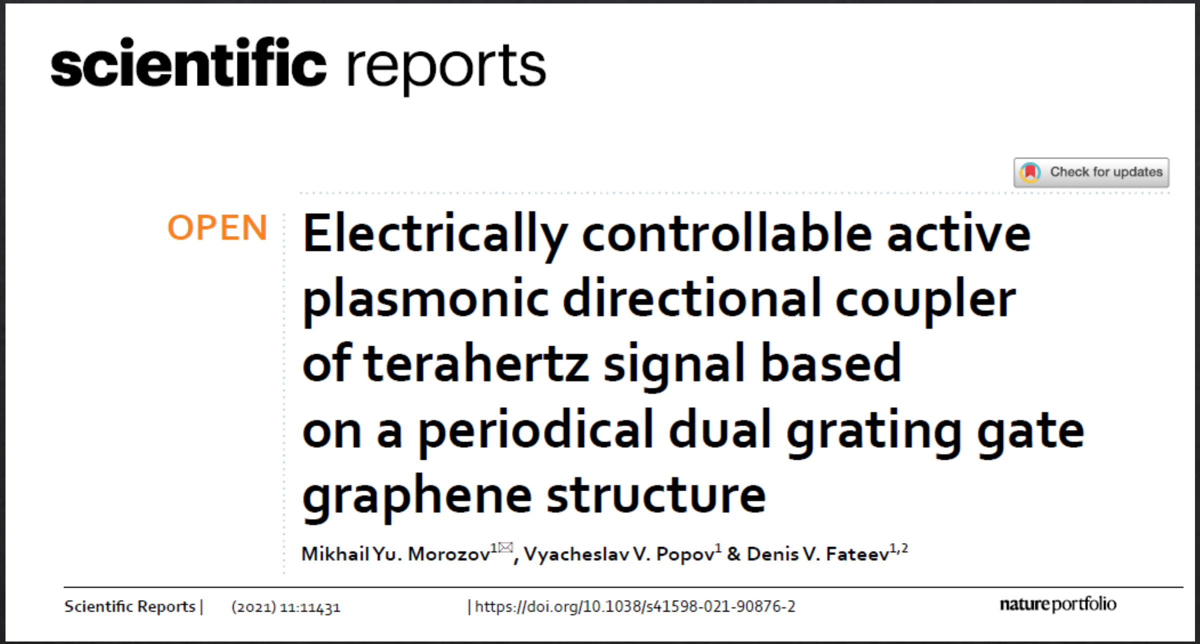
Conclusion:

The integration of phase-change materials and plasmonics into the silicon photonics platform offers a promising route for the development of fast, low-power, integrated photonic memory and computing devices and systems.



3D and 2D device cross section

Directional Coupler


scientific reports

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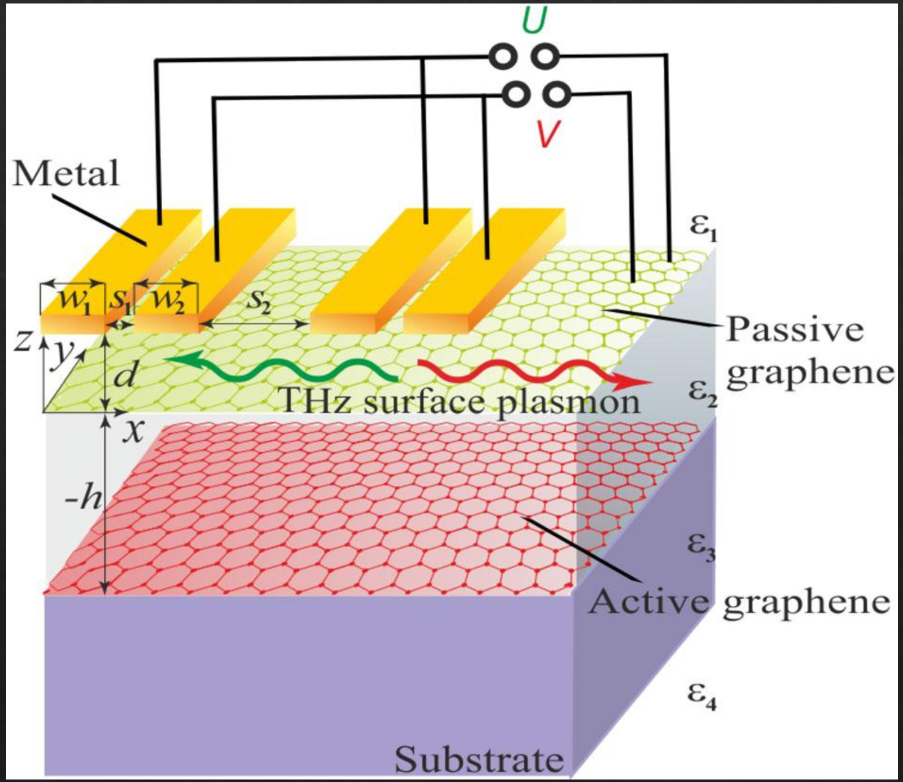
OPEN Electrically controllable active plasmonic directional coupler of terahertz signal based on a periodical dual grating gate graphene structure

Mikhail Yu. Morozov[1✉], Vyacheslav V. Popov[1] & Denis V. Fateev[1,2]

Scientific Reports | (2021) 11:11431 | https://doi.org/10.1038/s41598-021-90876-2

nature portfolio

Conclusion:
a concept of an electrically controllable plasmonic directional coupler of terahertz signal based on a periodical structure with an active (with inversion of the population of free charge carriers) graphene with a dual grating gate and numerically calculate its characteristics had been proposed.



Schematic view of the structure

nature COMMUNICATIONS

ARTICLE

https://doi.org/10.1038/s41467-020-14539-y OPEN

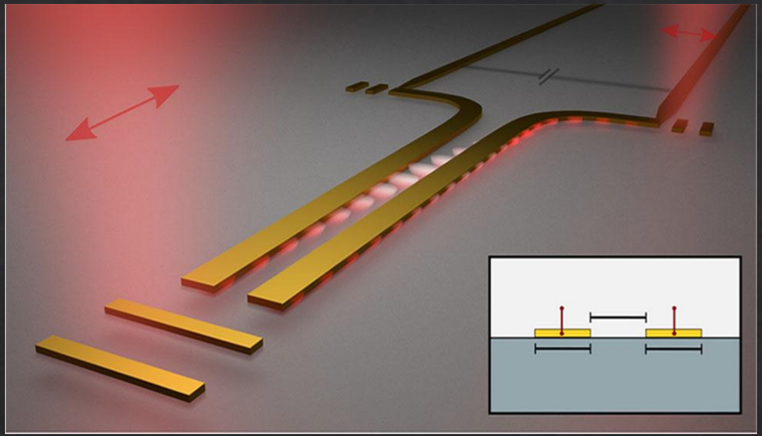
Plasmonic monolithic lithium niobate directional coupler switches

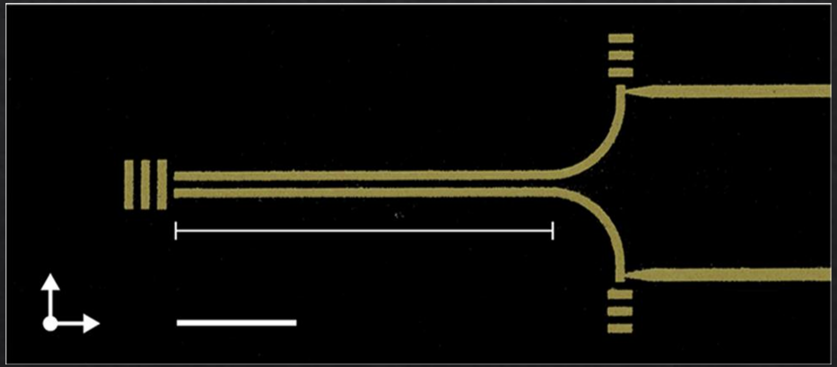
Martin Thomaschewski [1*], Vladimir A. Zenin [1], Christian Wolff [1] & Sergey I. Bozhevolnyi [1*]

NATURE COMMUNICATIONS | (2020)11:748 | https://doi.org/10.1038/s41467-020-14539-y | www.nature.com/naturecommunications

Conclusion:

Extreme confinement allows to achieve a 90% modulation depth with 20 um-long switches characterized by a broadband electro-optic modulation efficiency of 0.3 V cm. The LN plasmonic platform enables a wide range of cost-effective optical communication applications that demand um-scale footprints, ultrafast operation and high environmental stability.





Plasmonic monolithic lithium niobate directional coupler switch.

Thank You

For

Listening