EPIC Online Technology Meeting on Metamaterials and Metalenses:

Tunable metasurfaces and its applications

Junghyun Park

9th of Jan, 2023

Samsung Advanced Institute of Technology (SAIT)

SAMSUNG

Light Detection And Ranging (LiDAR)

- Applications: autonomous driving, improving AR/VR, gesture sensing…
- Approaches
  - Non-scanning (flash LiDAR)
  - Scanning
    - Mechanical (MEMS, rotating mirror, Risley prism…)
    - Non-mechanical (electro-optic, OPA)

Improving AR/VR

Image from https://propakistani.pk/2019/08/24/samsung-launches-a-3d-scanning-app-for-the-galaxy-note-10/

Autonomous driving

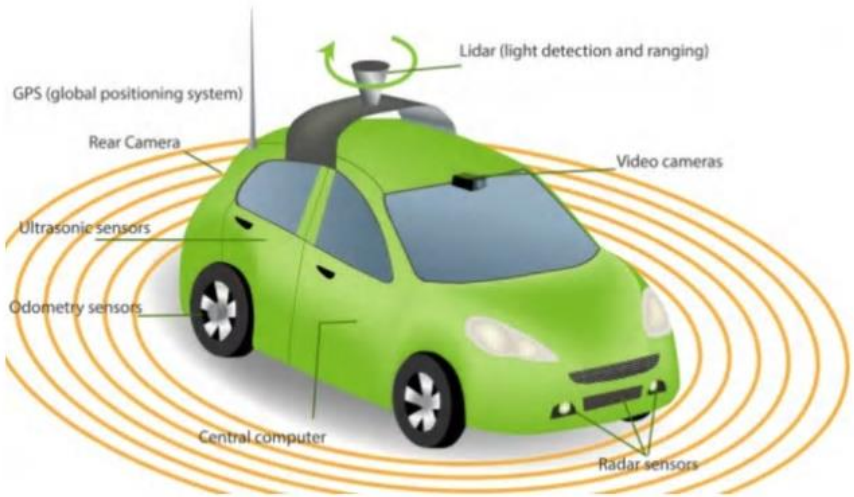
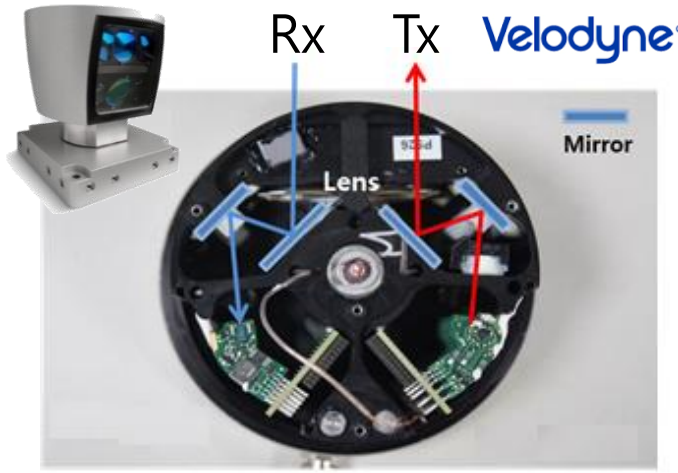


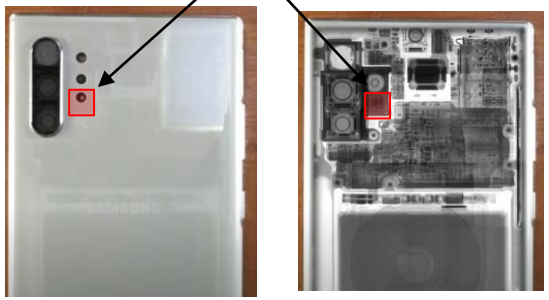
Image from https://www.engineering.com/IOT/ArticleID/18285/How-Sensors-Empower-Autonomous-Driving.aspx



HDL-64E

Size	25.4cm(h), 20.3cm(d)
Price	$75,000

LiDAR in mobiles

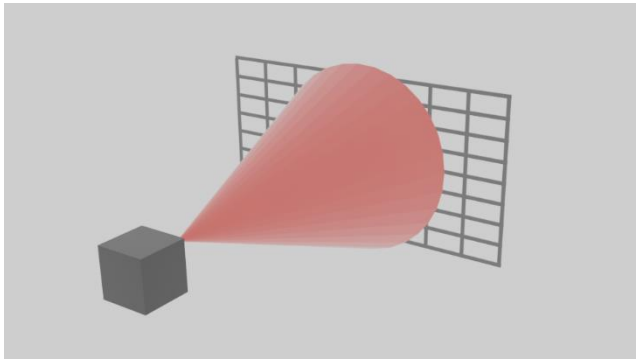
	flash	spot array	scanning
indirect ToF	Galaxy Note 10+ (Sep. 2019) ToF sensor (Samsung 33D) 		
direct ToF		iPhone 12Pro (Oct. 2020) 	

LiDAR → 3D = θ_x + θ_y + z

	flash	spot array	scanning
indirect ToF	How to achieve the information for (θ_x, θ_y)		
direct ToF	How to extract the distance information (z)		

Approaches for $\theta_x + \theta_y$

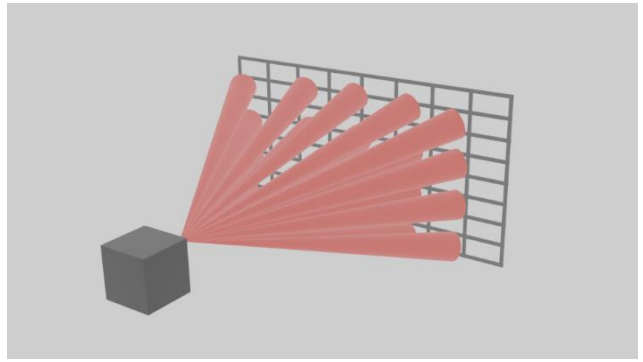
	flash	spot array	scanning



Principle: whole area illumination

Pros: high resolution

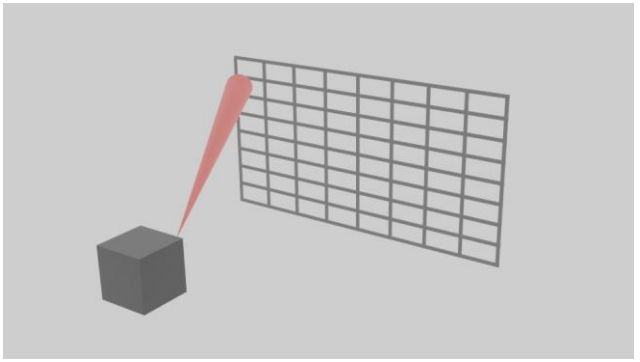
Cons: short distance ($1/z^2$ intensity decrease)



Principle: DOE-based spots

Prons: long distance compared to Flash

Cons: low resoluation (8x8 or 24×24)

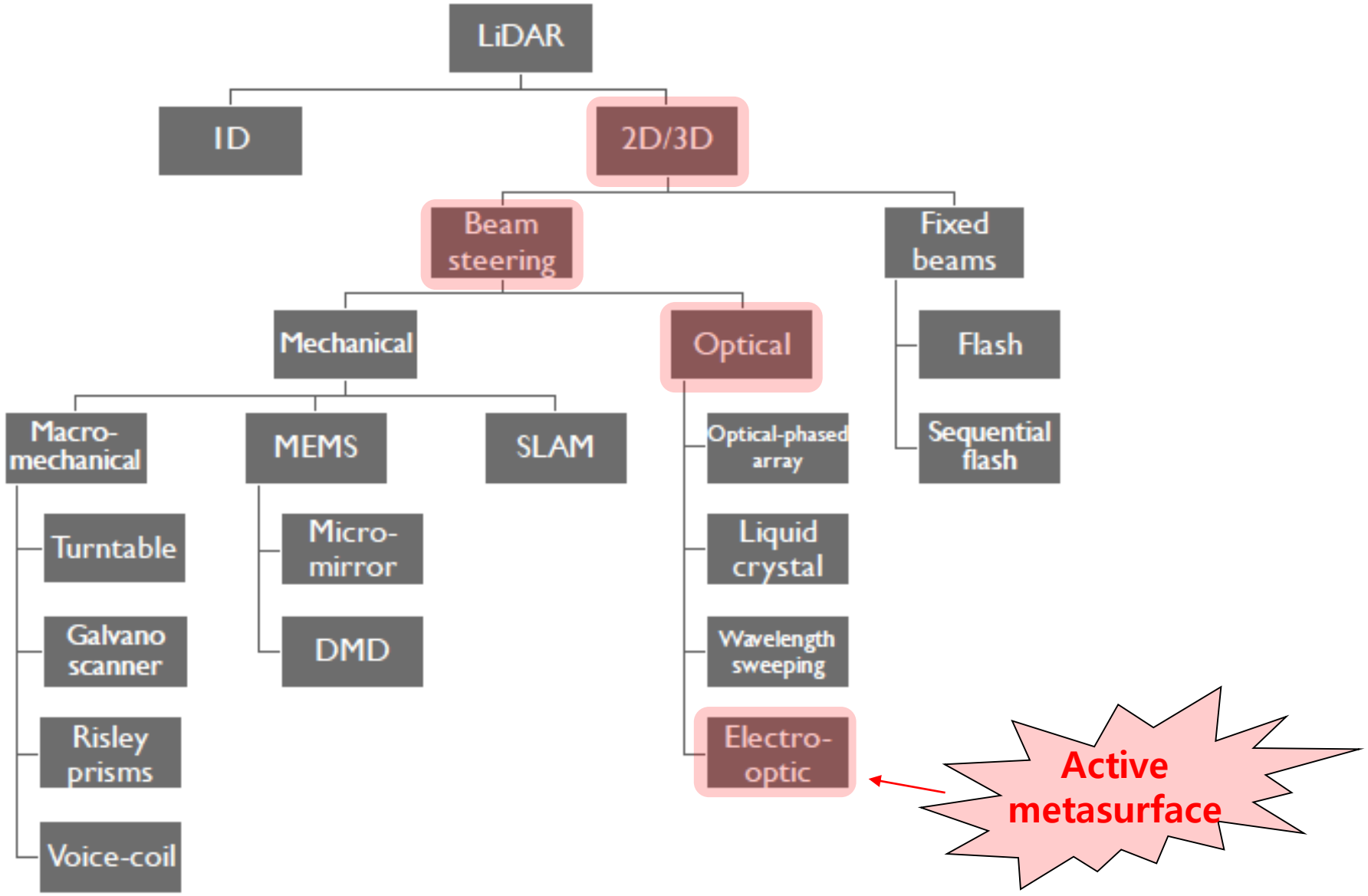


Principle: raster scanning for each scan point

Pros: Unit cell detector available (SiPM)
long distance (v.s. flash, spot)
high resolution

Issue: do we have good beam scanners?

When LiDAR meets the active metasurface…

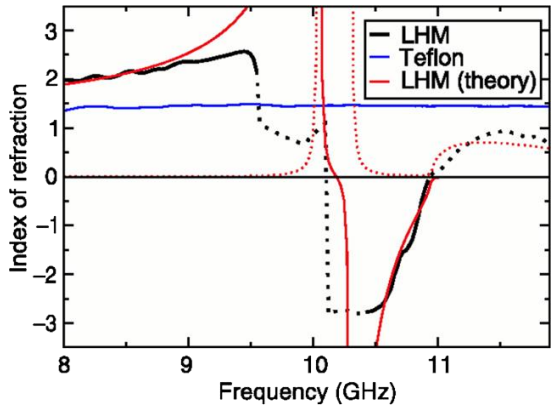


Yole, "LiDAR for Automotive and Industrial Applications 2020"

Metamaterials and metasurfaces

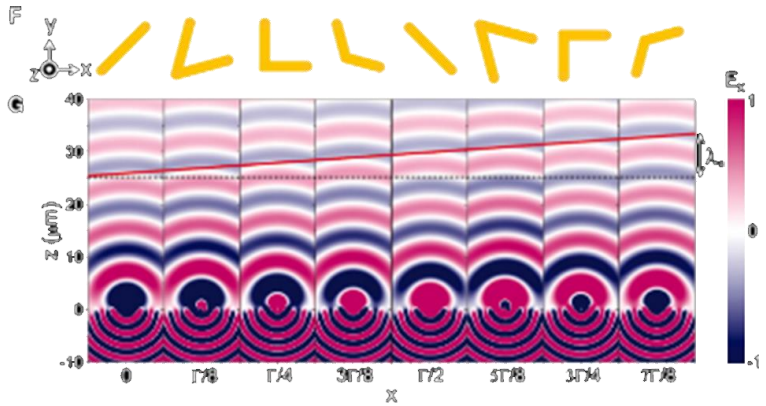
SAIT

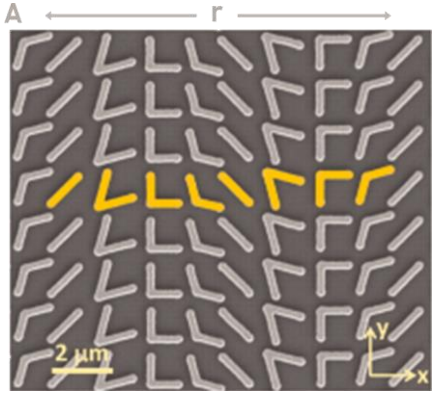
Metamaterials artificial material with properties unobtainable in nature



Negative refraction
Science 292, 77 (2001)

Metasurfaces arbitrary control of optical properties at the sub-λ scale



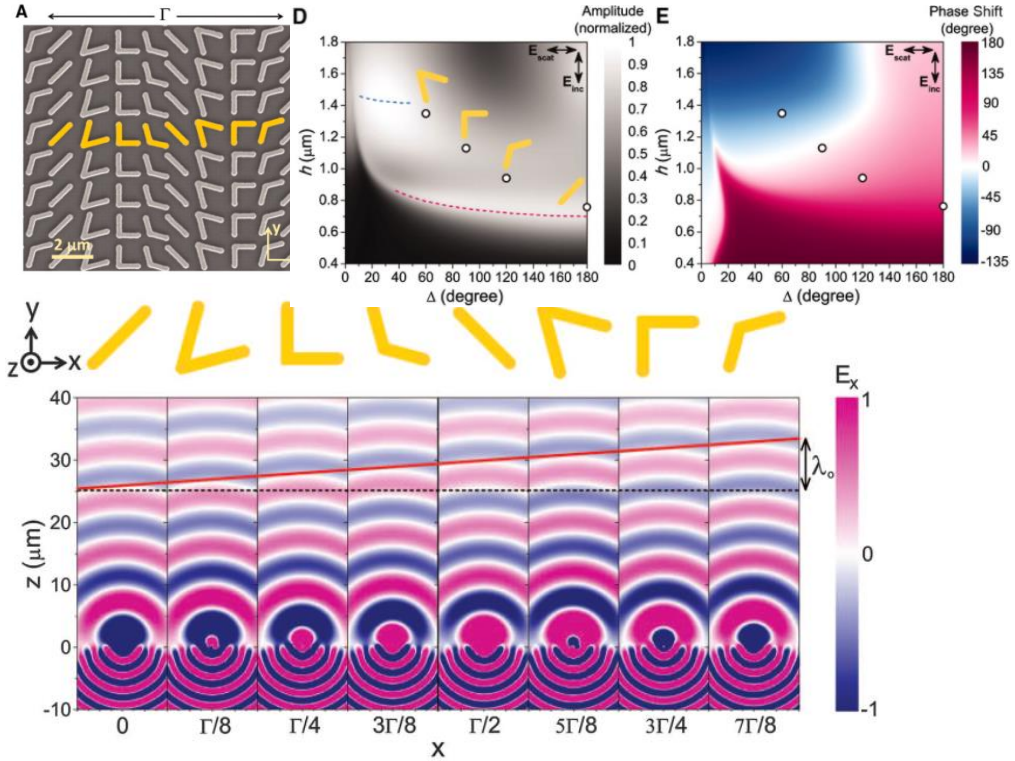


Generalized laws of
reflection and refraction
Science 334, 333 (2011)

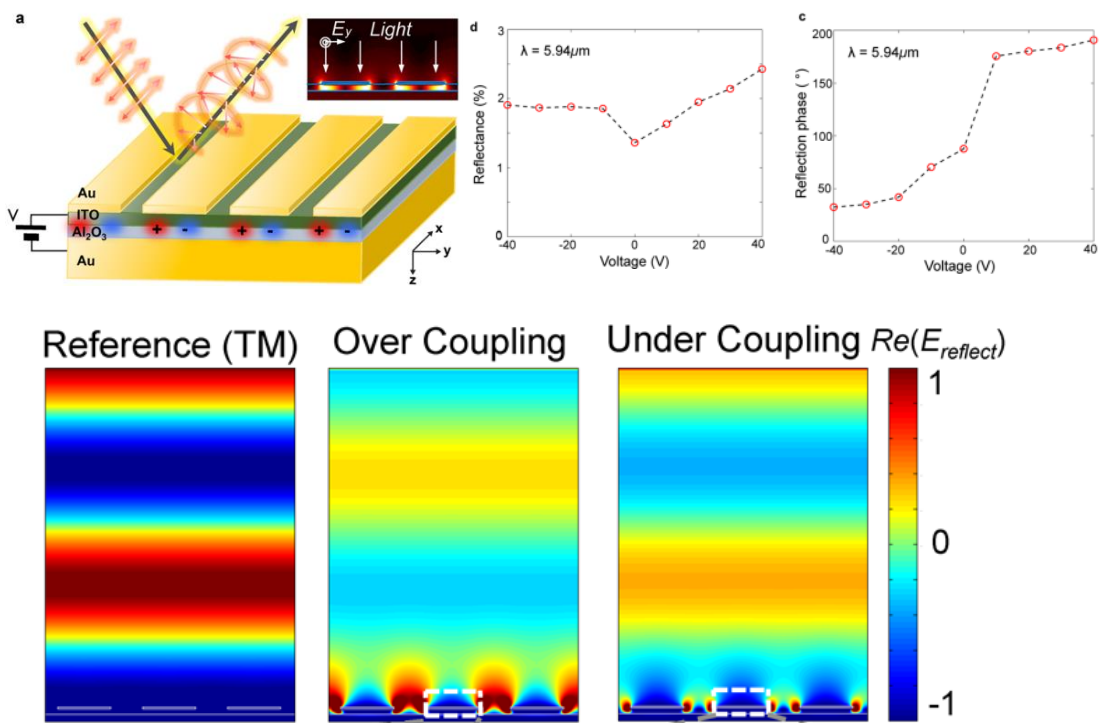
Passive v.s. active metasurfaces

- Passive metasurface: change of size or shape to assign spatial variance
- Active metasurface: change of control signal for spatio-temporal functions

  (≒ tunable, reconfigurable, time-varying, post-fabrication tuning)



Science 334, 333 (2011).



Nano Lett. 17, 407 (2017).

Indium Tin Oxide as a gate-tunable material

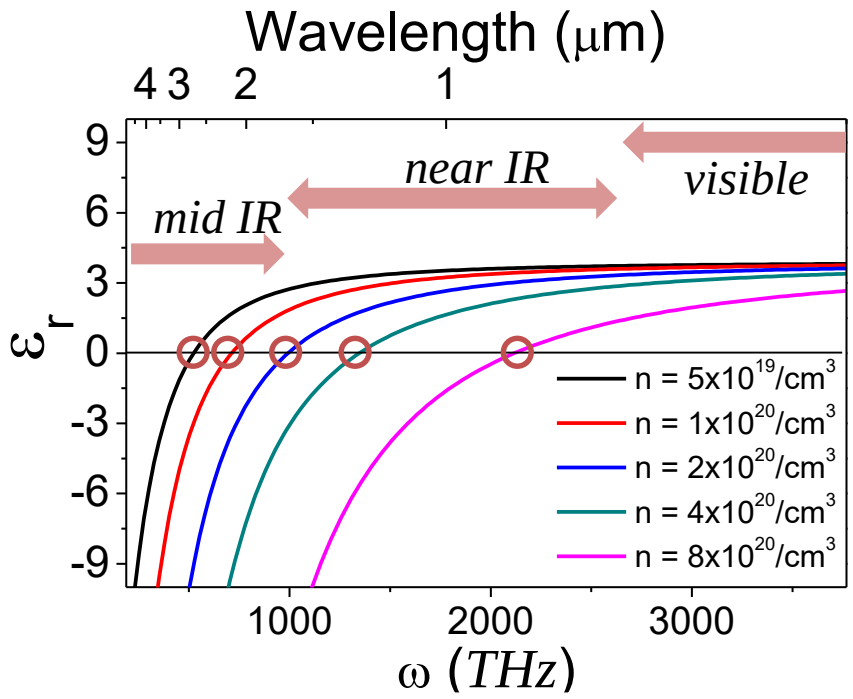
- Carrier density can be controlled by accumulation and depletion of charges.
- Plasma frequency is widely tunable with carrier concentration.
- Gate-tuning allows for an ultrafast modulation with a low switching energy.

Drude's model

$$\varepsilon = \varepsilon_\infty - \frac{\omega_p^{\,2}}{\omega^2 + i\Gamma\omega}$$

$$\omega_p^{\,2} = \frac{ne^2}{\varepsilon_0 m^*}$$

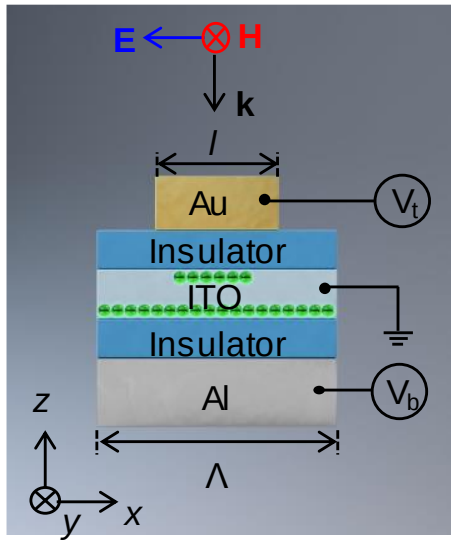
ε: dielectric constant
ε_∞: infinite-frequency permittivity
ω_p: plasma frequency
ω: angular frequency
Γ: scattering frequency
n: carrier density
e: electron charge
m^*: electron effective mass



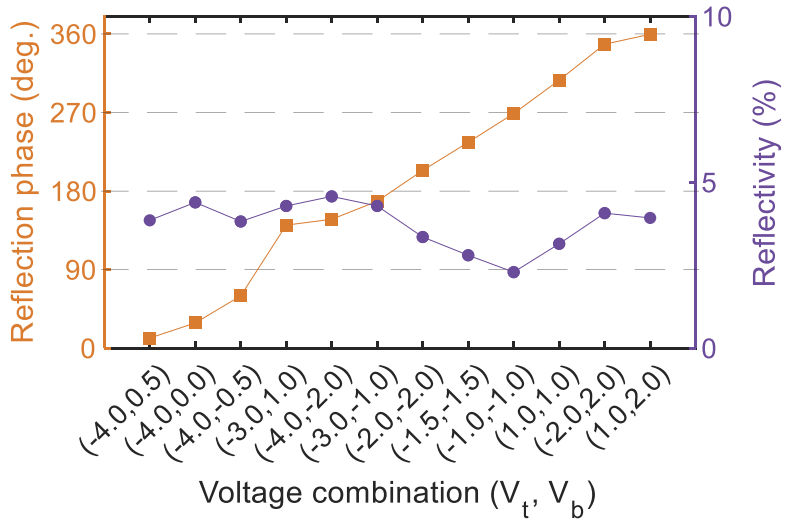
Two control parameters enable complex modulation

- By separately adjusting top and bottom gates (V_t, V_b), we can represent all desired complex reflection coefficient.
- Constant-amplitude and 360°-phase change allow highly directional dynamic beam steering.

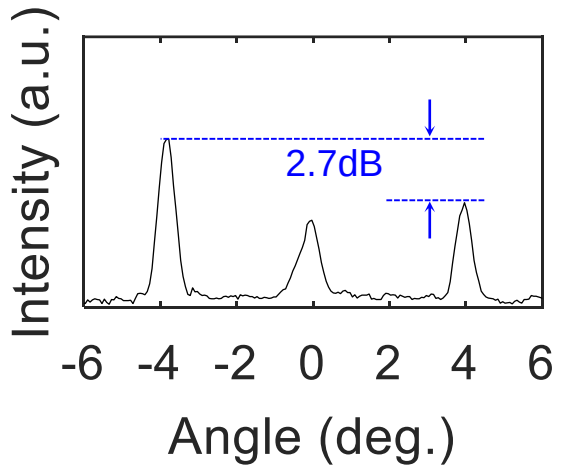
ITO layer inside plasmonic nano-resonator



$\Delta\varphi = 360°$
$\varphi \sim R$ decoupled



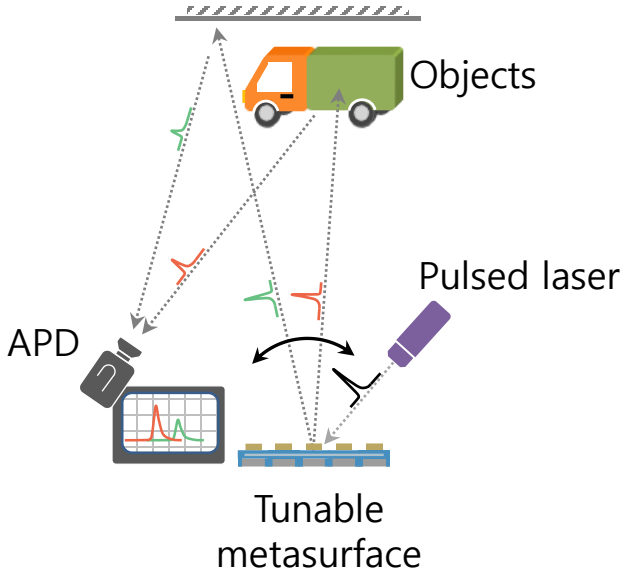
$\eta_{1st} > \eta_{0th}$



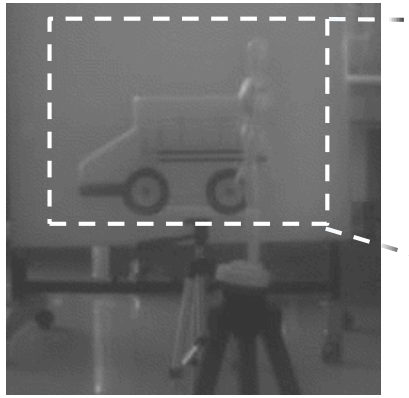
Solid state beam steering for LiDAR application

- Beam steering + ToF ☞ depth image
- Tx: metasurface + pulse laser (repetition rate 10 kHz, pulse width 10 ns)
- Rx: Avalanche photodetector (APD) array (16×5) with sensitivity 2.5 A/W
- Field of view: 6° (H), resolution 0.2° (H), detection range: ~5 m

Schematic of LiDAR

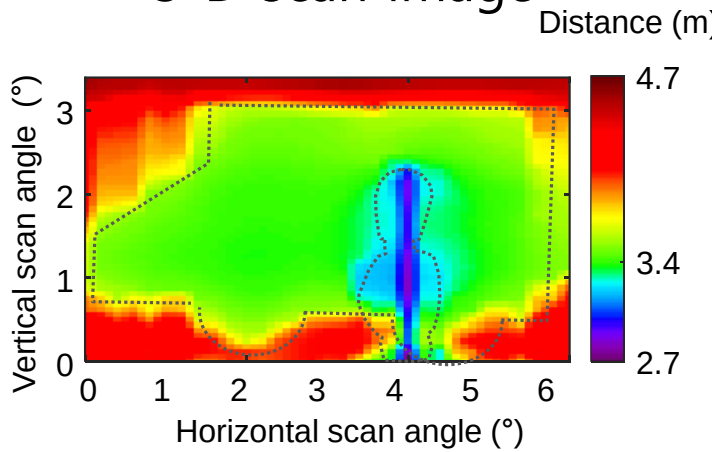


Beam scanning movie



Scan region

3-D scan image



* Vertical scanning done by mechanical tilting

J. Park et al., "All-solid-state spatial light modulator with independent phase and amplitude control for three-dimensional LiDAR applications," Nature Nanotechnol. 16, 69 (2021).

ToF: **T**ime **o**f **F**light Tx: Transmitter Rx: Receiver