جہانِ تازہ کی افکارِ تازہ سے ہے نمود
کہ سنگ و خشت سے ہوتے نہیں جہاں پیدا
(اقبالؒ)

Meta/Flat-Optics: Enabling Novel Science and Applications

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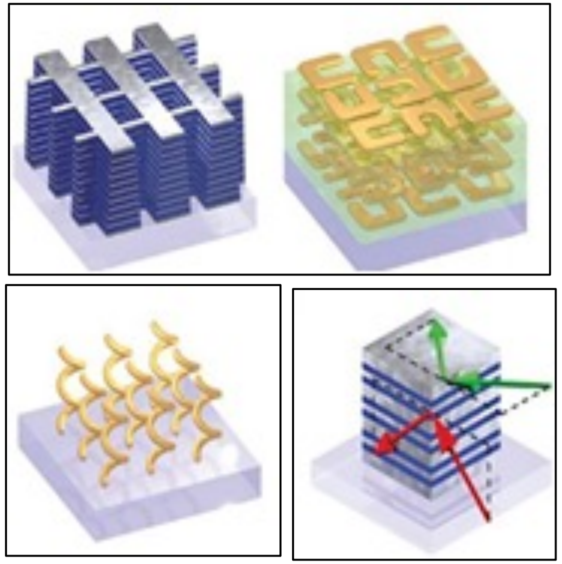
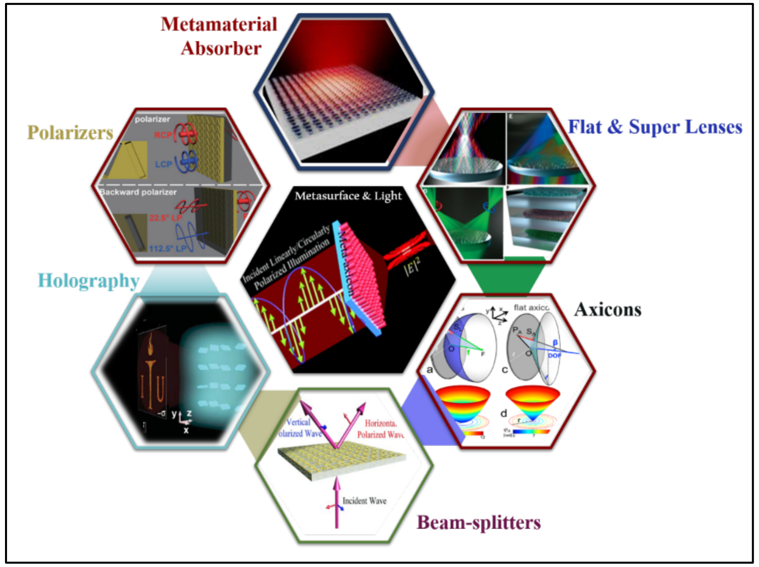
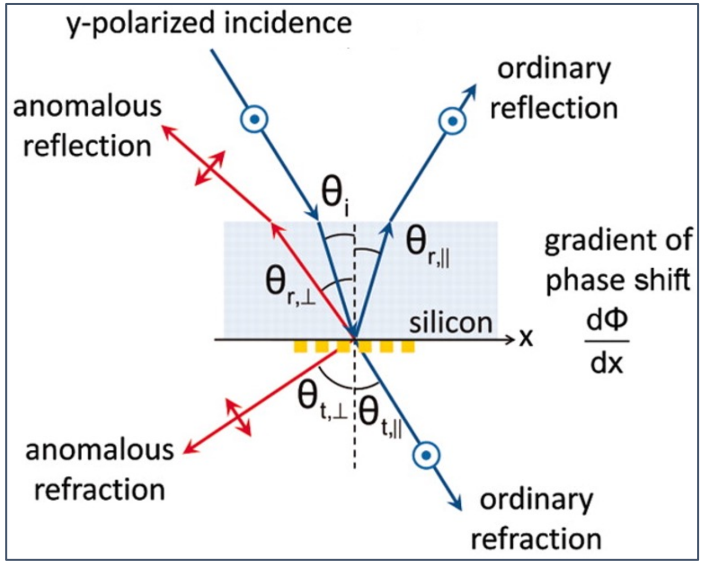
Metasurfaces/Meta-devices: Meta-optics/Flat Optics

- Metasurfaces can be considered as the **planner/two-dimensional equivalent** of bulk metamaterials.
- The effective permittivity, permeability, and refractive index are of less interest in metasurfaces.
- In contrast, the **interface reflection and transmission** resulting **from the tailored surface** impedance, including their amplitude, phase, and polarization states are of significant importance.







Optical Components

Optical Components

Optical Components

Optical Components:

i. Lenses & Assemblies

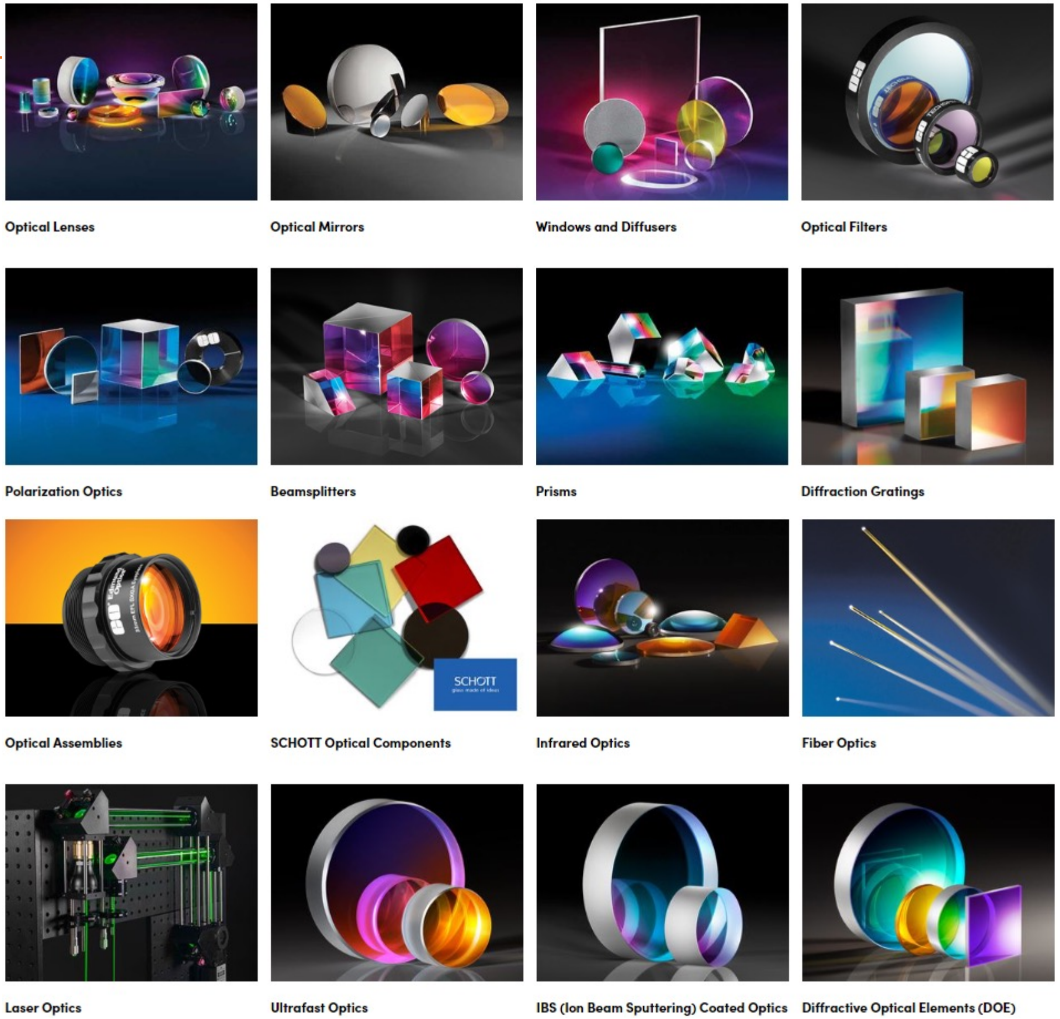
ii. Mirrors

iii. Prisms

iv. Coatings (not a component; but used on different components to improve their functionalities)

And many more

They **can be combined** into **higher functioning assemblies**.



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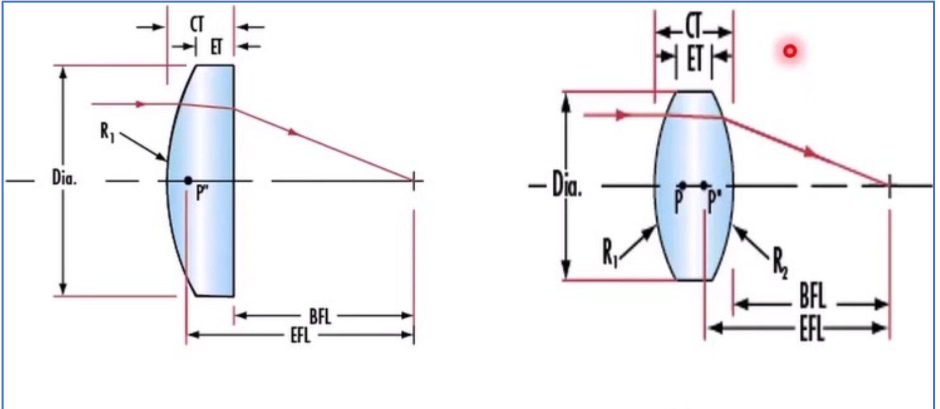
Optical Comments

Optical Components → Lenses

Lens geometries: Lenses come in many **<u>different shapes and sizes</u>**; each geometry **<u>uniquely performing a different manipulation of light</u>**.

Convex Lenses:

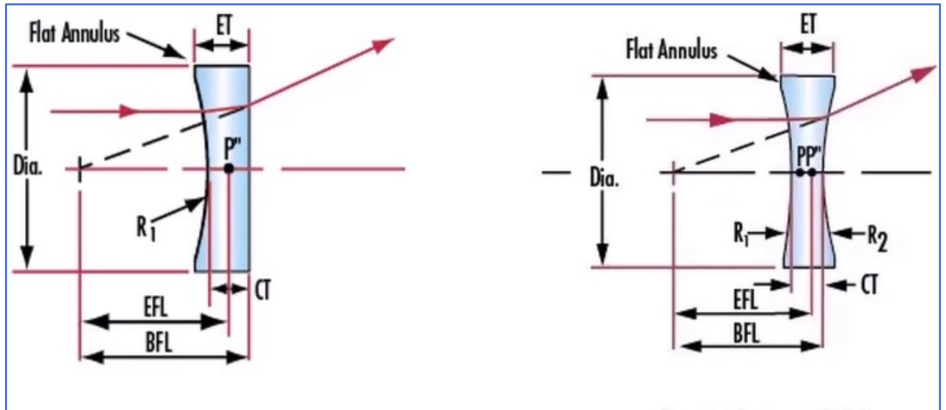
- They **<u>are converging (or positive)</u>** lenses, thicker in the center and thinner by the edges, which **<u>focus a collimated (parallel light) to a single spot</u>** known as the focal point.
- They may create images with different combinations of magnification, image location, up righted-ness, and image type.



Plano-convex (PCX) Double Convex (DCX)

Concave Lenses:

- They are **<u>diverging (or negative) lenses</u>**, thinner in the center and thicker by the edges, which **<u>disperses passing beams</u>**.
- They create a smaller virtual image on the same sides of the lens on which throughput is entered.
- They create upright, minified, virtual images, while a convex lens



Plano-concave (PCV) Double Concave (DCV)

Optical Components → Lenses

- ***An Imaging Lenses:*** They are also known as the **machine vision lenses, objective lenses or objectives**.
- An objective lens (the lens that gather light directly from the object) is usually **made up of a group of lenses** that **work together** to produce the **desired imaging parameters**.

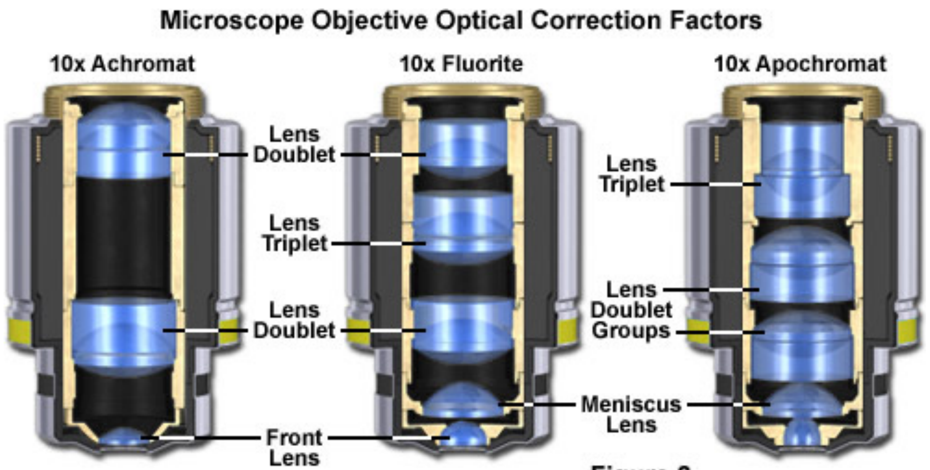


Figure 2

Microscope Objective Correction for Optical Aberration

Objective Specification	Spherical Aberration	Chromatic Aberration	Field Curvature
Achromat	1 Color	2 Colors	No
Plan Achromat	1 Color	2 Colors	Yes
Fluorite	2-3 Colors	2-3 Colors	No
Plan Fluorite	3-4 Colors	2-4 Colors	Yes
Plan Apochromat	3-4 Colors	4-5 Colors	Yes

https://zeiss-campus.magnet.fsu.edu/articles/basics/objectives.html

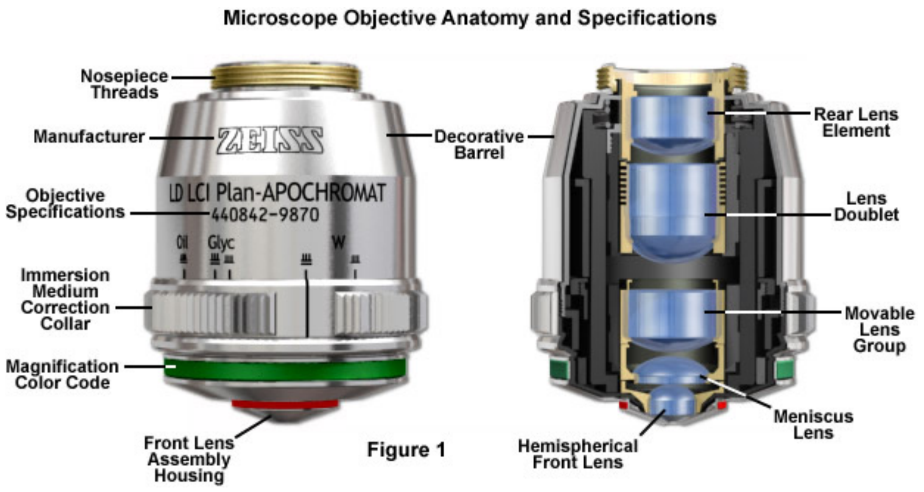
Optical Systems

Optics: Optical Systems

Optical Systems

Fundamental Parameters of Optical Systems:

- Optical **design is a complex process**, there are **both** considerations of the **optical parameters** of the system as well as the **practical considerations** such as the lens **housing and control mechanism**.



Optical Systems

Optical Systems:

There are mainly **two types** of optical systems

- ***i) Imaging Systems:*** Any optical system whose **main goal** is to **transfer an image to a detector**.
  - ✓ **Examples:** Cameras, Human Eye, Microscope Objectives, Lens Assemblies etc.
- ***Ii) Non-imaging Systems:*** All other forms of optical systems. They **collect, disperse, resize, focus or collimate light**.
  - ✓ **Examples:** Lasers, illumination, Projectors etc.

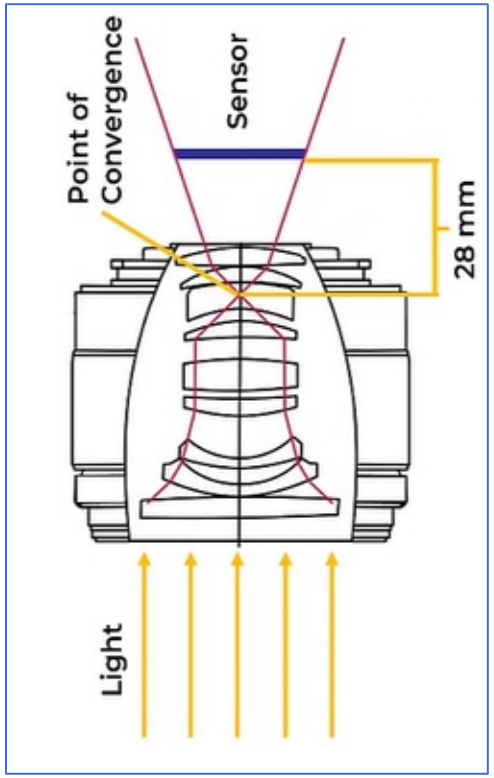
Before beginning various any project, you will **need to determine** which **type of optical system** is **best fit for your application**.

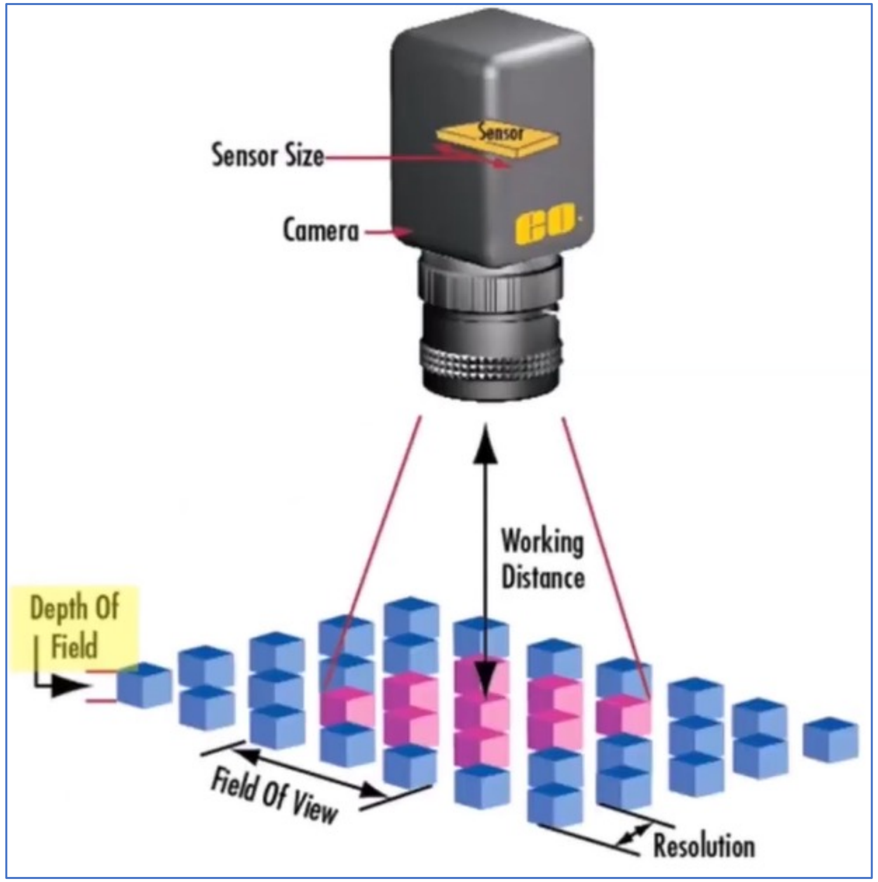
Optical Systems → Imaging Systems

i) Imaging System: Camera:

One of the **most familiar imaging system** is a simple **camera**. How it works?

- ✓ **Light from the object** to be imaged **enters the lenses**.
- ✓ **Assembly of lens elements** manipulates the incident light and **focus it on a detector** (film, digital sensors etc.).
- ✓ Then, **photos are developed** through various processes.





Optical Systems → Non-imaging Systems

ii) Non-imaging Systems:

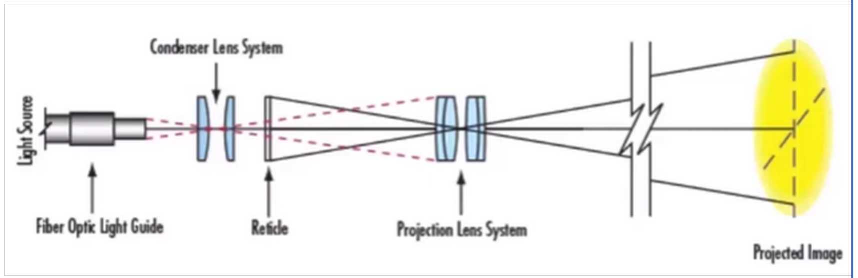
- **Laser Systems**:
  - ✓ Materials processing,
  - ✓ Medical lasers,
  - ✓ Sensing,
  - ✓ Direct energy.
- **Illumination Systems**:
  - Projectors
  - Automotive headlamps.

Laser System for Material Processing:

- Mirrors, lenses, beam expanders, and other optics assemblies **manipulate and direct lasers** onto material to **cut, weld, mask or engrave** (i.e., laser cutting).
- Designed for certain focused spot size, laser power and wavelength to achieve desired results.

Projectors:

- Basic **projection lens system collect light** from the divergent light source.
- Sends out the light for desired working distance and projected image size.
- Unlike an imaging system, **light is not focused to a point**.



Meta/Flat Optics

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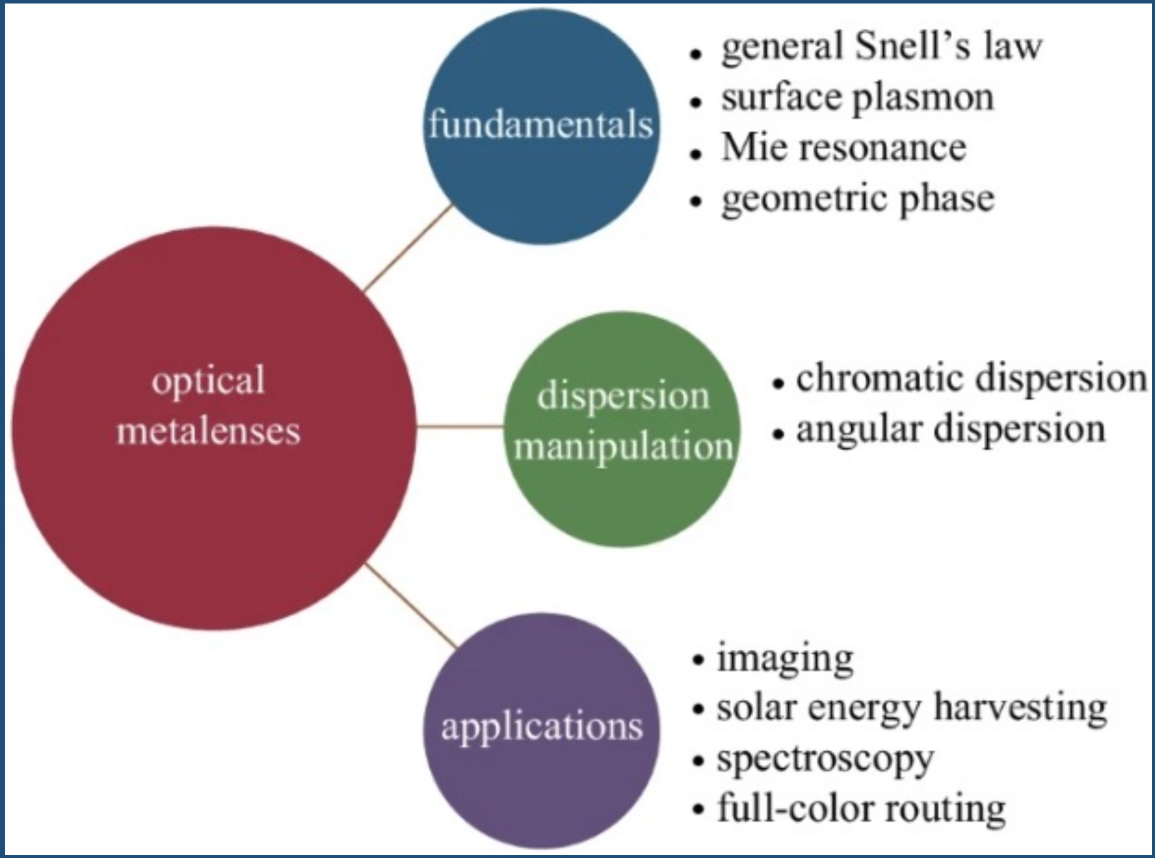
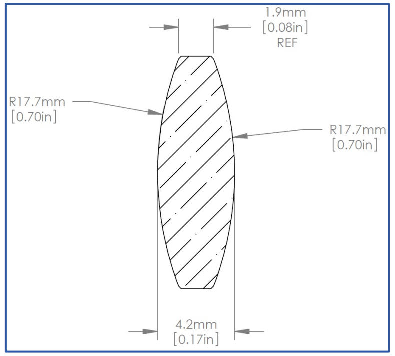


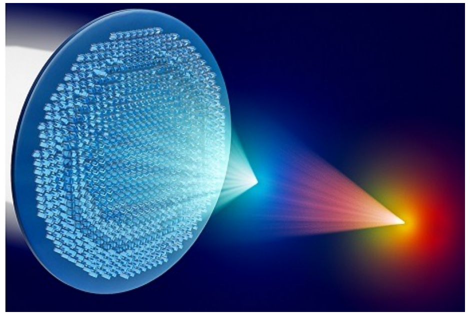
Meta/Flat-optics

Meta/Flat-optics → Promise to Ultra-compact Optical Systems

Conventional Optics to Meta-optics

LB4854-A





$T = 4.2\,mm \approx 8400\,\lambda \approx \mathbf{10^4\lambda}$

$T \approx \lambda$

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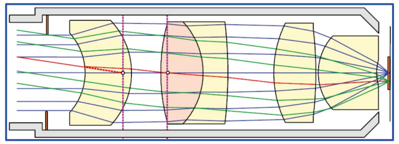
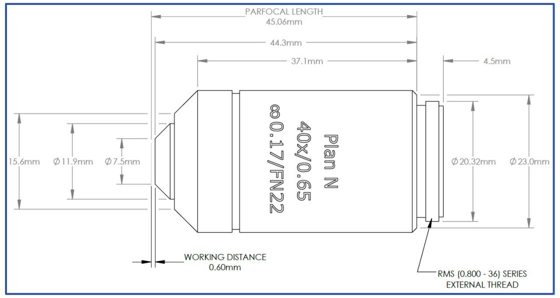


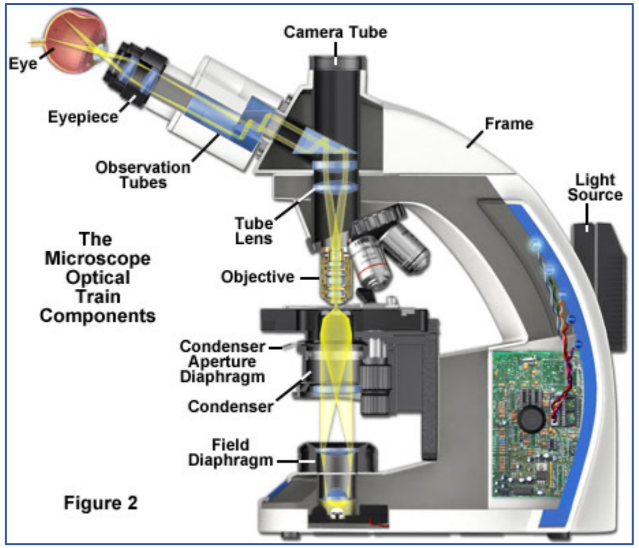
Simillry story for all convtional optical devices

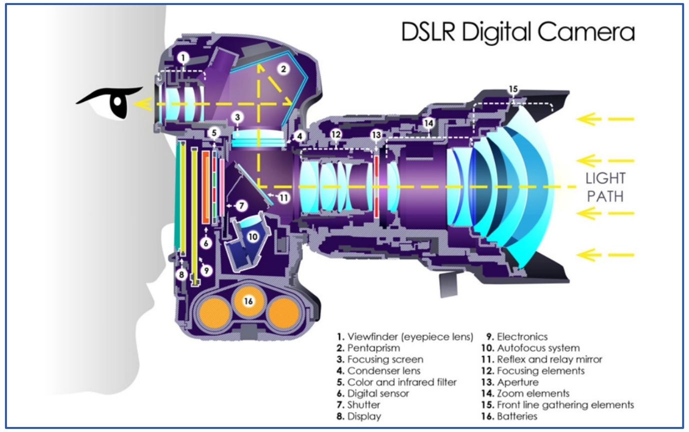


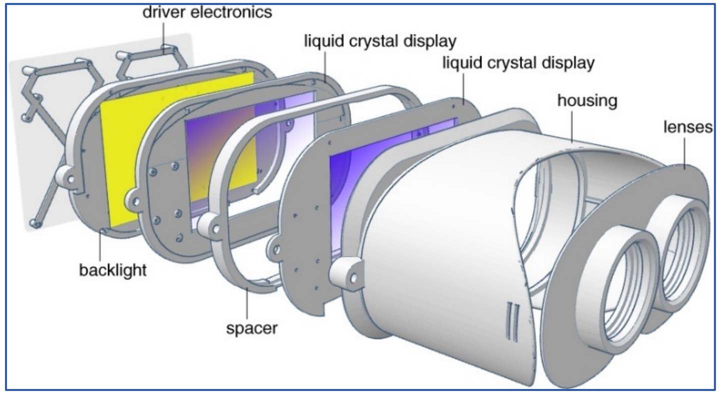
$T = 45.06\,mm \approx 90120\,\lambda \approx \mathbf{10^5\lambda}$

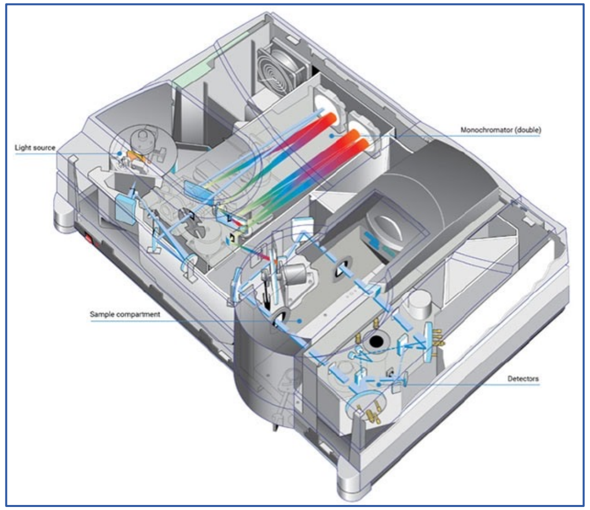
$T \approx \lambda$

Conventional Optical Systems: Bulky with large footprint





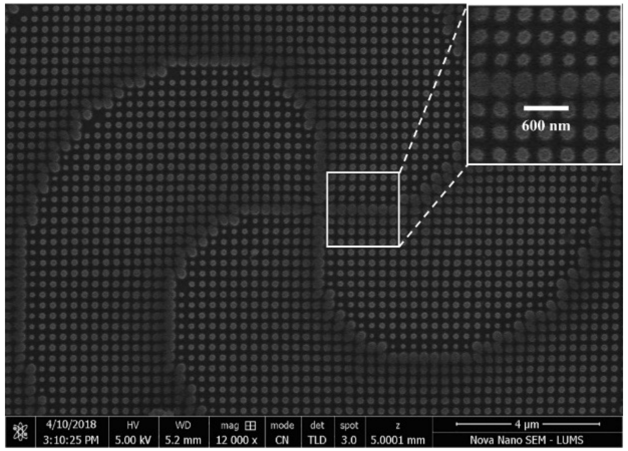




Meta/Flat-Optics → Entry to Industry

***Meta-optics** have the **potential to revolutionize optical products** by **replacing bulky curved** optical elements with **thin, flat surfaces**.*

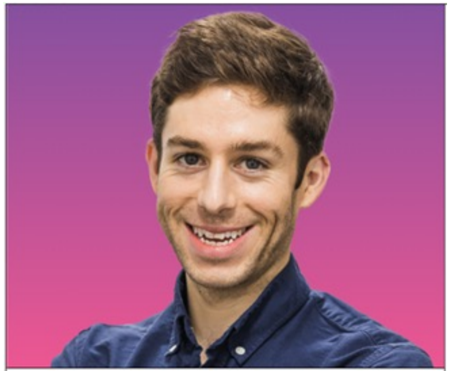
*Metalenses are a **key enabling technology** for the **next generation of compact imaging, sensing, and display** applications*



Meta/Flat-Optics → Entry to Industry

metalenz

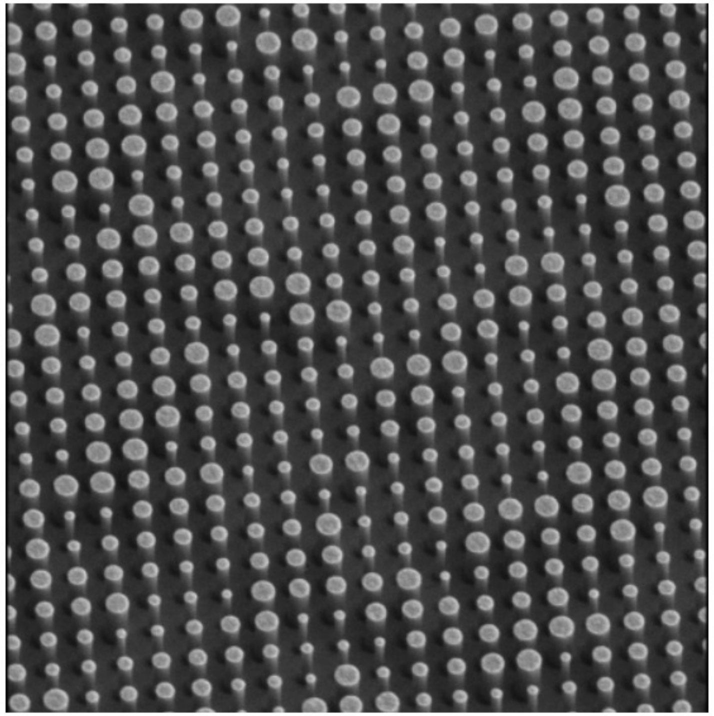
TECHNOLOGY PRODUCTS MARKETS COMPANY NEWSROOM



Rob Devlin Co-Founder and CEO

About Us

We are a fabless semiconductor optics company on a mission to revolutionize optical sensing and empower billions of devices with new information. Using our metasurface technology, we are changing the way that people and machines interact with and understand the world.



Metalenses: Planar Optics on a Chip

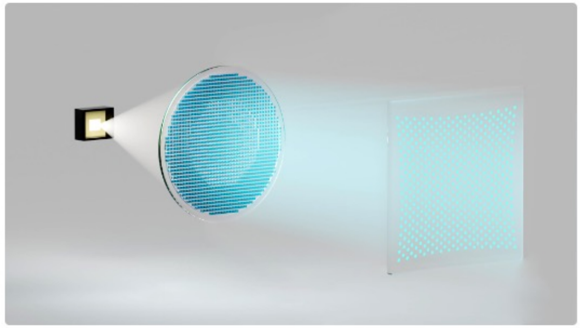
Metalenses use planar surfaces consisting of sub-wavelength structures called "nanopillars" to manipulate light and provide a degree of control not possible with traditional refractive lenses. Metasurface responses can be tuned for all properties of light including phase, wavelength, amplitude and polarization. Metalenses can combine multiple optical functions into a single element. The level of accuracy and control combined with multifunctional capability in a single surface results in a compact, optically stable module ideal for device miniaturization.

Combine the function of five optical elements into one meta-optic.

Meta/Flat-Optics → Products

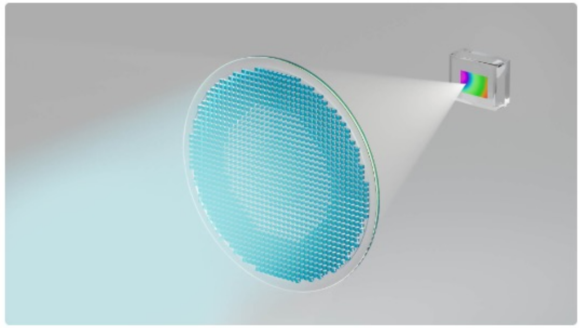
Hot Product | Consumer electronics | LIDAR | Optical communication | Customization

Home > Products



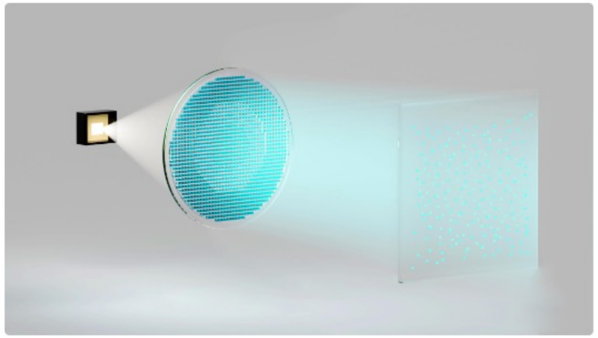
MetaToF™ TX lens MetaToFTX®

As the TX module of ToF, MetaToFTX™ replaces traditional multiple collimating lenses and diffra...



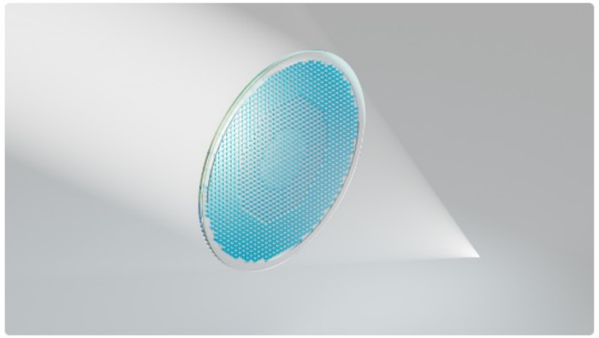
MetaToF™ RX lens MetaToFRX®

As the RX module of ToF, MetaToFRX™ replaces conventional receiving lensing system，reducin...



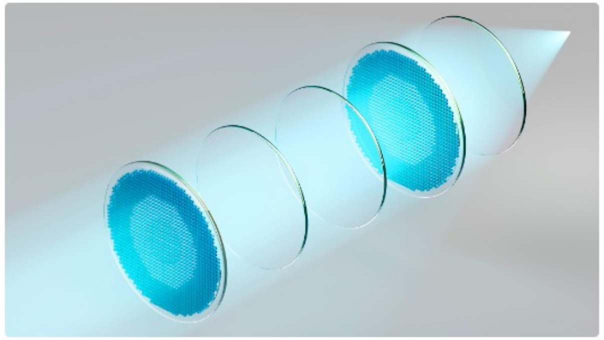
Metalens for Structured Light Metastruclight™

Structured light metalens (Metastruclight™) will re-define structured light module;Metastruclig...



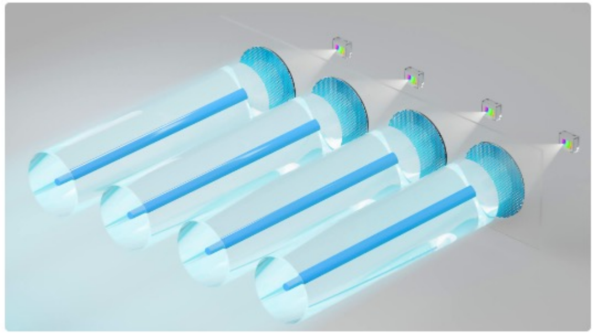
In-display Fingerprint recognition Metalens® Fing...

Metalens® Fingerprint, a metalens® that is applied to an in-display fingerprint recognition mo...



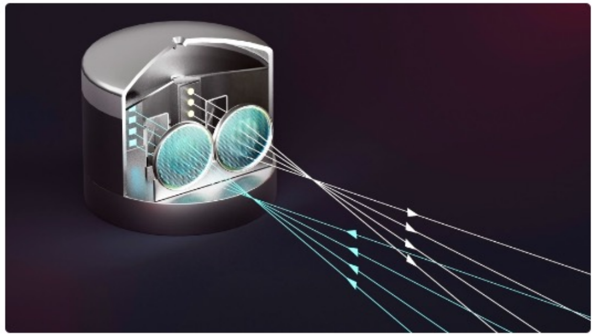
Metalens® Camera

MetaLenX launches the meta-refractive hybrid lensing system Hybridmeta®, based on ray-traci...



Metalens for optical communication

MetaLenX launches Metalens® Opticom products for optical communication. The present prod...



Metalens® LIDAR

Metalens® LIDAR focuses on lidars, including optical systems in Tx and Rx modules;Metalens® ...

Meta/Flat-optics

Meta-Optics → Entry to Industry

Hair diameter: 17 µm to 181 µm

PlanOpSim
Enlightened Planar Optics

PlanOpSim is a photonics problem solver.

PlanOpSim : a company driven by experts for experts dedicated to the success of Meta Optics via Software and Services.

Component Design

PlanOpSim
Enlightened Planar Optics

29 Boterbloemstraat
Melle, 9090
BELGIUM

+32485565772
info@planopsim.com

Services

- Testing, design and prototyping
- Optical modelling
- Software Customization
- Optical measurement setups

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NEXTCORPS LUMINATE

OPTICA Formerly OSA

Meta/Flat-optics

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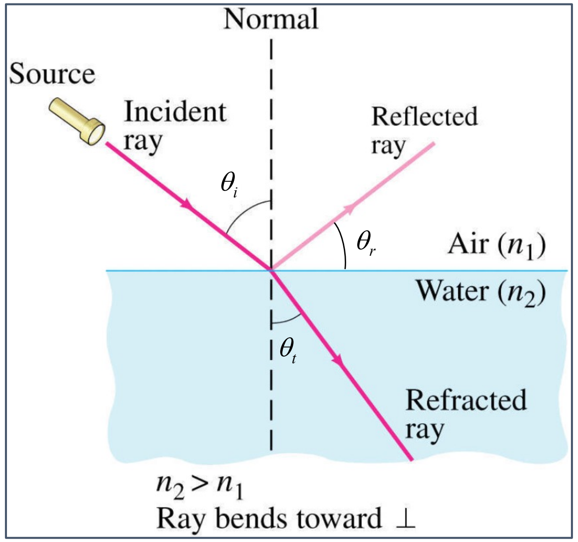
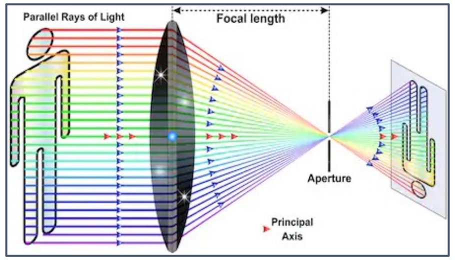
Conventional vs Generalized Snell’s Law

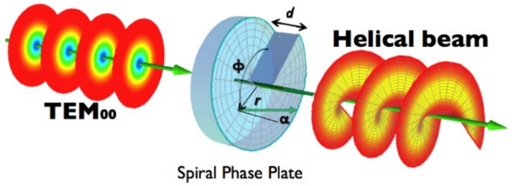
Conventional Snell’s Law:

- **Propagation effects:** ***nd* & *kd*** controls **phase, amplitude and polarization** of EM wave.
- **Consequence:** construction of bulky devices which are not compatible with for integrated optics.

$$\theta_i = \theta_r \qquad n_1 \sin\theta_i = n_2 \sin\theta_t$$

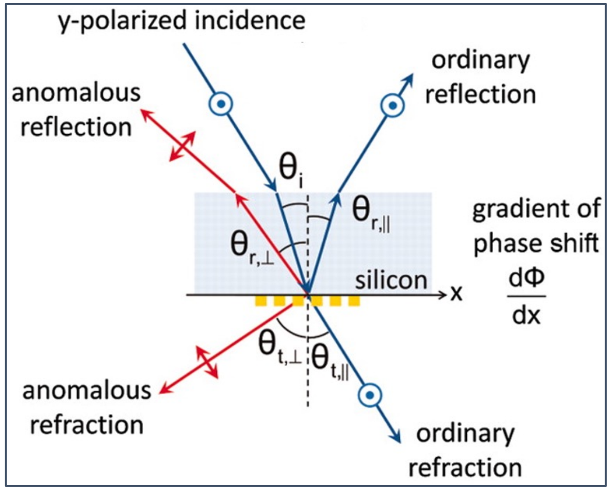






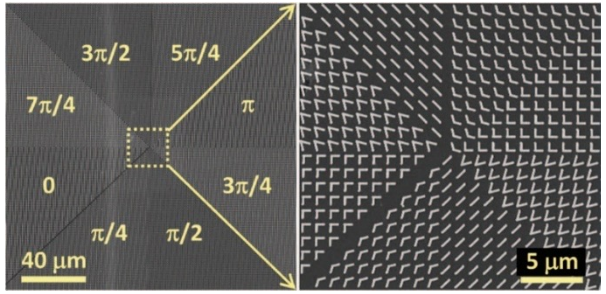
Generalized Snell's Law:

- Introduction of **abrupt phase changes** into the optical path to **control the wave-fronts** i.e., **phase, amplitude and polarization** of an incident EM wave.
- **Achieved** through **arrays subwavelength resonators**



Anomalous Reflection:

$$n_t \sin\theta_t - n_i \sin\theta_i = \frac{\lambda_0}{2\pi}\frac{d\Phi}{dx}$$



Anomalous Refraction:

$$\sin\theta_t - \sin\theta_i = \frac{\lambda_0}{2\pi n_i}\frac{d\Phi}{dx}$$

Meta/Flat-optics

Generalized Snell's Law

The incident electric and magnetic fields can be expressed as

$$\boldsymbol{E_i} = \hat{y}E_{i0}e^{ik_1(x\,sin\theta_i+z\,cos\theta_i)}$$

$$\boldsymbol{E_r} = \hat{y}E_{r0}e^{ik_1(x\,\sin\theta_r - z\,\cos\theta_r) - i\Phi_r}$$

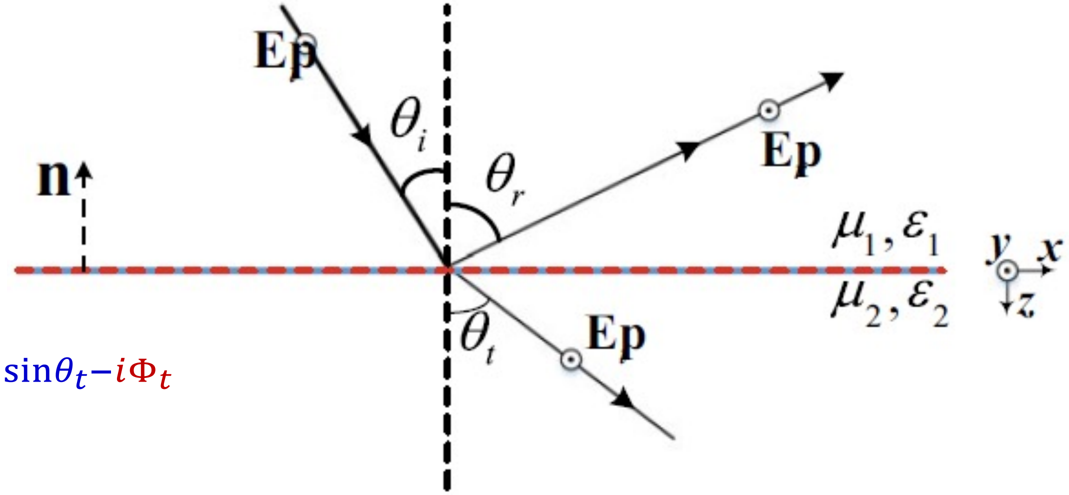
$$E_t = \hat{y}E_{t0}e^{ik_2(x\,sin\theta_t + z\,cos\theta_t) - i\Phi_t}$$

$$H_i = \frac{1}{\eta_1}\left[\hat{k}_i\times\boldsymbol{E}_i\right] = (\hat{z}\,sin\theta_i - \hat{x}\,cos\theta_i)\frac{E_{i0}}{\eta_1}e^{ik_1(x\,sin\theta_i+z\,cos\theta_i)}$$

$$H_r = \frac{1}{\eta_1}\left[\hat{k}_r\times\boldsymbol{E}_r\right] = (\hat{z}\,sin\theta_r + \hat{x}\,cos\theta_r)\frac{E_{r0}}{\eta_1}e^{ik_1(x\,sin\theta_r+z\,cos\theta_r)- i\Phi_r}$$

$$H_t = \frac{1}{\eta_2}\left[\hat{k}_t\times\boldsymbol{E}_t\right] = (\hat{z}\,sin\theta_t - \hat{x}\,cos\theta_t)\frac{E_{t0}}{\eta_2}e^{ik_2(x\,\sin\theta_t+z\,\cos\theta_t)-i\Phi_t}$$

According to the continuity of the tangential components of the EM fields,



$$E_{i0}e^{ik_1x\,sin\theta_i} + E_{r0}e^{ik_1x\,\sin\theta_r - i\Phi_r} = E_{t0}e^{ik_2x\,\sin\theta_t - i\Phi_t}$$

$$-\cos\theta_i\frac{E_{i0}}{\eta_1}e^{ik_1x\,sin\theta_i} = cos\theta_r\frac{E_{r0}}{\eta_1}e^{ik_1x\,sin\theta_r- i\Phi_r} = -\cos\theta_t\frac{E_{t0}}{\eta_2}e^{ik_2x\,\sin\theta_t-i\Phi_t}$$

Generalized Snell's Law

$$E_{i0}e^{ik_1x\,\sin\theta_i} + E_{r0}e^{ik_1x\,\sin\theta_r\,-\,i\Phi_r} = E_{t0}e^{ik_2x\,\sin\theta_t\,-\,i\Phi_t}$$

$$-\cos\theta_i\frac{E_{i0}}{\eta_1}e^{ik_1x\,\sin\theta_i} = \cos\theta_r\frac{E_{r0}}{\eta_1}e^{ik_1x\,\sin\theta_r-\,i\Phi_r} = -\cos\theta_t\frac{E_{t0}}{\eta_2}e^{ik_2x\,\sin\theta_t-i\Phi_t}$$

$$k_1x\,\sin\theta_i = k_1x\,\sin\theta_r - \Phi_r = k_2x\,\sin\theta_t - \Phi_t$$

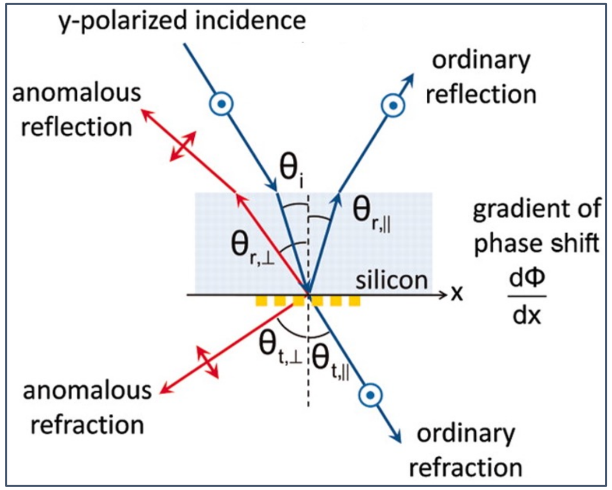
$$k_1x\,\sin\theta_r - k_1x\,\sin\theta_i = \Phi_r$$

$$k_1x\,\sin\theta_i - k_2x\,\sin\theta_t = \Phi_t$$

Taking the derivatives with respect to *x*

$$k_1\,\sin\theta_i - k_1\,\sin\theta_r = \frac{\partial\Phi_r}{\partial x}$$

$$k_1\,\sin\theta_i - k_2\,\sin\theta_t = \frac{\partial\Phi_t}{\partial x}$$



The reflection and transmission angles can be solved as

$$\theta_r = \sin^{-1}\left[\sin\theta_i + \frac{\lambda_1}{2\pi}\frac{\partial\Phi_r}{\partial x}\right],$$

$$\theta_t = \sin^{-1}\left[\frac{\lambda_2}{\lambda_1}\sin\theta_i - \frac{\lambda_2}{2\pi}\frac{\partial\Phi_t}{\partial x}\right]$$

With the phase gradient on the interface, the **anomalous reflected and transmitted** waves propagating in the arbitrary direction become possible.

For no phase gradient, we get traditional Snell's law

$$\theta_r = \theta_i, \qquad \theta_t = \sin^{-1}\left[\frac{\lambda_2}{\lambda_1}\sin\theta_i\right]$$

Imaging

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- Metasurfaces can be considered as the **planner/two-dimensional equivalent** of bulk metamaterials.
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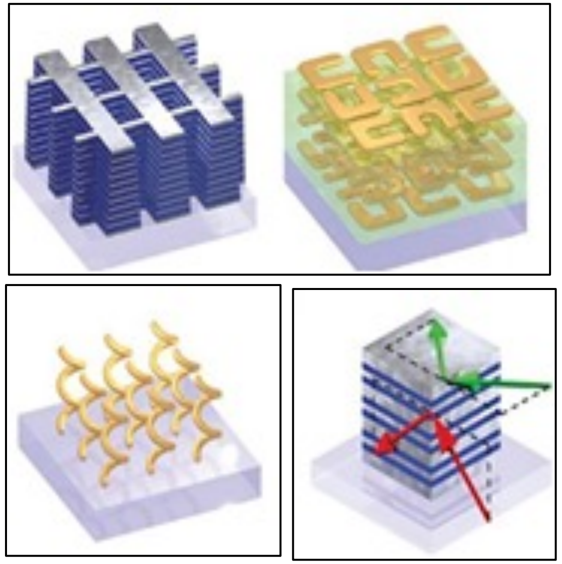
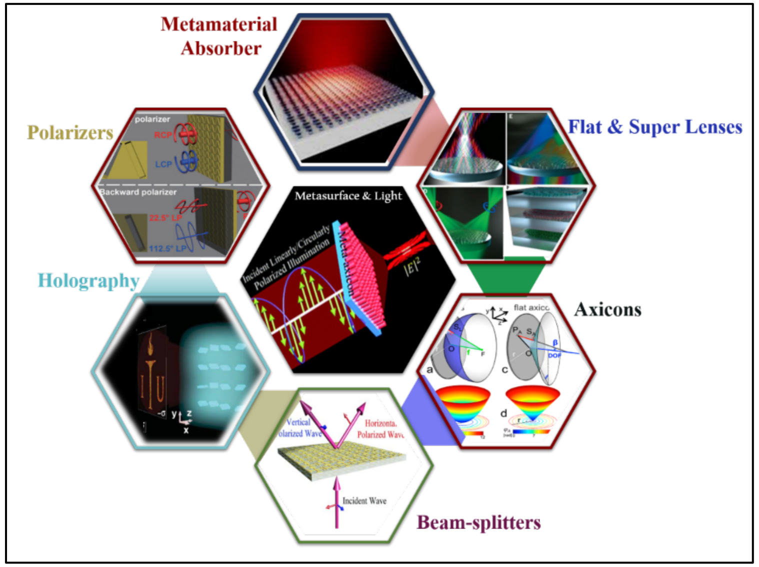
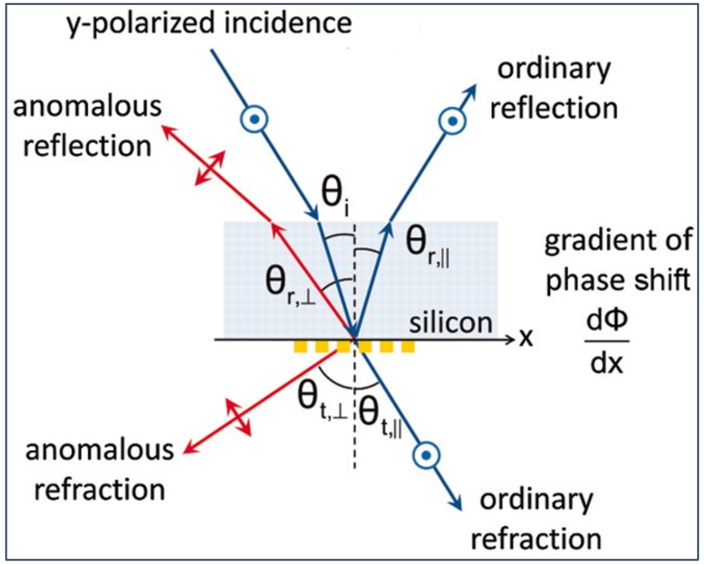
- In contrast, the **interface reflection and transmission** resulting **from the tailored surface** impedance, including their amplitude, phase, and polarization states are of significant importance.







Optical Components → Prisms

Meta-optics vs Refractive Optics

- In a classical refractive lens, the **phase function** of the lens is delivered by a **continuous curved surface**. This refractive lens phase function **spans over multiples of the 2π**.

- In meta-optics, this **modulo-2π phase function** is **implemented using nanostructures**, which are significantly **smaller than the wavelength** of light.

- This **allows** metalenses to **deliver functionality like refractive lenses** while offering new lens capabilities and trade spaces.

Meta-optics vs Diffractive Optics

- In a diffractive lens, the lens **operates in modulo-2π**, where the **N×2π phase values** are mapped back to 2π and implemented accordingly.

- Metasurface is a **type of diffractive component**, however, **not every diffractive component is a metasurface**.
- Metasurfaces possess **unique properties**, like
  - They have nonconventional in its physics of phase accumulation.
  - Metasurface must have a **subwavelength quasi-periodic** structure, while CDL is based on a super-wavelength quasi-periodic structure.
  - They can **manipulate the polarization** of light, Metasurfaces can also **show resonant behavior**,

Meta-optics @ MicroNano Lab

Meta-optics @ MicroNano Lab

MetaMagus

Meta-Optics → MicroNano Lab → MetaMagus

Ingenious Design

Attain ground-breaking outcomes through AI based innovative design techniques.

Metatom Design & Database

MetaMagus has developed a database of versatile meta-atom designs via deep-learning enabled models. This database offers ready to use designs as well as rapid customization of meta-atoms for different design targets. Thus it enables time-efficient large-scale production of meta-atoms.

Meta-device design tool

In contrast to the conventional approaches, MetaMagus proposes AI enabled fast and efficient design of complex gradient meta-devices. It also contains a library of some commonly used meta-lenses, meta-holograms and other meta-devices.

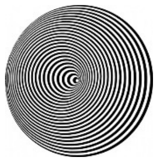
MetaLOGIX

- Polarization Meta-optics
- Multifunctional Meta-Optics
- Tunable Meta-optics

System Level Integration & Customization of Meta-Optics

Once the individual components are ready, they are assembled and perfectly aligned to develop meta-optical systems. Ray tracing software is used for simulating meta-optical systems.

Engineering Light-Matter Interactions through MetaLOGIX



Meta-lensing

Light-structuring

Meta-holography

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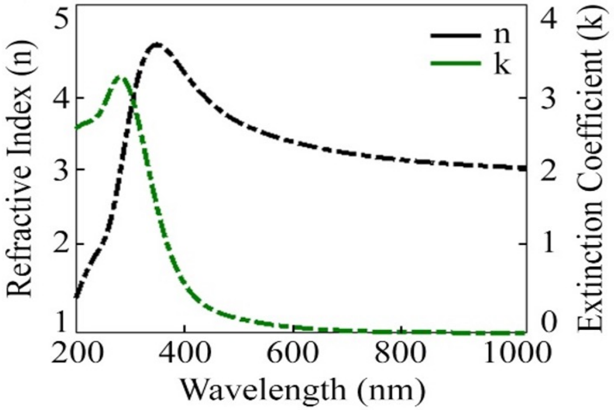
Designing a Meta-device

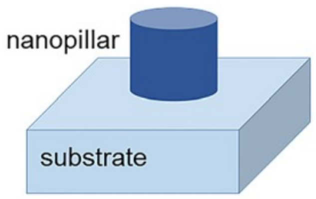
Material Selection



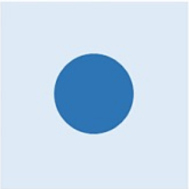
Goal: *Cost effective, highly-efficient, high-index, loss-less dielectric, CMOS compatible, with simple fabrication steps*

Step 1 (Unit Cell)

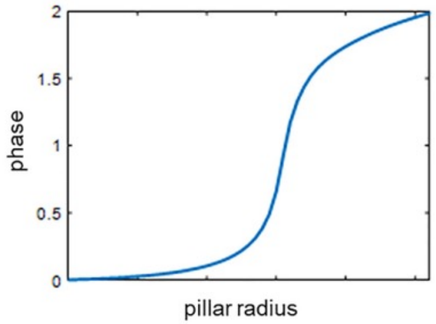
perspective view



top view

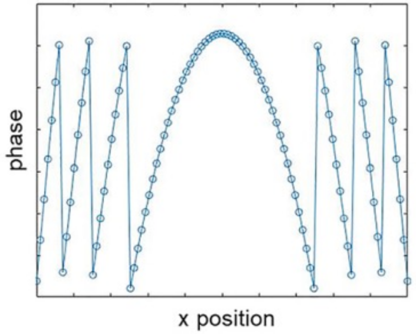


Step 2 (Phase Map)



pillars with increasing radius

Step 3 (Phase Profile)

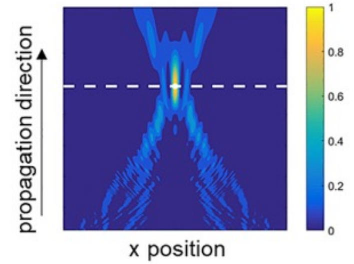


phase profile equation

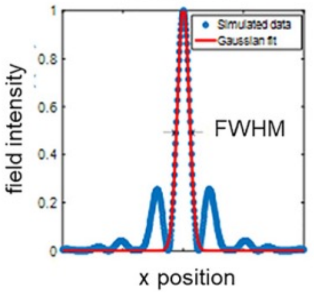
$$\varphi(x) = -2\pi/\lambda \times \left(\sqrt{f^2 + x^2} - f\right)$$

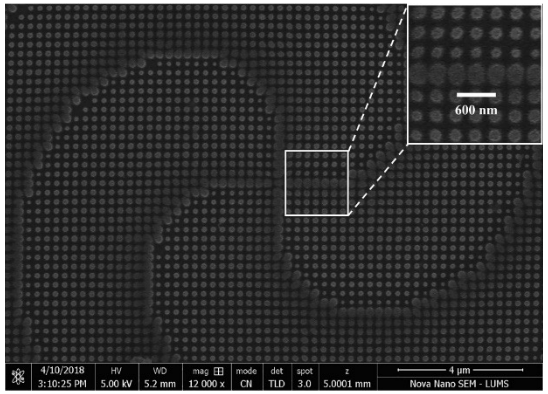
Step 4 (Lens Modeling)

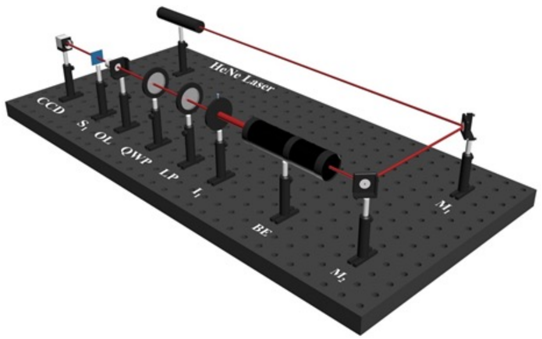
constructive interference



focal profile







Design Cycle

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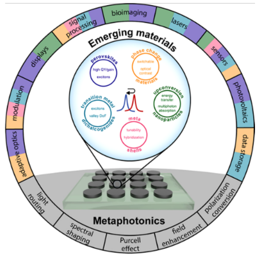
Meta-optics: Design & Development Steps

Design Strategy



- Identification of the target phenomenon
- Mathematical equations and underlying physics

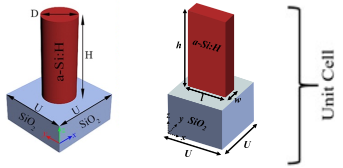
✓ Putting forward target EM phenomenon

✓ Identifying underlying physics

Meta-atom & Meta-device Design & open-source options

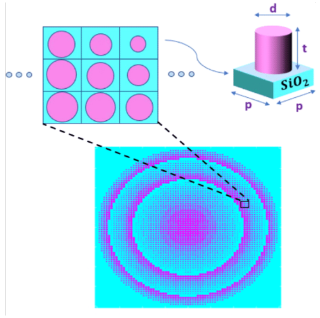
- Conventional methods
- Time consuming & Expensive
- FEM, FDTD, PSO, GA
- AI driven method: 98% faster

✓ AI driven rapid optimization of individual meta-atom



- Meta-device phase mask optimization
- Periodic arrangement of meta-atoms as meta-device

✓ AI driven complete meta-device design and optimization

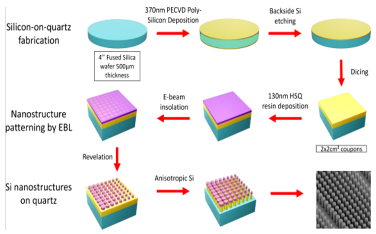


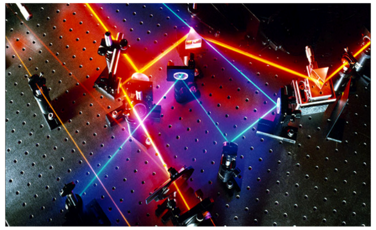
- Cost-effective large-scale fabrication
- Results characterization

✓ Fabrication & Characterization

✓ Integration of individual meta-device in the meta-optical system

Meta-system Design





Design Cycle

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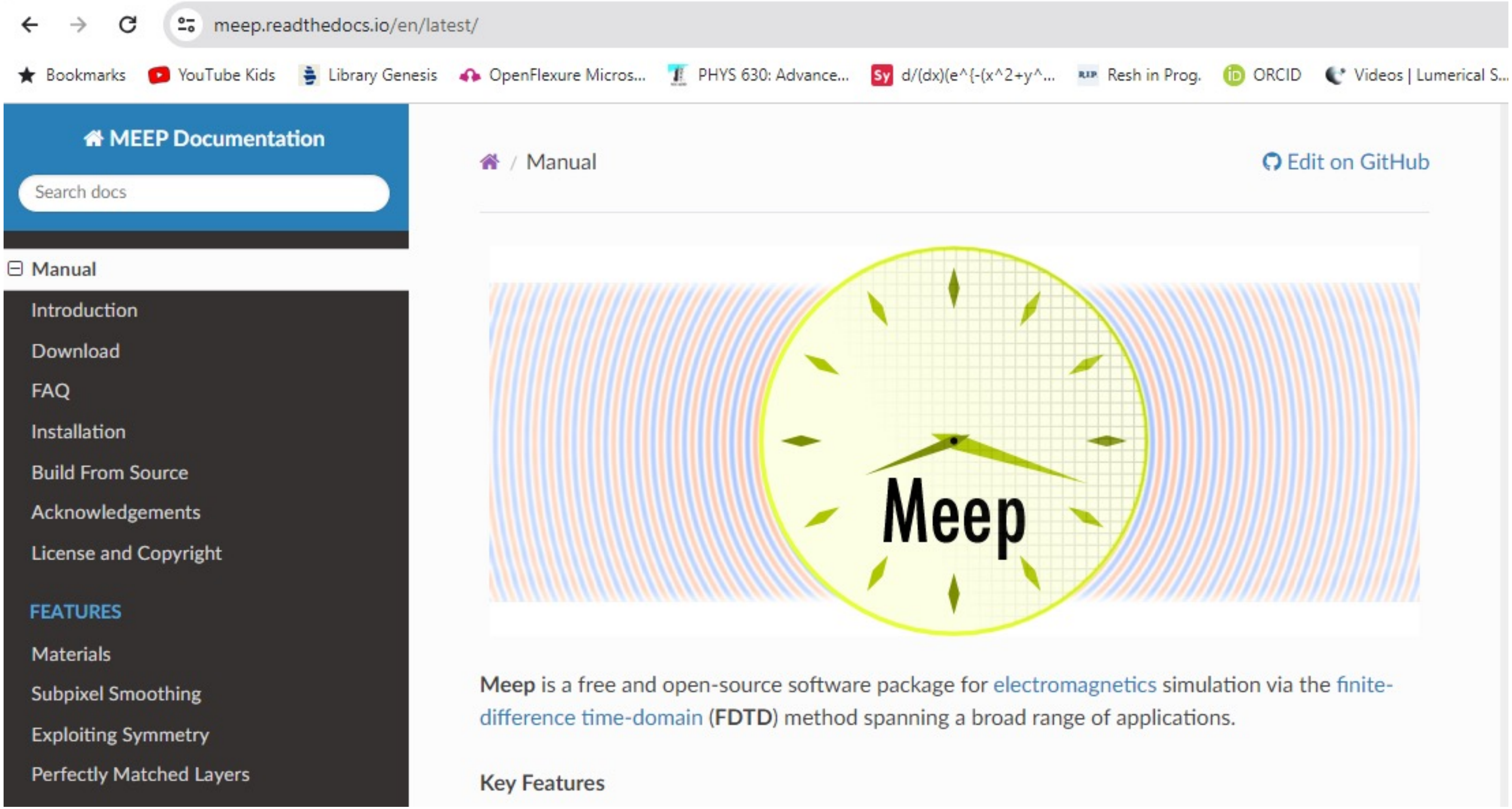
Meta-optics: Design & Development Steps



MetaLOGIX

Pixel-Level Design Strategies

Geometric Phase

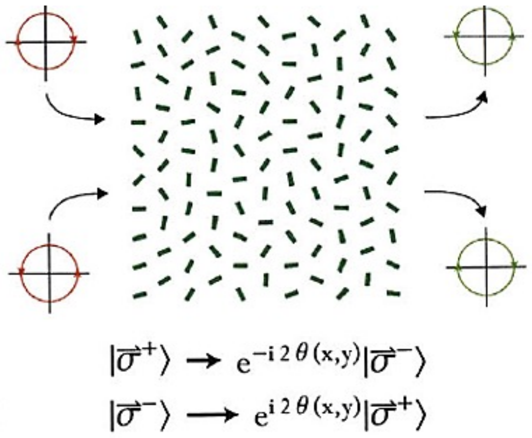
Jones calculus for a half wave plate transmission:

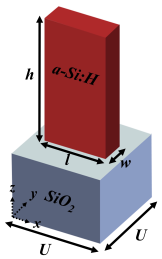
$$J = R(\theta).T.R(-\theta),$$

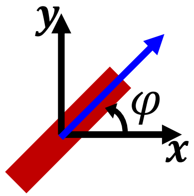
$$T = \begin{bmatrix} T_{xx} & 0 \\ 0 & T_{yy} \end{bmatrix} \qquad R(\vartheta) = \begin{bmatrix} \cos\vartheta & \sin\vartheta \\ -\sin\vartheta & \cos\vartheta \end{bmatrix}$$

Overall transmitted electric field is:

$$\vec{E}_t = \frac{T_{xx}+T_{yy}}{2}.\vec{E}_{LCP} + \frac{T_{xx}-T_{yy}}{2}.e^{i2\vartheta}.\vec{E}_{RCP}$$





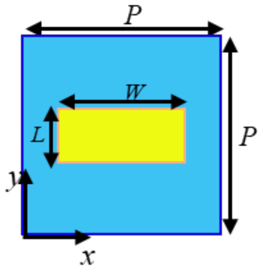


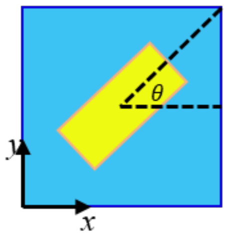
Optimization of Meta-atoms

<u>**Optimal response**</u> $\hat{\Psi}_n$ by solving the <u>**optimization function**</u> with constraint Ψ set as:

$$\hat{\Psi}_n := \begin{cases} \underset{\Psi}{\operatorname{argmin}}\, T_{co}(\Psi) \\ \underset{\Psi}{\operatorname{argmax}}\, T_{cr}(\Psi) \end{cases} ;\ \Psi \in \begin{cases} l_{min} \le L \le l_{max} \\ w_{min} \le W \le w_{max} \\ P < \dfrac{\lambda_n}{2NA} \\ H = \text{as per A.R} \end{cases}$$

$T_{co}(\Psi)$ and $T_{cr}(\Psi)$ are the objective functions.

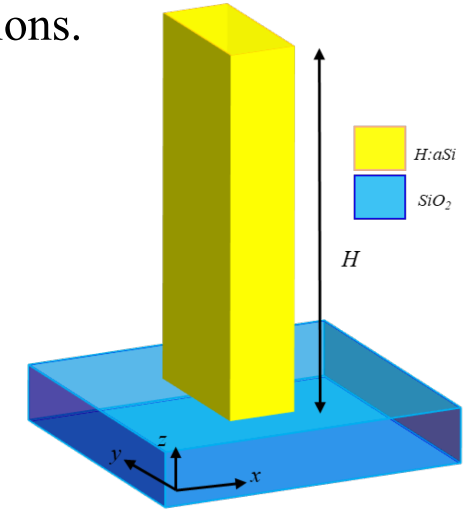




Multiwavelength Response

Ultimate optimal output Ω for multiple wavelengths:

$$\Omega = \hat{\Psi}_1 \cap \hat{\Psi}_2 \cap \hat{\Psi}_3$$

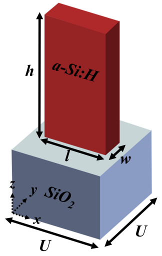


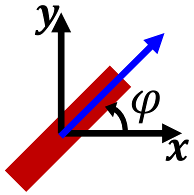
Metadevices

Meta-devices: Underlying Principle

Afnan, et. al. Laser Photonics Rev. **2019**, 1900065 *Afnan, et. al. Laser Photonics Rev.* **2019**, 1900065

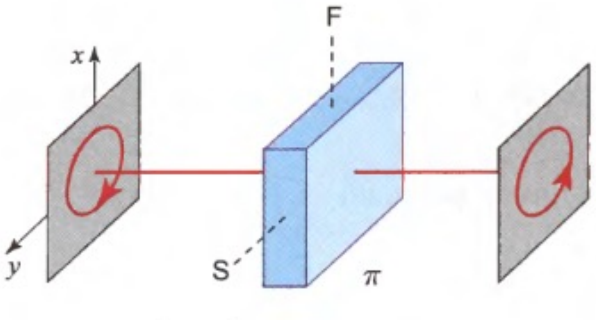
- Transmission matrices for a **Nano-half-wave plate**:





$$T = \begin{bmatrix} T_{11} & 0 \\ 0 & T_{22} \end{bmatrix}, \quad T' = R(-\varphi) \cdot T \cdot R(\varphi) = \begin{bmatrix} \cos\varphi & \sin\varphi \\ -\sin\varphi & \cos\varphi \end{bmatrix} \begin{bmatrix} T_{11} & 0 \\ 0 & T_{22} \end{bmatrix} \begin{bmatrix} \cos\varphi & \sin\varphi \\ -\sin\varphi & \cos\varphi \end{bmatrix}$$

$$\vec{E}_{in} = \vec{E}_{LCP} = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 \\ i \end{bmatrix}$$



(b) Half-wave retarder

$$\vec{E}_{in} = \vec{E}_{RCP} = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 \\ -i \end{bmatrix}$$

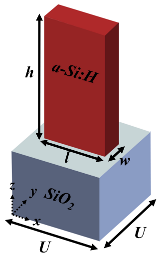
$$\vec{E}_t = \frac{T_{11}+T_{22}}{2} \cdot \vec{E}_{LCP} + \frac{T_{11}-T_{22}}{2} e^{i2\varphi} \vec{E}_{RCP}$$

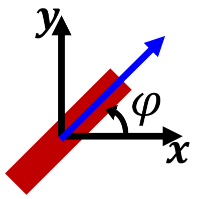
- **Co-polarized** light: No phase change,
- **Cross-polarized** light: $\Phi = 2\varphi \Rightarrow$ twice the rotation of nano-half-wave plate

Meta-devices: Underlying Principle

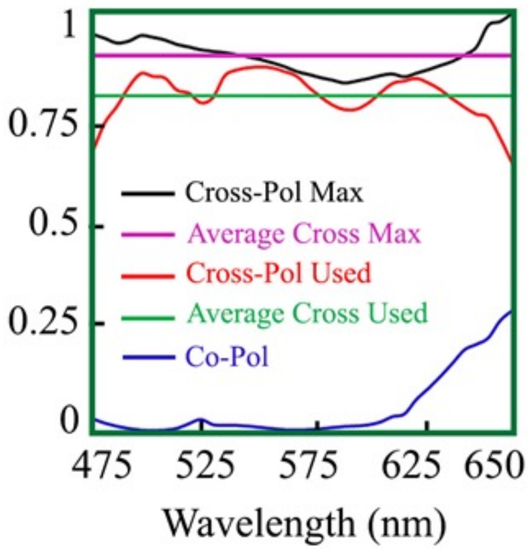
Afnan, et. al. Laser Photonics Rev. **2019**, 1900065

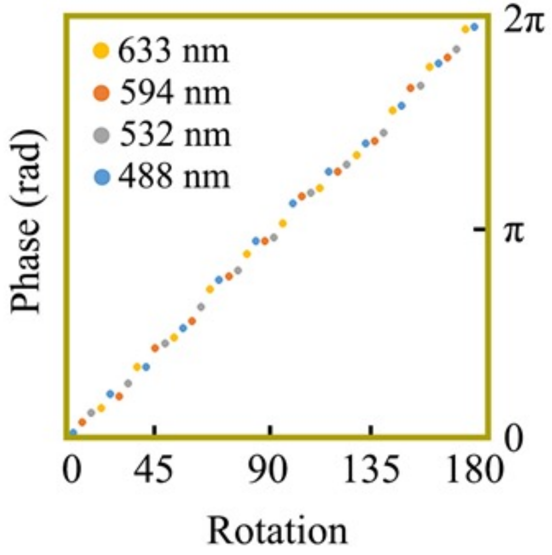
Afnan, et. al. Laser Photonics Rev. **2019**, 1900065

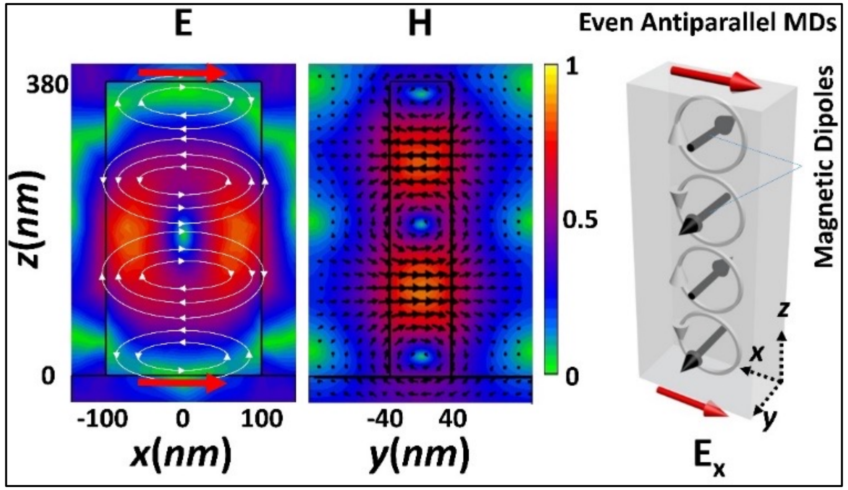


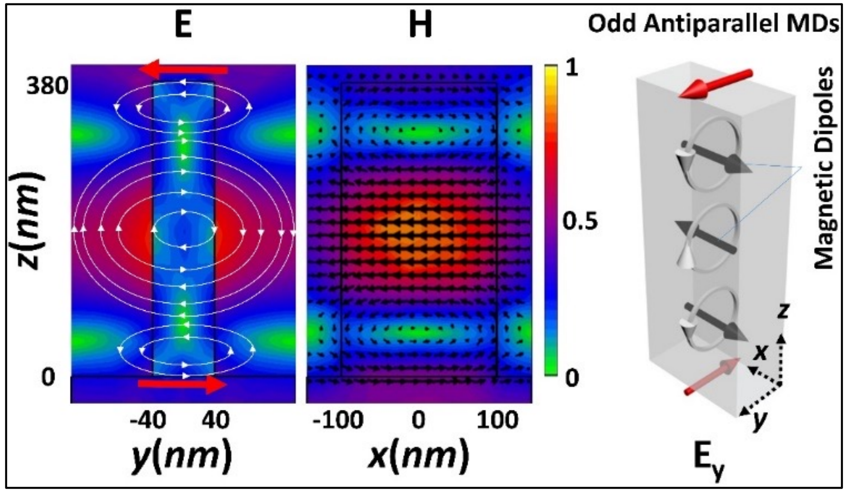


$$\vec{E}_t = \frac{T_{11}+T_{22}}{2}\cdot \vec{E}_{LCP} + \frac{T_{11}-T_{22}}{2} e^{i2\varphi}\vec{E}_{RCP}$$







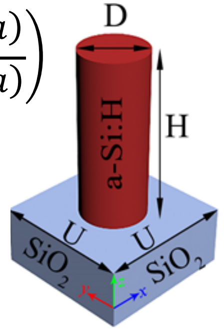


MetaLOGIX

Pixel-Level Design Strategies

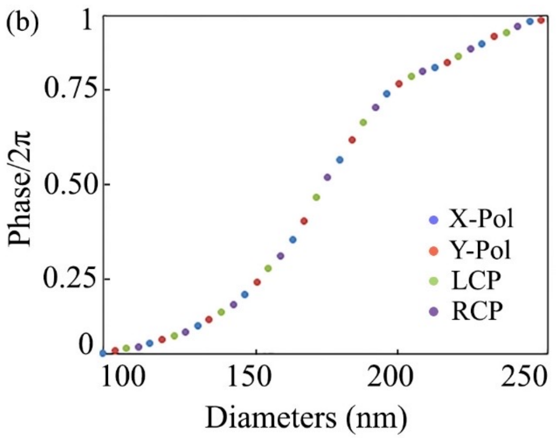
Index-waveguide Theory

$$\left(\frac{J_m'(pa)}{paJ_m(pa)}+\frac{K_m'(pa)}{qaK_m(qa)}\right)\left(\frac{n_c^2J_m'(pa)}{paJ_m(pa)}+\frac{n_a^2K_m'(pa)}{qaK_m(qa)}\right)$$
$$= m^2\left[\left(\frac{1}{qa}\right)^2+\left(\frac{1}{pa}\right)^2\right]^2\left(\frac{\beta}{K_0}\right)^2$$



Mode Condition Equation

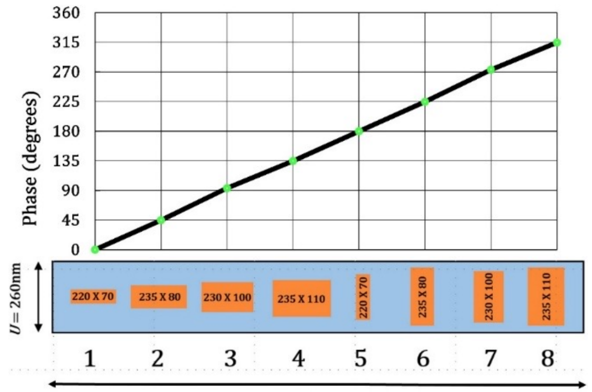
$$\begin{cases} n_{eff}=\dfrac{\beta}{k_0} \\ \varphi=\beta\cdot H \\ U<\dfrac{\lambda_d}{2NA} \\ \varphi=\dfrac{2\pi}{\lambda_d}\cdot n_{eff}\cdot H \end{cases}$$



Hybrid Phase

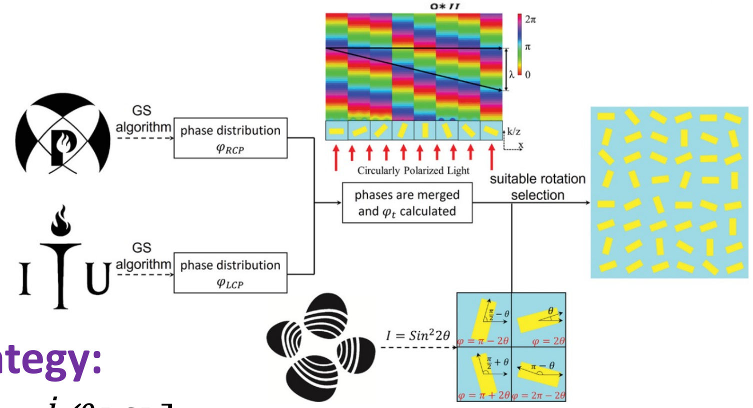
Merging Geometric & Propagation Phase:

$$\psi_f(x,y) = \alpha(x,y) - 2\varphi(x,y),$$
$$\psi_b(x,y) = \alpha(x,y) + 2\varphi(x,y)$$
$$\varphi(x,y) = \frac{\psi_b(x,y)-\psi_f(x,y)}{4},$$
$$\varphi(x,y) = \frac{\psi_b(x,y)+\psi_f(x,y)}{2}$$



Maulu's Law of orientation degeneracy

$$I(\theta) = I_0 \sin^2 2\theta$$



Spin-decoupled Design Strategy:

$$\varphi(x,y) = \arg\left[e^{i\cdot\varphi_{LCP}} + e^{-i\cdot\varphi_{RCP}}\right]$$

ACS Appl. Mater. Interfaces, 14, 31, 36019–36026, 2022

MetaLOGIX

Di-Pixel-Level Design Strategies

Diatomic Meta-atoms:

- For both nano-fins with propagation phases $e^{i\tau_1}$ and $e^{i\tau_2}$, the reflection matrix using Jones calculus can be written as

$$R_1 = R(-\phi_1)\begin{bmatrix} e^{i\tau_1} & 0 \\ 0 & e^{i(\tau_1+\pi)} \end{bmatrix} R(\phi_1) \quad (1)$$

$$R_2 = R(-\phi_2)\begin{bmatrix} e^{i\tau_2} & 0 \\ 0 & e^{i(\tau_2+\pi)} \end{bmatrix} R(\phi_2) \quad (2)$$

- combining Jones matrix after conversion into circular basis and adding the coupling effects , the total reflectance can be written as

$$R_T = \frac{1}{2} e^{i2\pi M/P_x} \begin{bmatrix} 0 & e^{-i(2\phi_1-\tau_1)} + e^{-i(2\phi_2-\tau_2)} \\ e^{i(2\phi_1+\tau_1)} + e^{i(2\phi_2+\tau_2)} & 0 \end{bmatrix} \quad (3)$$

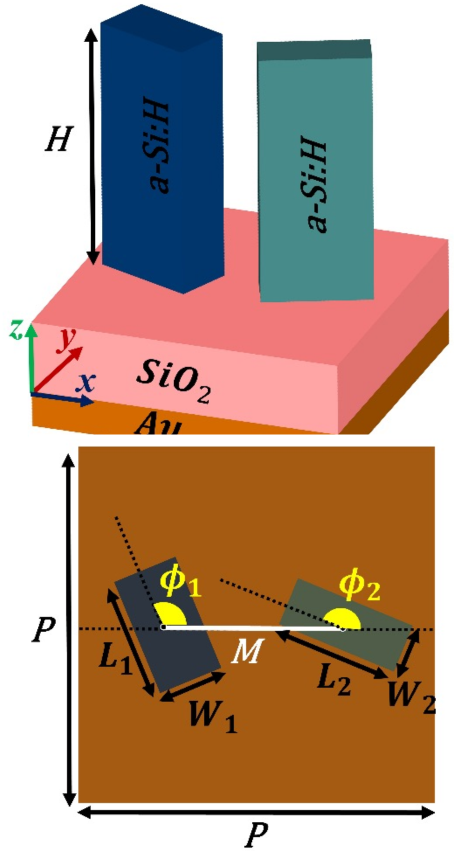
- Assuming $\boldsymbol{\tau_1 - \tau_2 = \frac{\pi}{2}}$, $\boldsymbol{\Delta\phi = \phi_1 - \phi_2 = -\frac{\pi}{4}}$, and $\boldsymbol{P_x = 2M}$

$$R_T^{cir} = e^{i(\tau_1+\pi)} \begin{bmatrix} 0 & 0 \\ e^{i2\phi_1} & 0 \end{bmatrix} \quad (4)$$

$$R_T^{cir} = e^{iq} \begin{bmatrix} 0 & 0 \\ e^{i2\phi_1} & 0 \end{bmatrix} \quad (5)$$

Max. Reflectance for LCP

Max. Absorption for RCP



Meta-Mogus: AI-driven Rapid Design & Optimization

MetaMagus

Meta-Optics → MetaMagus → Meta-Atom Design

META-ATOM DESIGN & DATABASE DEVELOPMENT

FORWARD PREDICTIONS

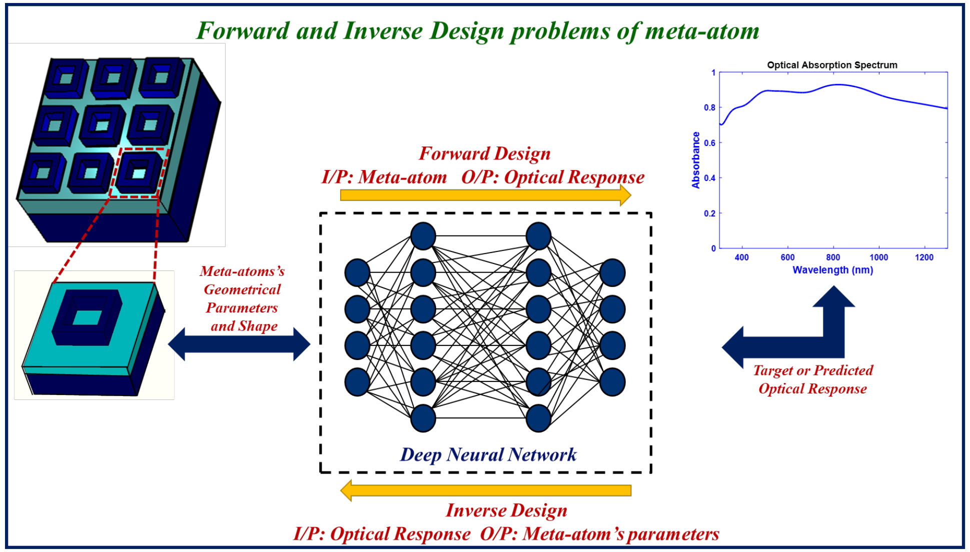
Input: Meta-atom geometry
Output: Optical Response

$$[\emptyset, A] = f_{L,W,H,P,n,k,\lambda}\,(E_{incident})$$

INVERSE DESIGN

Input: Target Optical Response
Output: Optimized Meta-atom Geometry

$$[L, W, H, P] = f_{n,k,\lambda}\ [\emptyset, A]$$



SALIENT FEATURES

- 98% FASTER THEN SIMULATIONS
- GEOMETRICAL DIVERSITY
- WAVELENGTH GENERALIZATION
- MATERIAL'S PHYSICS INCLUSION
- PHASE BASED OPTIMIZATION
- TRANSFER LEARNING
- LARGE SEARCH SPACES

Metaphotonics

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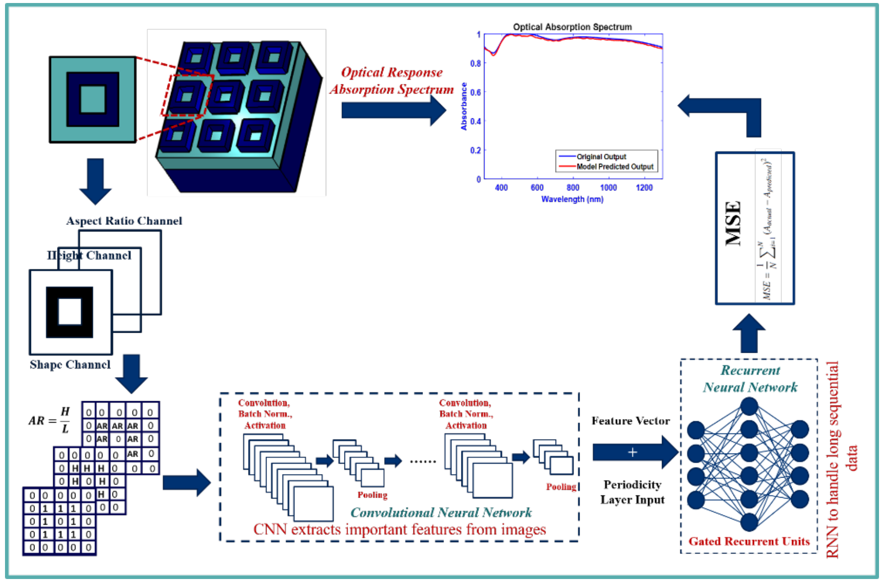
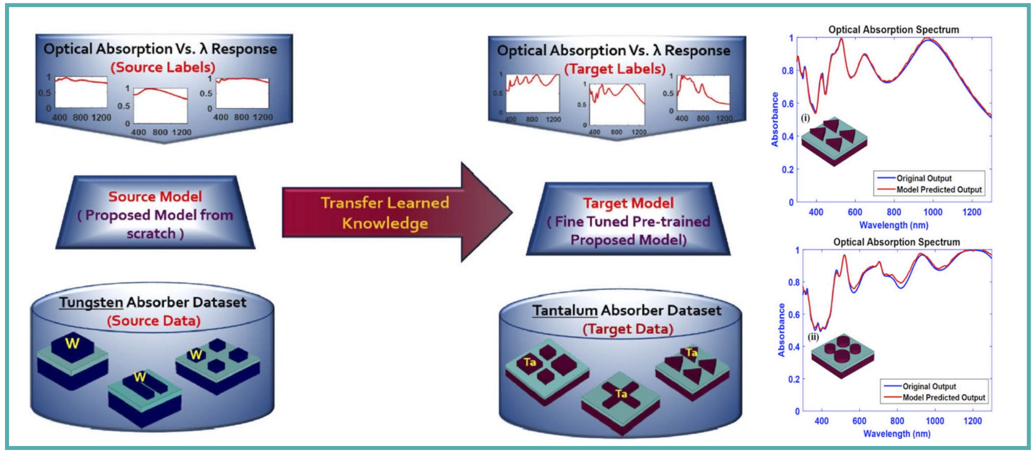
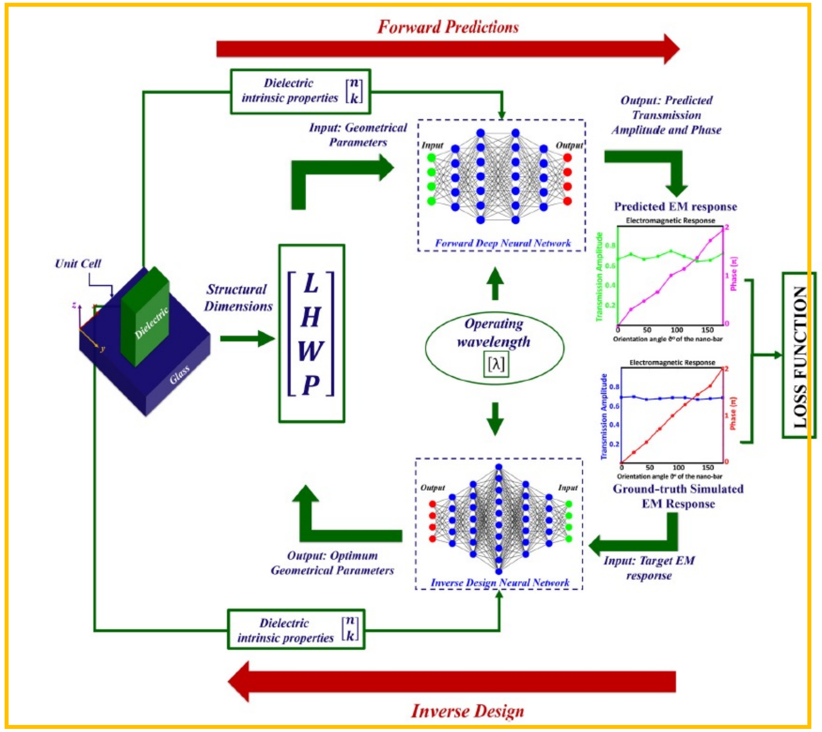
AI-driven Design & Optimization



Materials:

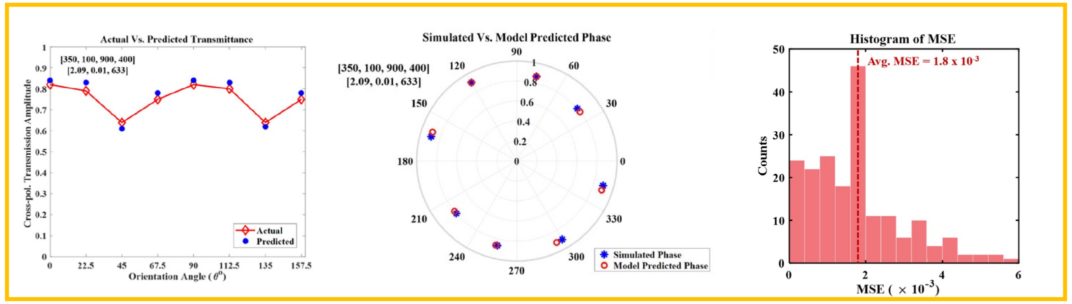
- Cr
- Ta





Dielectrics:

- a-Si:H
- TiO2
- GaN
- GaP
- Mod. a-Si:H
- Si_3N_4 (Unseen)

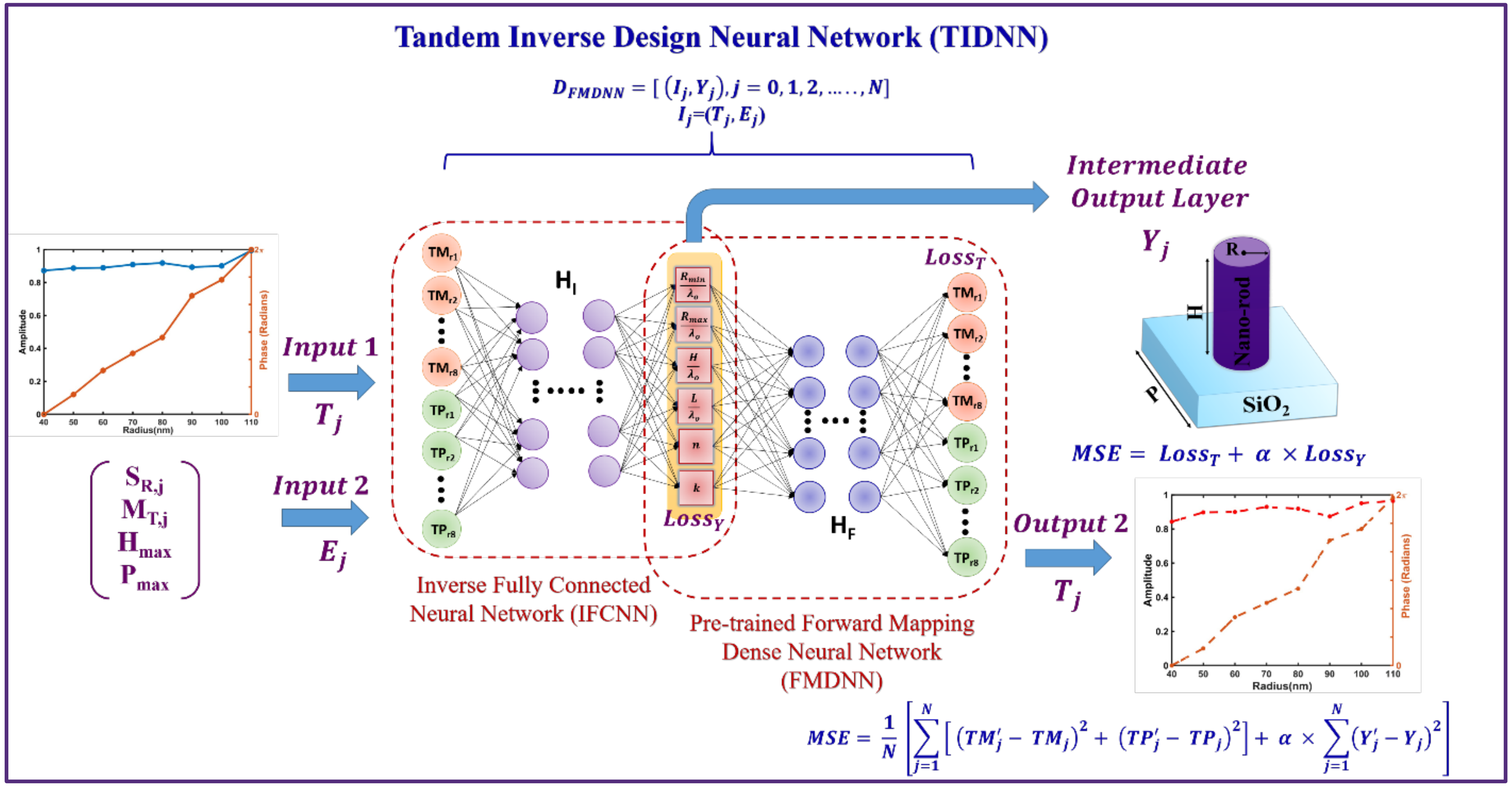


MetaMagus

Meta-Optics → MetaMagus → Meta-Atom Design

Additional Physics based knowledge in the networks:

- **Additional Physics based knowledge** in the networks
- Tandem Inverse Design Neural Network
- **Reduced Architectural Complexity**
- **Reduced Dataset demands**
- Predicts EM transmission amplitude & phase
- Provides optimum design parameters for desired EM response



Meta-Optics → MetaMagus → Meta-Atom Design

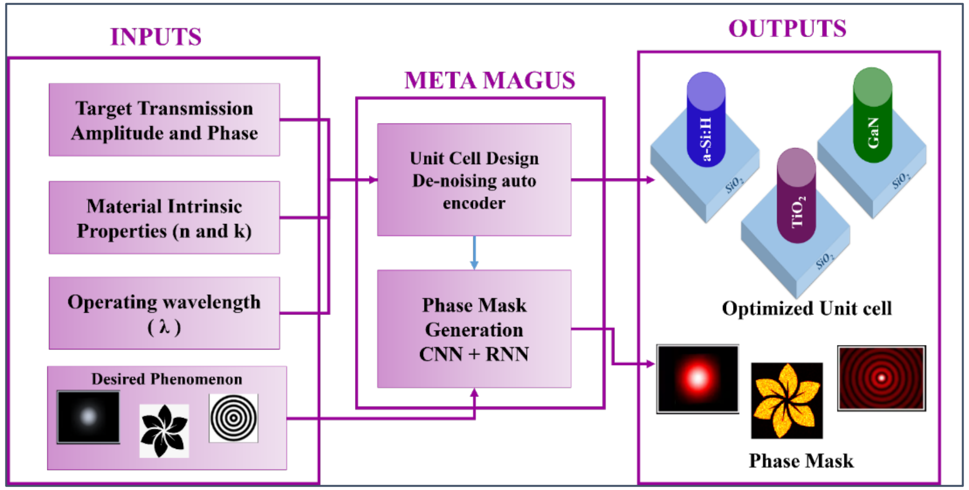
Advantages Conventional Optimization Approaches:

- Cost effective
- Time Efficient
- Comparable accuracy without even solving Maxwell's equation
- Generates result in single solver run
- Allows us to search over a larger span of dimensions

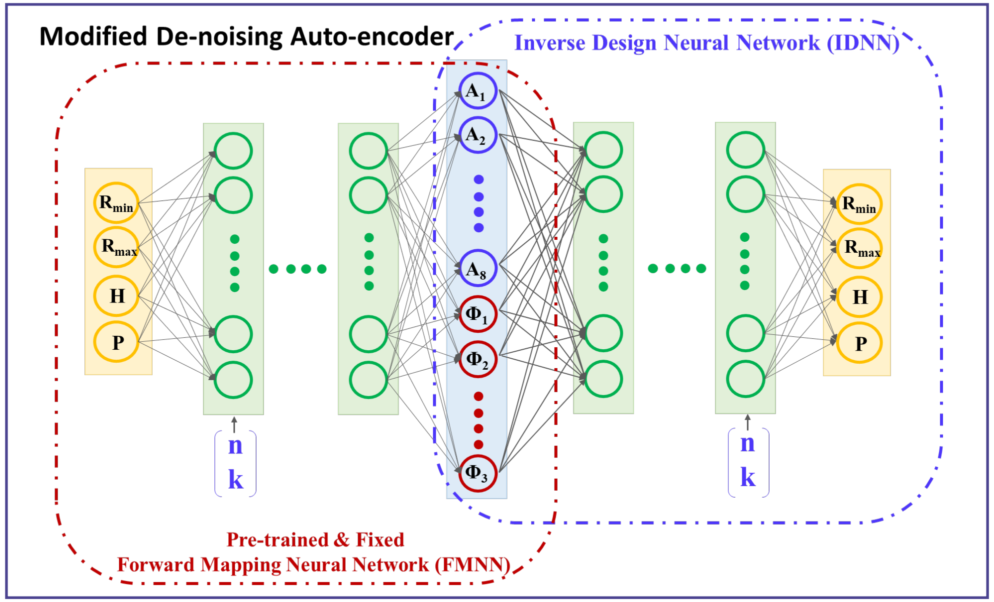
↓Features	METHODS			
	DL Model	CST OPTIMIZATION TOOLS		
		Trust Region Frame Work	Genetic Algorithm	Particle Swarm Algorithm (PSO)
Prior Knowledge of Parameters Range Required?	No.	Yes	Yes	Yes
No. of Parameters to be Optimized	4	4	4	4
Max. Range of parameters	1000 nm	500 nm	500 nm	500 nm
Time Consumed	~1.8 sec	~25 min	~3 hours	~3.5 hours
No. of Solver Runs	1	~36	~120	~125
Accuracy	97%	99%	100%	100%

Research

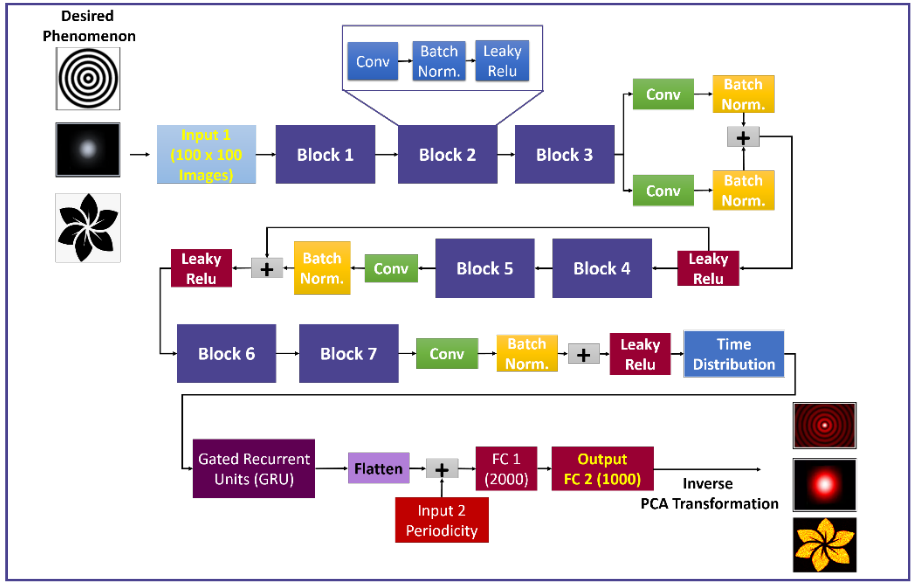
Meta-Optics → MetaMagus → Meta-Device Design



Unit Cell Design De-noising Auto-encoder



Meta-Device Phase Mask CNN+RNN



Meta-Optics → MetaMagus → Meta-Device Design

Potential Gap

- Unsupervised physics-driven deep neural network:
  - No need for computational tools, customized inclusion of physics, Efficient (Time & cost)
  - CMOS compatible library
  - Customization features
  - Robustness to design targets
  - Development of PDK's aligned with foundry fabrication facilities

Proposed Idea

Physics Driven Design Models to develop Novel Process Design Kits (PDKs)

- As metalens manufacturing continues to mature, we can expect to see great potential for PDKs, just as we see in the semiconductor and PIC industries.
- *PDKs will allow meta-lens designers to work with proprietary and verified meta-atom structures offered by foundries, keeping the designer's focus on the application as opposed to the subwavelength design.*
- In this manner, we aim to develop AI enabled PDKs having libraries of meta-atoms to serve as "black box" building blocks for metalens design.
- As each manufacturing run is costly both in terms of money and time, these types of analyses are crucial to reducing the number of runs by developing sufficiently robust designs.

Meta-optics @ MicroNano Lab

Meta-lensing

MetaLOGIX

Engineering Light-Matter Interactions:
Achromatic Meta-lensing

A nanostructure placed at a coordinate "r" should ideally fulfil the phase, group delay and group- delay- dispersion requirements simultaneously.

The target- phase profile to achromatically focus broadband incident light must fulfil the relationship:

$$\varphi_M(r,\lambda) = -\frac{2\pi}{\lambda}\left(\sqrt{r^2+f^2}-f\right) \rightarrow \varphi_M(r,\omega) = -\frac{\omega}{c}\left(\sqrt{r^2+f^2}-f\right)$$

Where

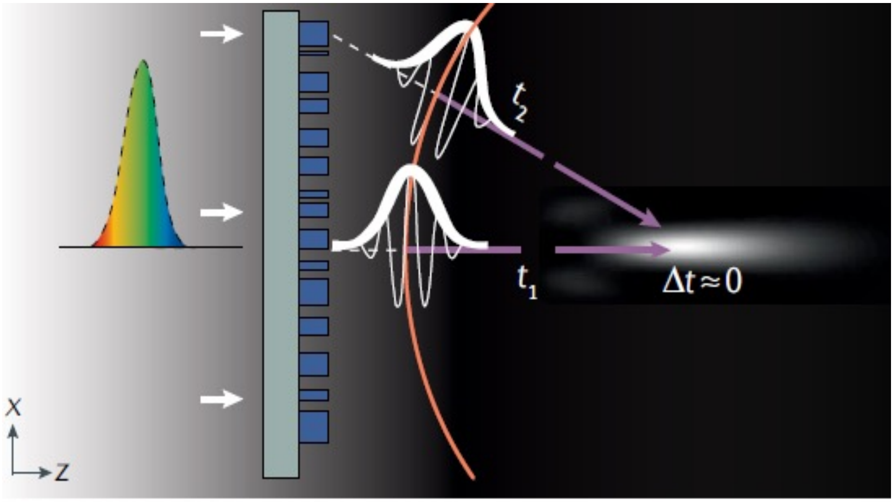
ω= angular frequency f= focal length r = spatial coordinate = $\sqrt{x^2+y^2}$ c = speed of light

$$\varphi(r,\omega) = \varphi(r,\omega_d) + \frac{\partial\varphi}{\partial\omega}\Big|_{\omega_d}(\omega-\omega_d) + \frac{\partial^2\varphi}{2\partial\omega^2}\Big|_{\omega_d}(\omega-\omega_d)^2 + O(\omega^3) + \cdots$$

Spherical transmitted wavefronts | Group Delay | Group Delay Dispersion

The required time delay is given by the **Group- Delay** profile:

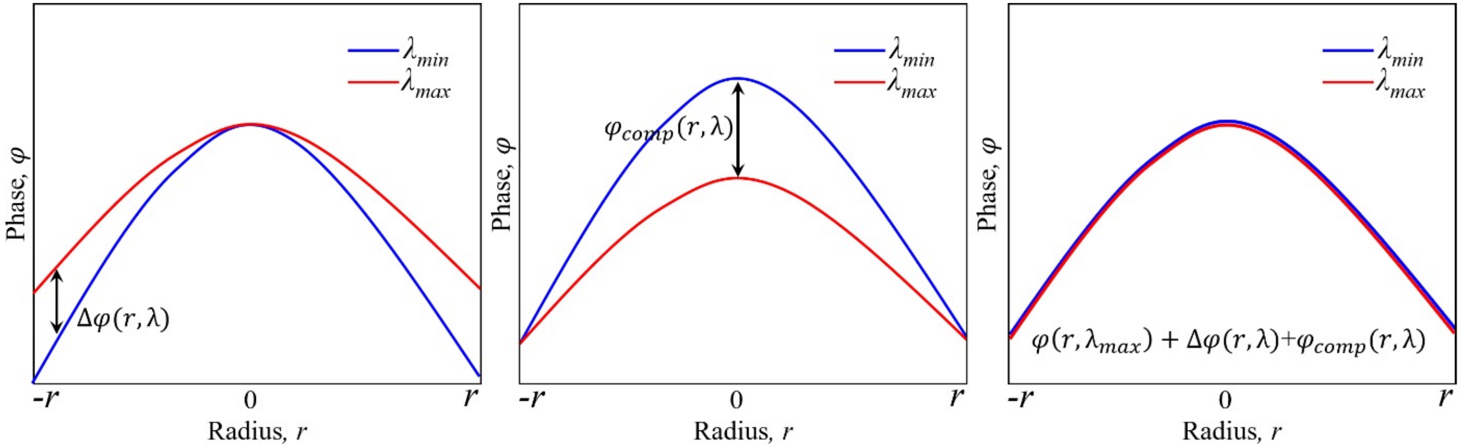
$$\frac{\partial\varphi(r,\omega)}{\partial\omega} = -\frac{\sqrt{r^2+f^2}-f}{c}$$



Chen, Wei Ting, et al. 13.3 (2018): 220-226.

MetaLOGIX

Engineering Light-Matter Interactions:
High NA Achromatic Meta-lensing



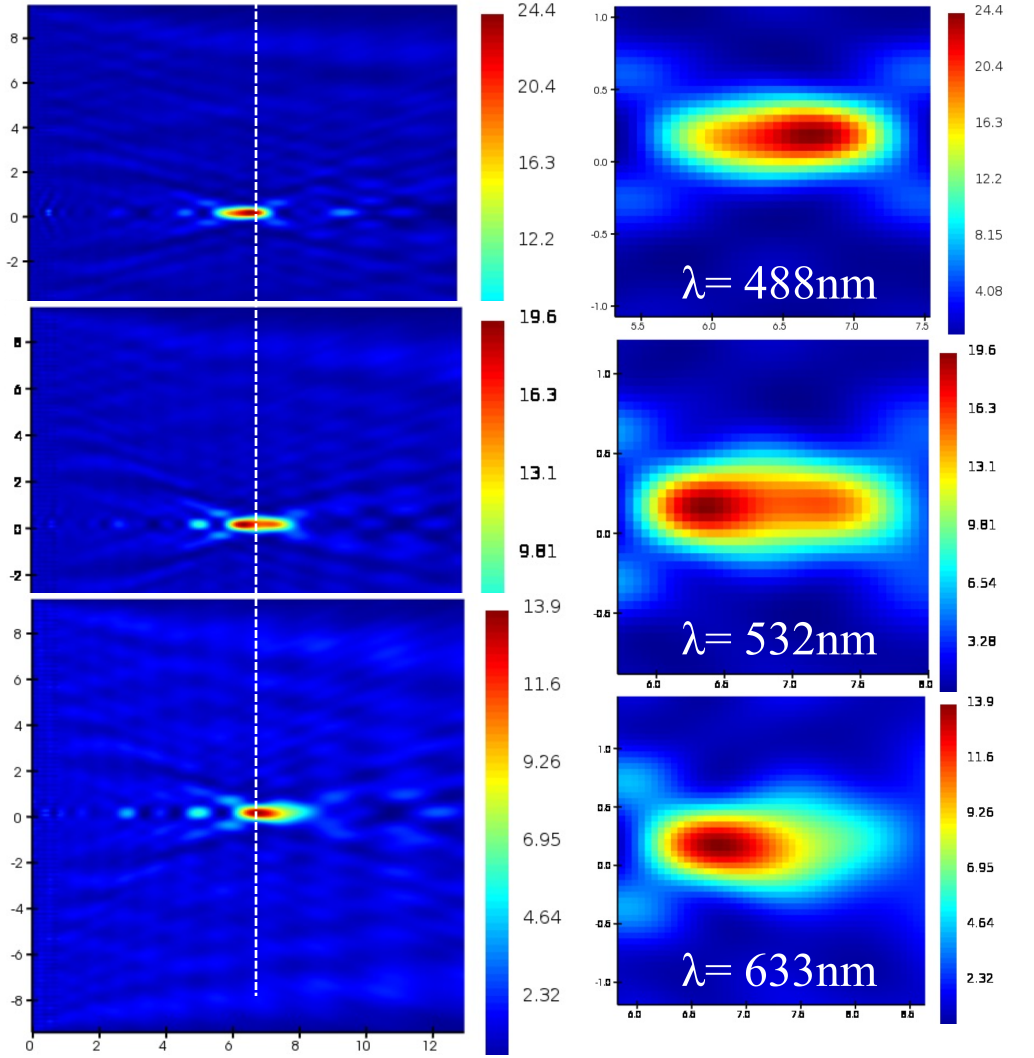
Chromatic aberration correction

$$\varphi(r,\lambda) = \varphi(r,\lambda_{max}) + \Delta\varphi(r,\lambda) + \varphi_{comp}(r,\lambda)$$

$$\boldsymbol{\varphi}(\boldsymbol{r},\boldsymbol{\lambda}) = -\frac{2\pi}{\lambda_{max}}\left(\sqrt{r^2+f^2}-f\right) + \left[-2\pi\left(\sqrt{r^2+f^2}-f\right) + \Gamma\cdot\frac{\lambda_{max}\lambda_{min}}{\lambda_{max}-\lambda_{min}}\right]\cdot\left(\frac{1}{\lambda}-\frac{1}{\lambda_{max}}\right)$$

Basic phase profile

Compensate phase profile $\boldsymbol{\varphi_{comp}}$



MetaLOGIX

Engineering Light-Matter Interactions:
Bifocal Achromatic Meta-lensing

Achromatic lens

$$\varphi_{AM}(r,\lambda) = \varphi(r,\lambda_{max}) + \Delta\varphi(r,\lambda) + \varphi_{comp}(r,\lambda)$$

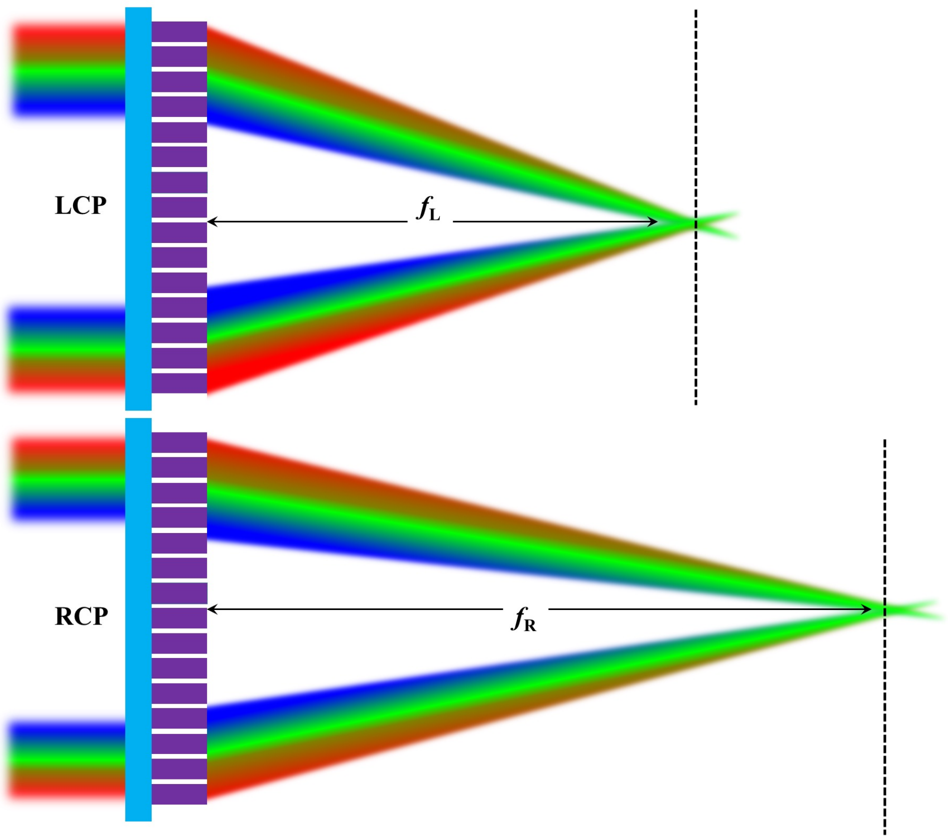
$$\varphi_{AM}(r,\lambda) = -\frac{2\pi}{\lambda_{max}}\left(\sqrt{r^2+f^2}-f\right) - 2\pi\left(\sqrt{r^2+f^2}-f\right)\left(\frac{1}{\lambda}-\frac{1}{\lambda_{max}}\right) + \varphi_{comp}(r,\lambda)$$

Bifocal Achromatic lens

$$\varphi_{MFAM} = \arg\left[e^{i\cdot\varphi_{AM\_L}} + e^{-i\cdot\varphi_{AM\_R}}\right]$$

$$\varphi_{AM\_R}(r,\lambda) = -\frac{2\pi}{\lambda_{max}}\left(\sqrt{r^2+f_R^2}-f_R\right) - 2\pi\left(\sqrt{r^2+f_R^2}-f_R\right)\left(\frac{1}{\lambda}-\frac{1}{\lambda_{max}}\right) + \varphi_{comp}(r,\lambda)$$

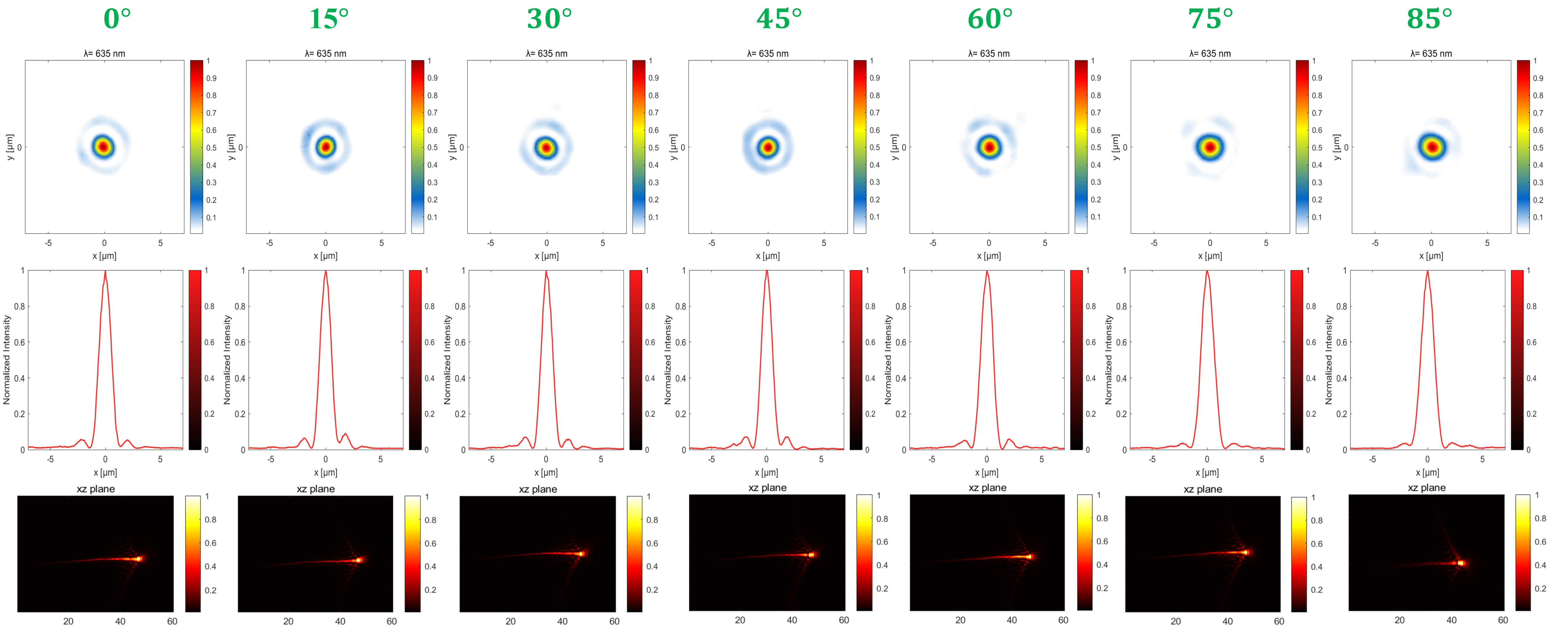
$$\varphi_{AM\_L}(r,\lambda) = -\frac{2\pi}{\lambda_{max}}\left(\sqrt{r^2+f_L^2}-f_L\right) - 2\pi\left(\sqrt{r^2+f_L^2}-f_L\right)\left(\frac{1}{\lambda}-\frac{1}{\lambda_{max}}\right) + \varphi_{comp}(r,\lambda)$$



MetaLOGIX

Engineering Light-Matter Interactions:
WFOV Meta-lensing

Measured Response at different AOI



Light Structuring

Light Beam: Stream of Photons

LM: $\hbar k$/photon

AM

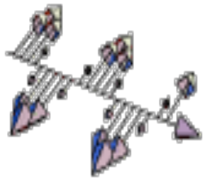
Along the Beam Axis: Perpendicular to Wave-fronts

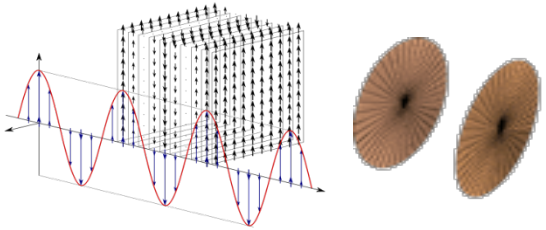
SAM: $\pm\hbar$/photon

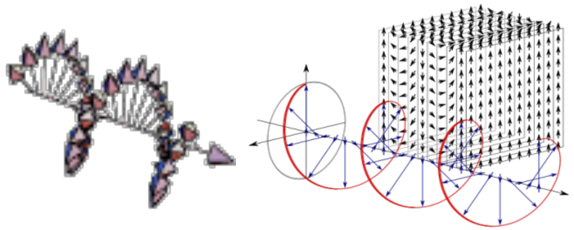
OAM: $m\hbar$/photon

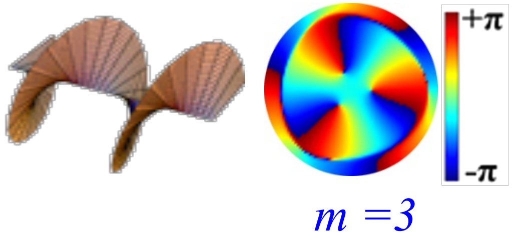
Associated with Pol. State i.e., Circular Polarization

Originating from Light's Helical Phase-front (Spatial Distribution)





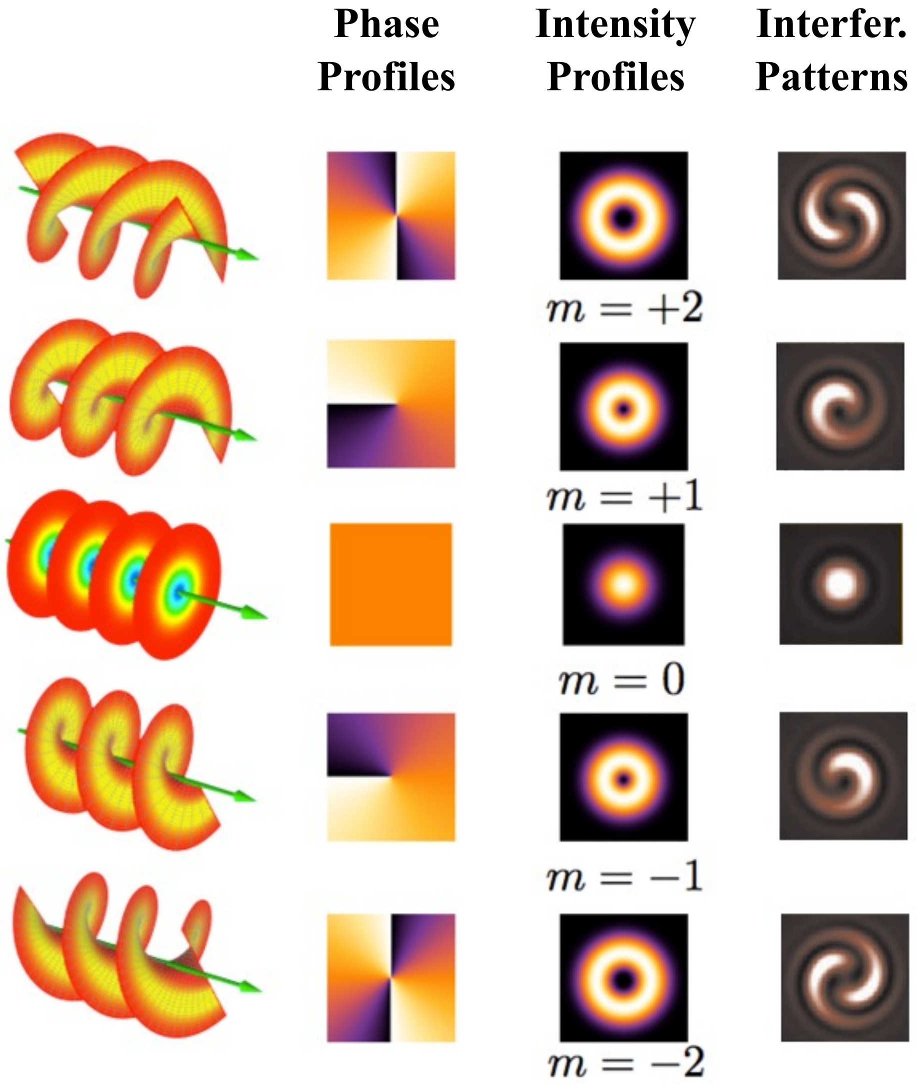




LM: Linear Momentum, **SAM:** Spin Angular Momentum, **OAM:** Orbital AM, ***m*:** Topological Charge, $\hbar$= Reduced Plank's constant=1.054*10^{-34}J.s.

Optical Vortex (OV) definition and Beam-shapes:

- In an OV [expressed by **exp(-$im\theta$)**], light is twisted around its axis.
- Because of **twisting**, light waves at the axis cancel each other, resulting in **ring-shaped light**.
- The OV is given a number, called the **topological charge (*m*)**, which shows **how many twists** the light does in **one wavelength**. The higher the number of the twist, the faster the light is spinning around the axis. **This spinning carries OAM**.
- **Interfering** an OV with a plane wave reveals **concentric spirals**. **Number of spiral arms = *m***.



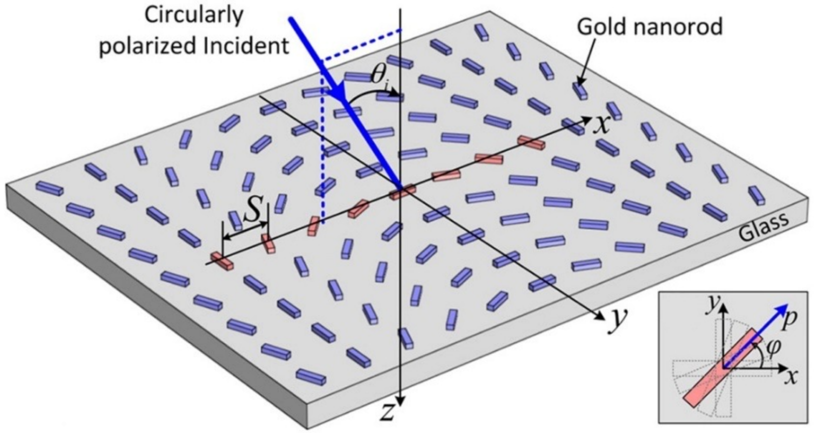
Spin-orbital AM of Visible Light via Ultrathin Metasurfaces:

Why Babinet-inverted is used?

- Because the proposed design follows **Babinet's principle** i.e., the field scattered by the complementary structure is equal to the its original structure.
- **Motivation** for Babinet-inverted design: **High** signal to noise (**SNR**) ratio for the scattered light.

Original Structure

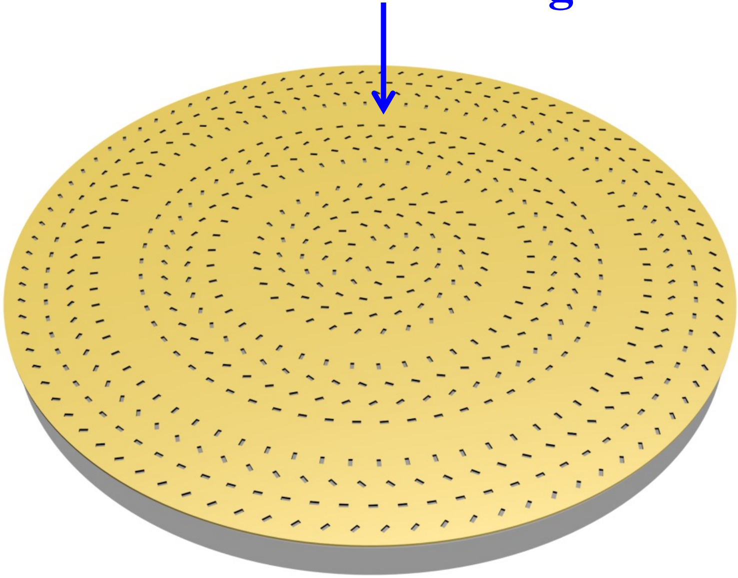
Gold nanobars on glass substrate



Nat. Comm. 12, 3, 1198, (2012).

Complementary Surface

Nano-voids etched into gold-film

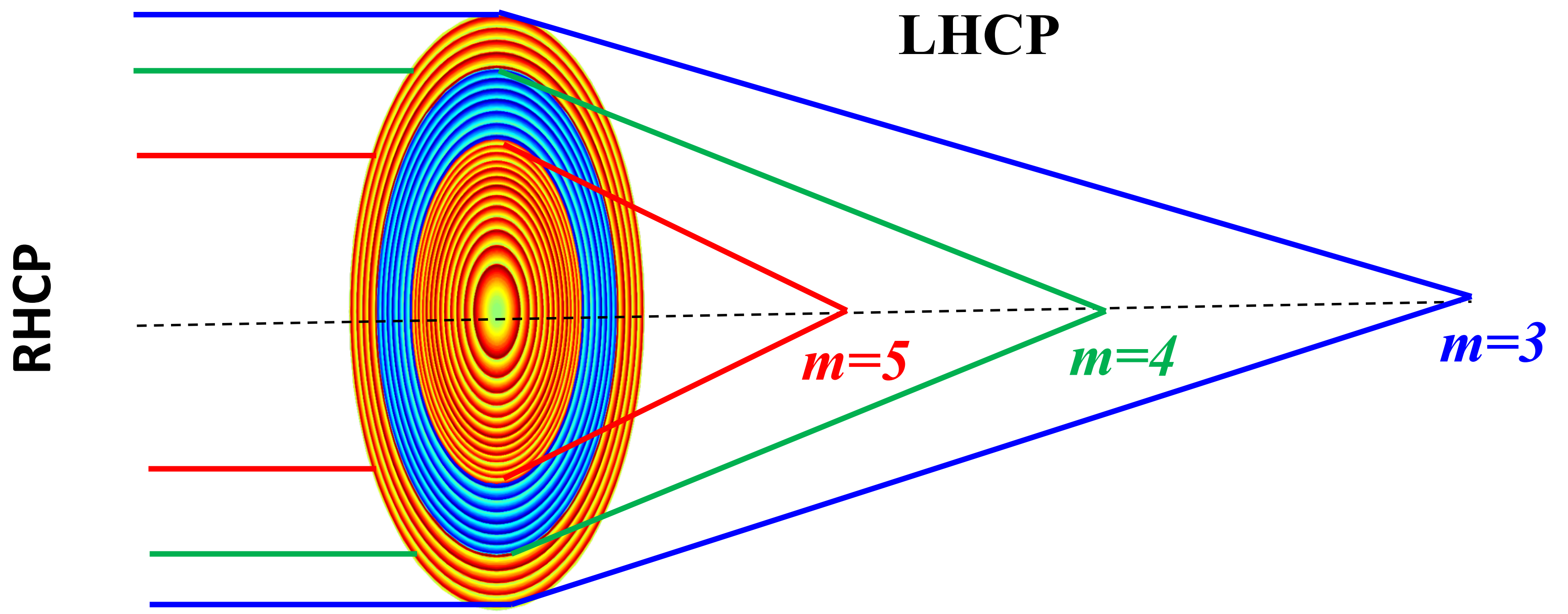


Proposed Babinet-inverted Design

Multi-focus OV Lenses (Contd…):

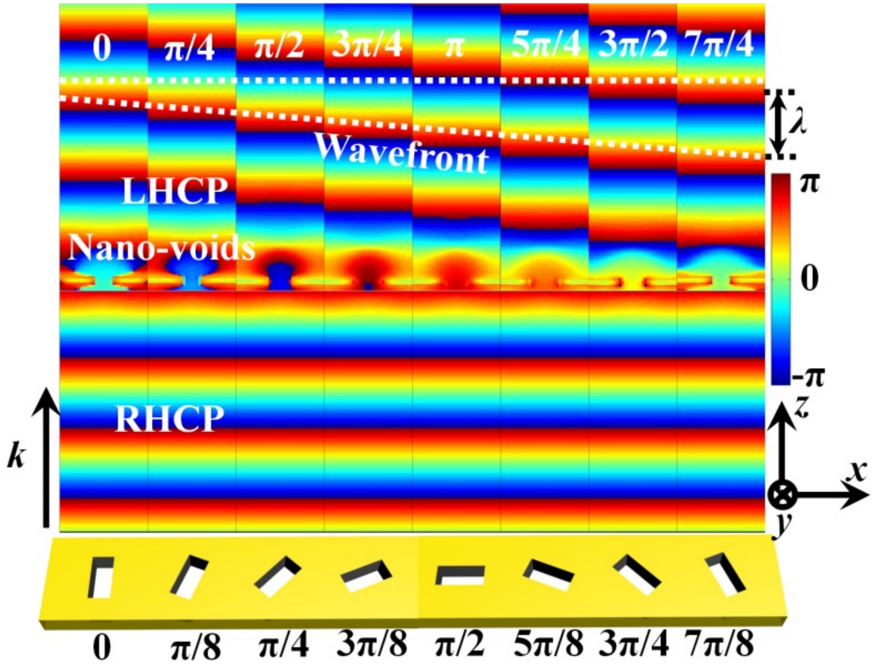
Angular Rotation for Focusing — **Angular Rotation for SPP**

$$\varphi_s = \varphi_{s1}(r) + \varphi_{s2}(r) = \pm 0.5\left[k_0\left(\sqrt{r_s^2 + f^2} - |f|\right) + m.\tan^{-1}\left(y/x\right)\right]$$

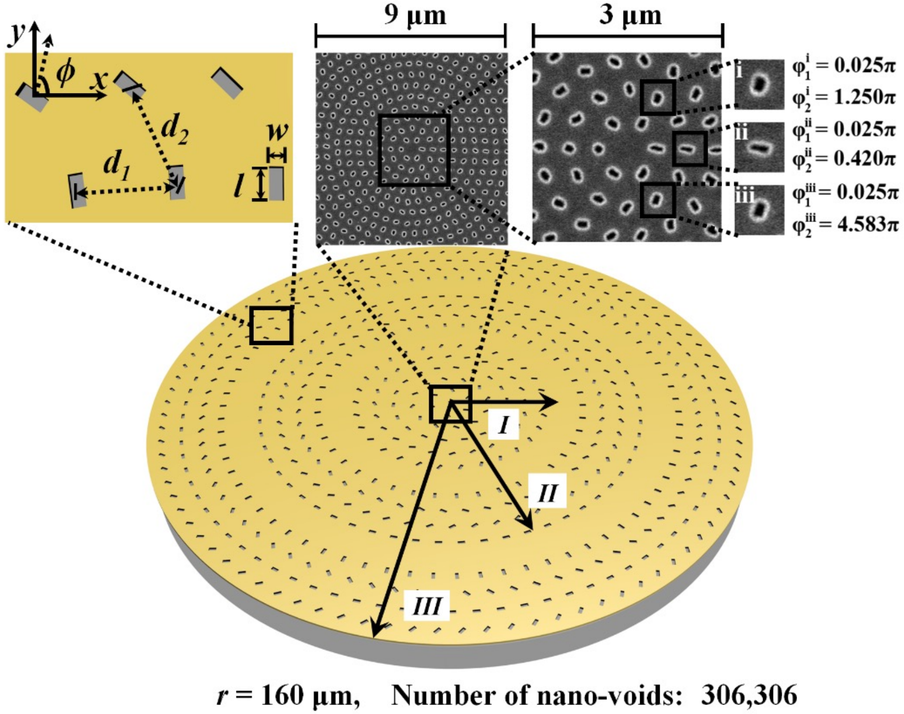


Multi-focus OV Lenses (Contd…):

Rotation vs Phase Varuiation



Desing details & SEM

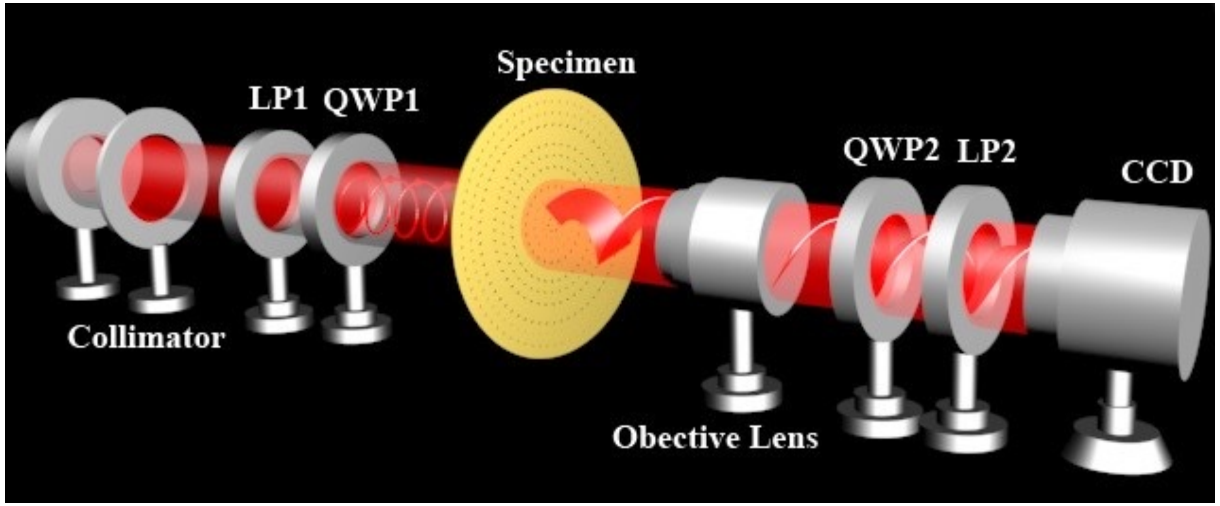


l×*w*×*h*=150×75×60 nm

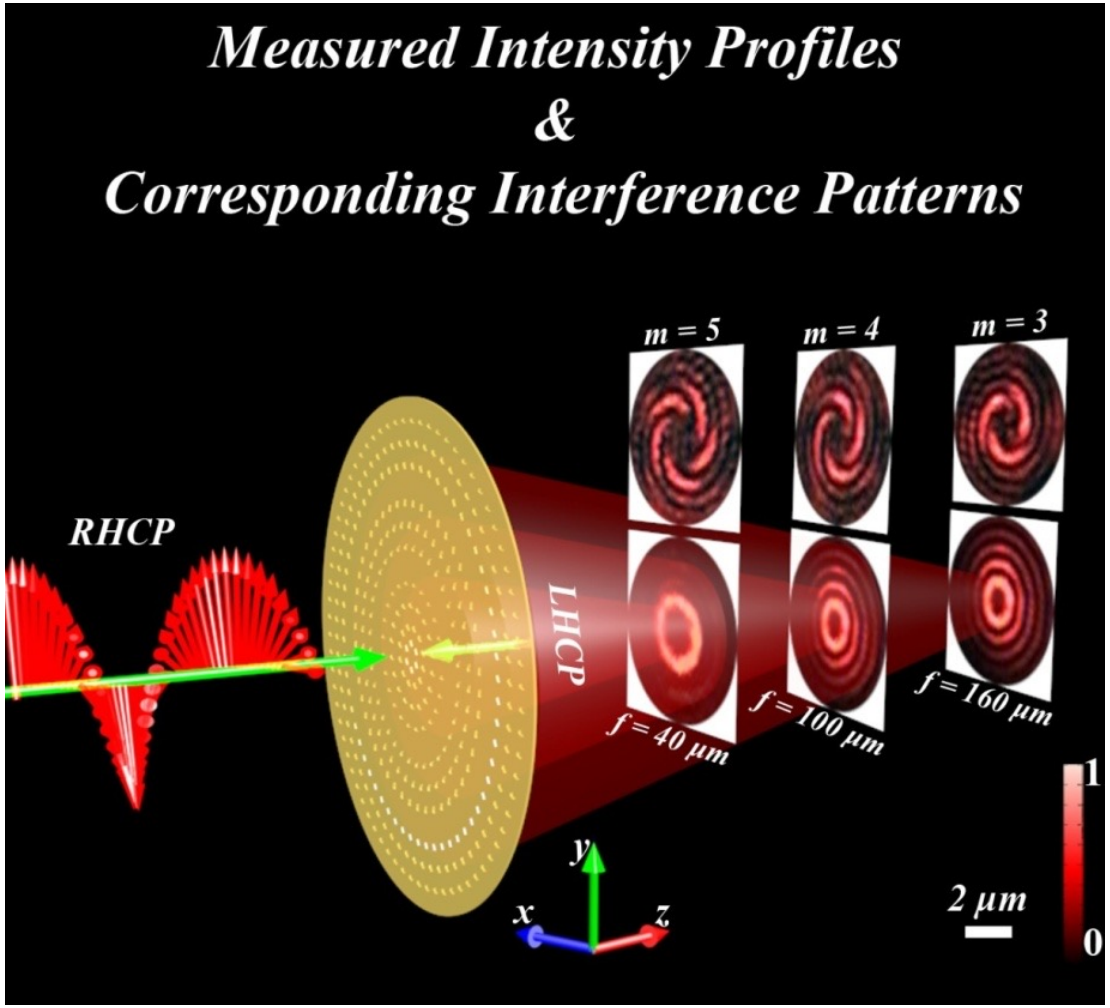
Adv. Matt., (2015).

Multi-focus OV Lenses (Contd…):

Experimental Set-up



RHCP-illumination/LHCP-detection



Where,

- LP1 & LP2 = Linear Polarizer, QWP1 & QWP2 = Quarter Wave Plates
- Objective Lens = × 100,
- Laser Source = HeNe Laser of **632. 8 nm** wavelength.

Adv. Matt., (2015).

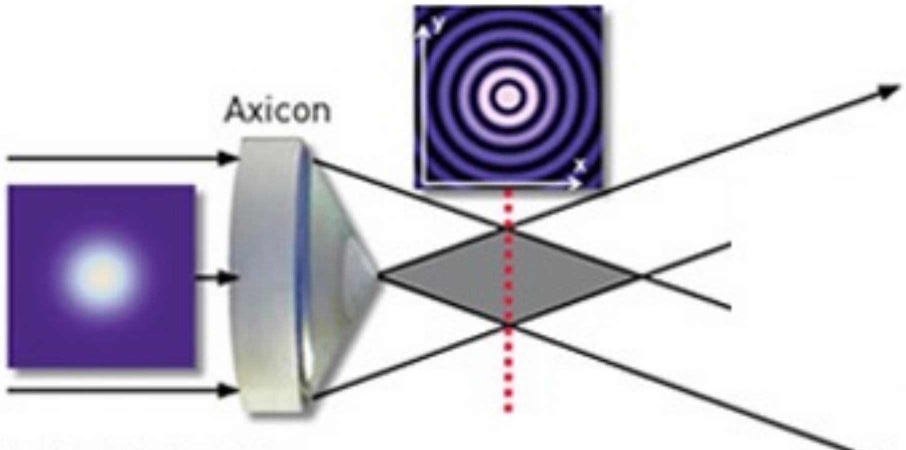
Flat Helical Axicons Lenses:

Motivation:

- An itriguing **concept of merging multiple bulk devices** into a single ultrathin device **is extended.**
- Phase profiles of **spiral phase plates and axicons** are integrated into a single metasurface to mimic the optical performance of **helical axicon**.

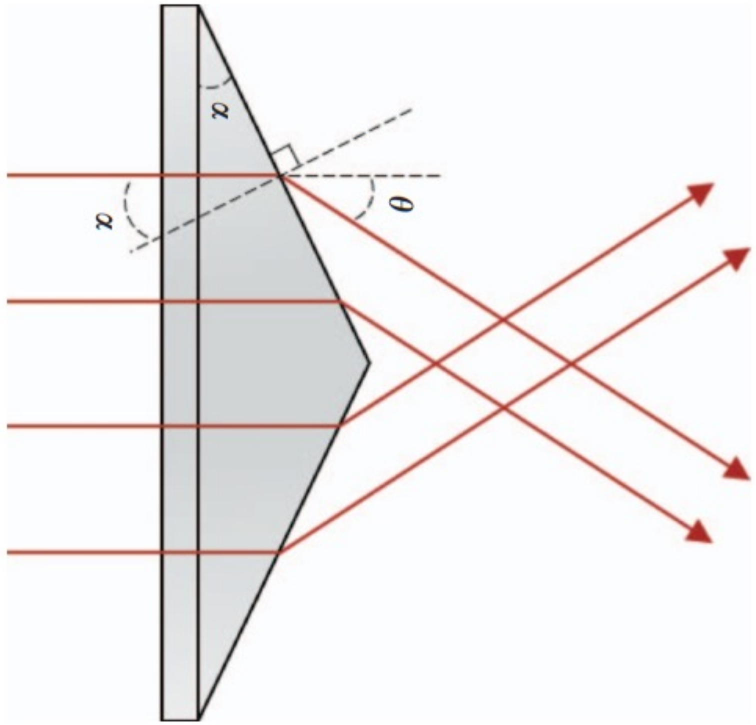
Axicon:

- A specialized type of lens that transforms a Gaussian beam into an approximation of a **Bessel beam** (with **greatly reduced diffraction**).



Courtesy of Andrew Forbes

Zero and Higher Order Bessel Beams via Meta-axicons



Numerical aperture (NA) of an axicon is related to the angle α

$$NA = \sin\theta = \sin[\sin^{-1}(n \cdot \sin\alpha) - \alpha]$$

Upper limit for α is 42 deg, and for NA is 0.75

For the generation of a **zeroth-order Bessel beam**, a radial phase profile ϕ (r)

$$\frac{d\varphi}{dr} = \frac{2\pi}{\lambda_d} \cdot \sin\theta$$

For an axicon with angle θ, the phase delay has to increase linearly with the distance from the center, creating a **conical phase distribution**

$$\varphi(x, y) = 2\pi - \frac{2\pi}{\lambda_d} \cdot \sqrt{x^2 + y^2} \cdot NA$$

For the **higher order Bessel beams**

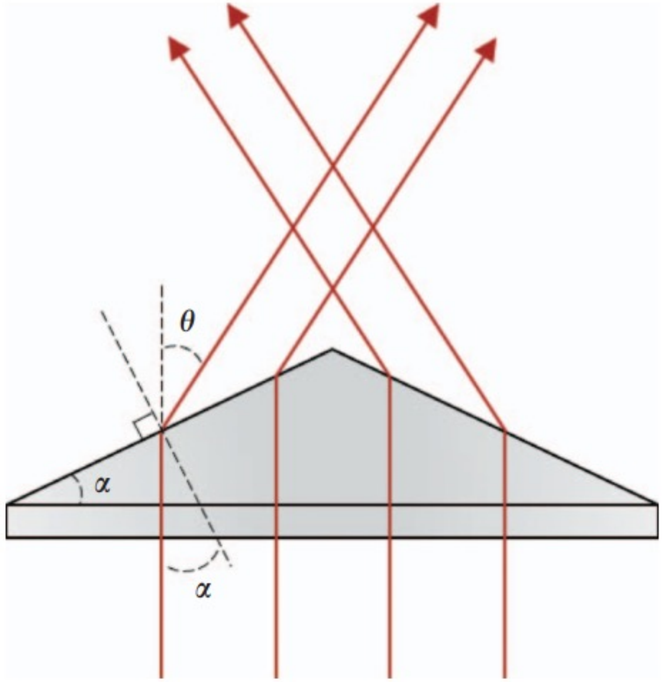
$$\varphi(x, y) = 2\pi - \frac{2\pi}{\lambda_d} \cdot \sqrt{x^2 + y^2} \cdot NA + m.\tan^{-1}(y/x)$$

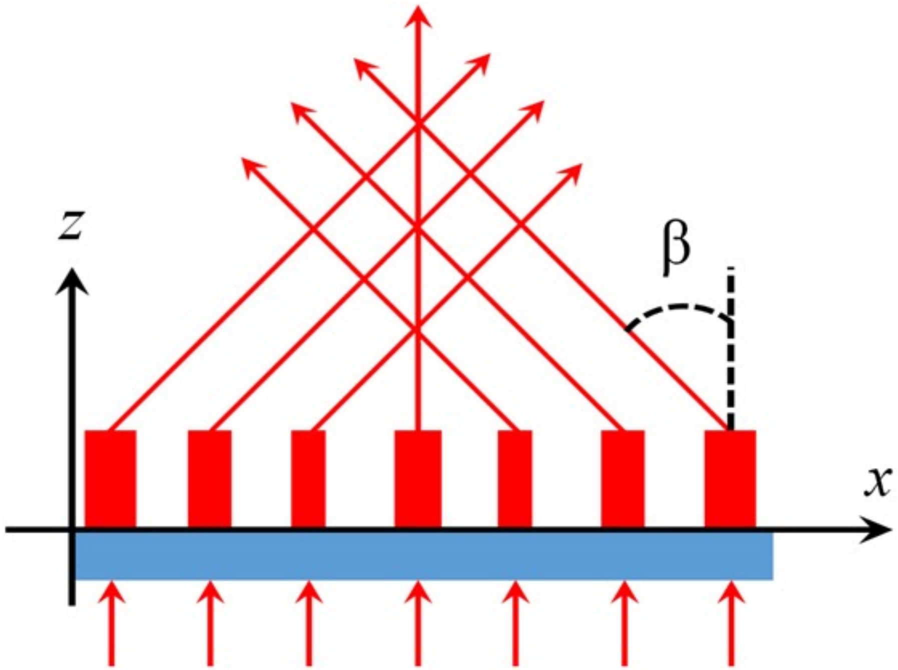
Light: Science & Applications (2017) 6, e16259

Zero and Higher Order Bessel Beams via Meta-axicons

INFORMATION TECHNOLOGY UNIVERSITY

Comparison between axicon and Metaaxicon:





- Bulky
- Sub-wavelength Focal Spot
- Lower NA (Upper Limit = 0.75)
- Can't generate Higher-order Bessel Beams as a standalone device

- Compact
- Sub-wavelength Focal Spot
- High NA
- Can generate Higher-order Bessel Beams as a standalone device

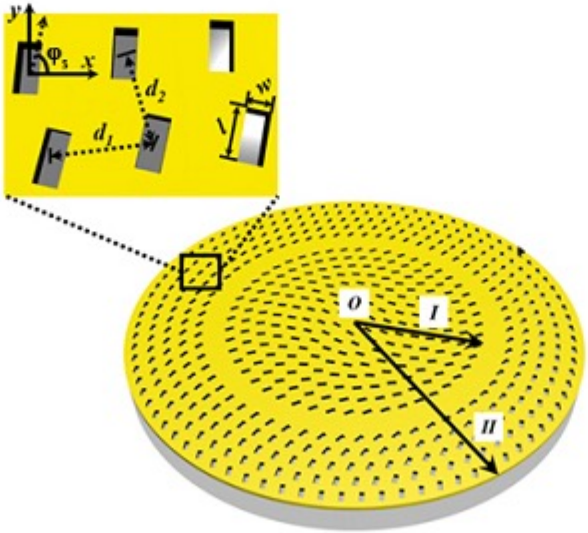
Flat Helical Axicons Lenses (Contd…):

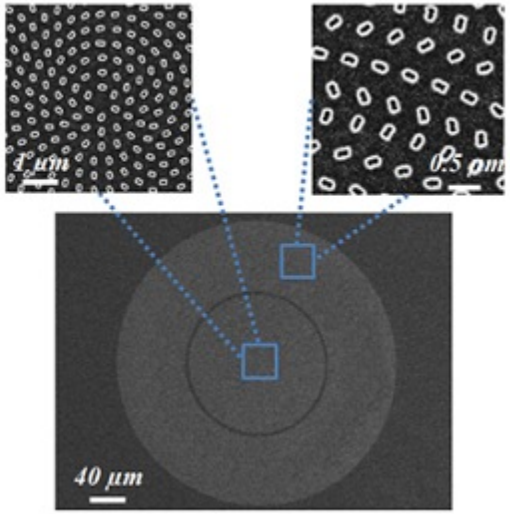
Phase profile of Helical Axicons Lenses:

Angular Rotation for Axicon

Angular Rotation for SPP

$$\varphi_s = \varphi_{s1}(r) + \varphi_{s2}(r) = \pm 0.5\left[k_0 r \sin\beta + m.tan^{-1}\left(y/x \right) \right]$$



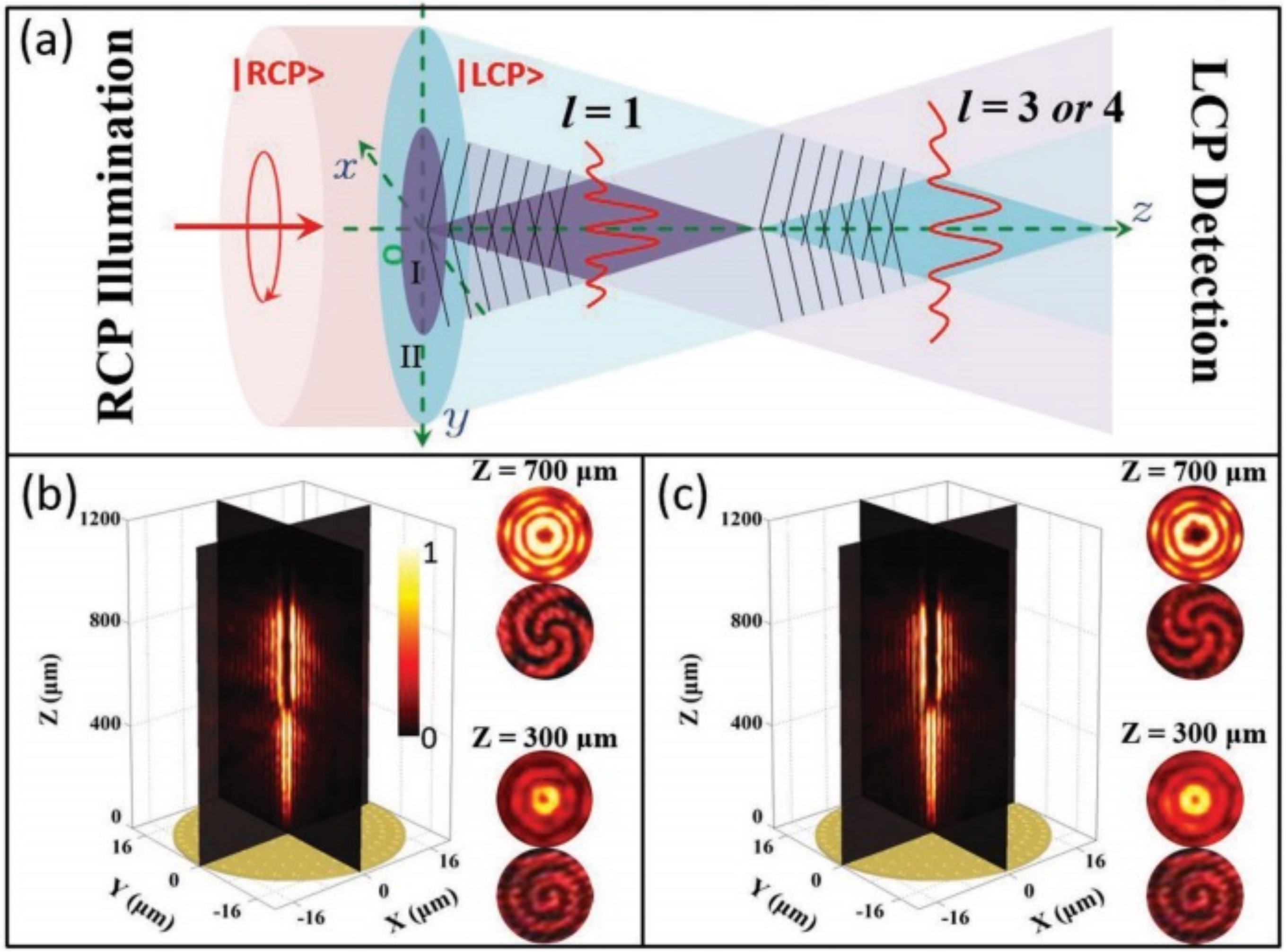


Adv. Fun. Mat.

Flat Helical Axicons Lenses (Contd…):

Schematic of Helical Axicon and Measured Results:

Inner = 0 to 430 µm,
outer = 470 to 950 µm.



Adv. Fun. Mat.

Meta-Holography

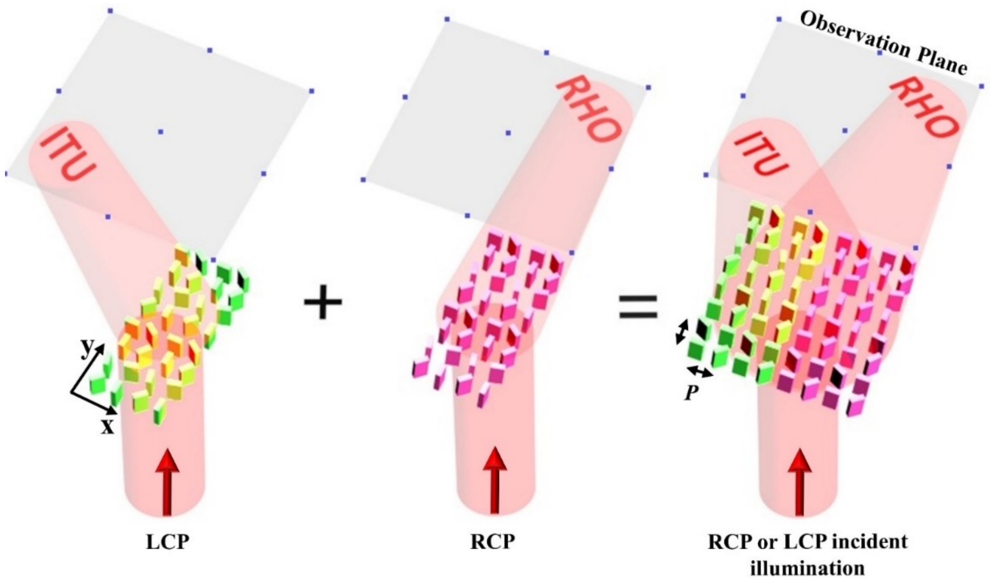
Spin-encoded Meta-Holograms

INFORMATION TECHNOLOGY UNIVERSITY

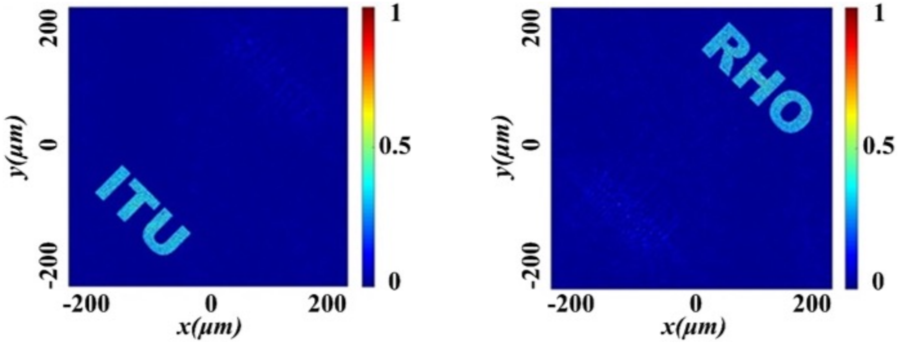
Design and Optimizations:

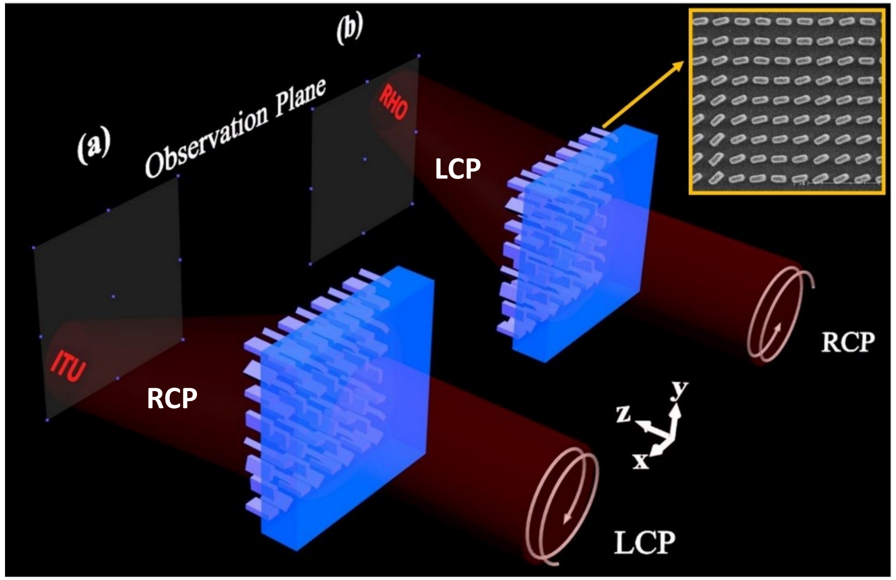
Afnan et. al., Laser & Photnics Review, 1900065, (2019)

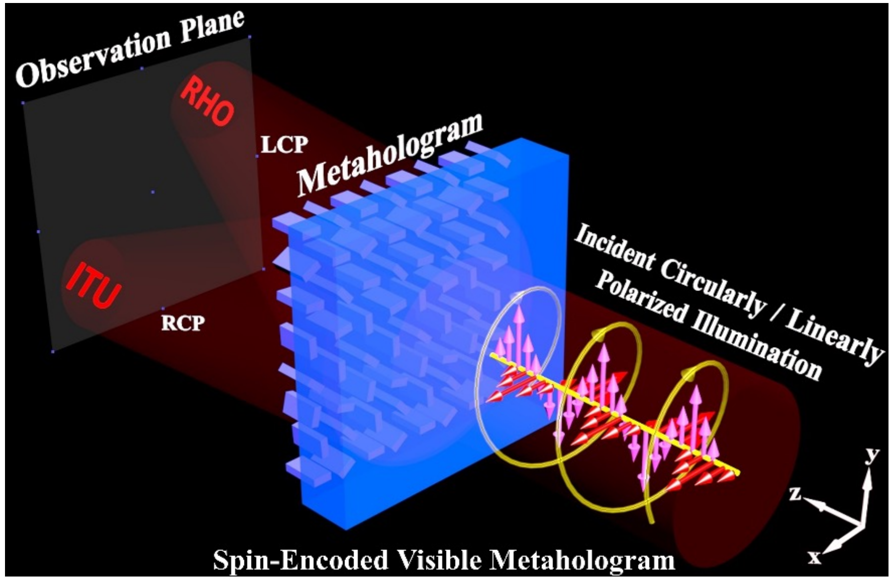
Design Topology



Simulation Results



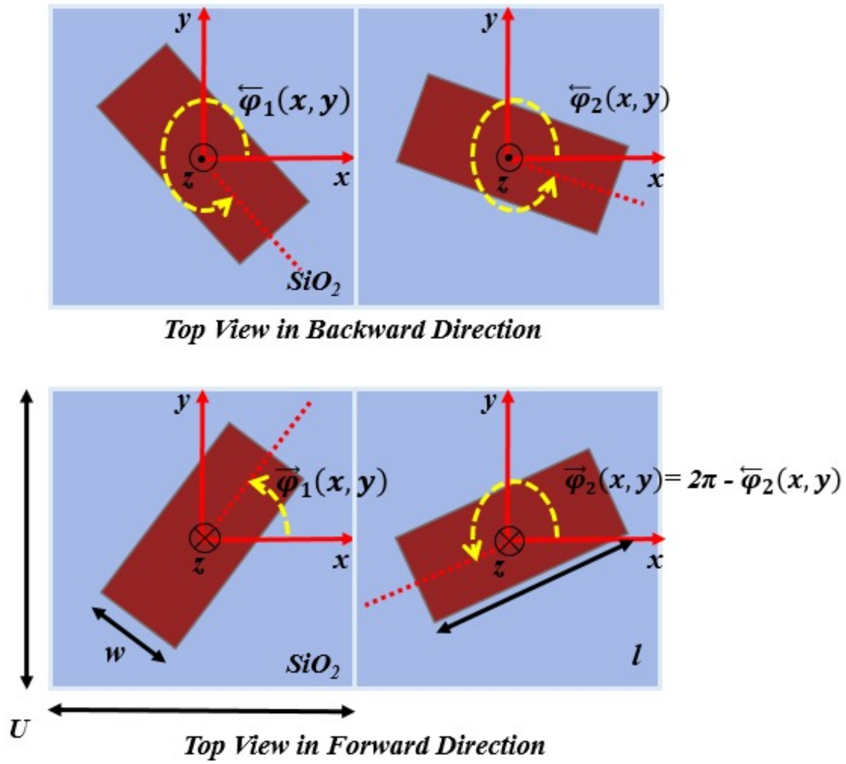


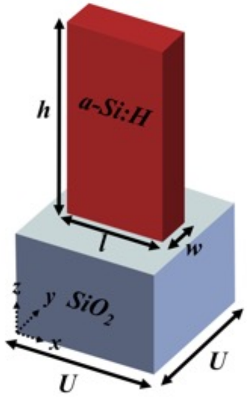


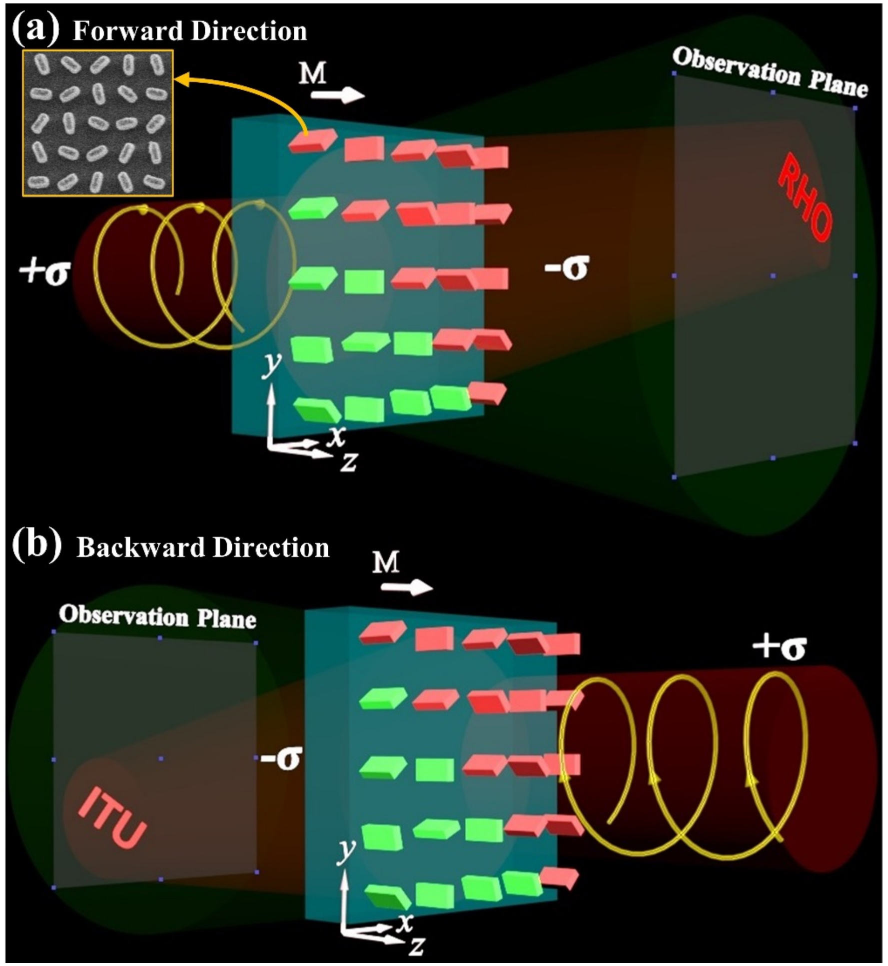
LCP/RCP = Left/Right Circularly Polarized, E/LP = Elliptically/Linearly Polarized

3.1) Direction-Multiplexed Meta-holograms

Direction-multiplexed Metaholograms:







$$\vec{E}_t = \vec{E}_{t1} + \vec{E}_{t2} = \left[\frac{T_{11}+T_{22}}{2}.\vec{E}_L + \frac{T_{11}-T_{22}}{2}e^{i2\vec{\varphi}_1}.\vec{E}_R\right] + \left[\frac{T_{11}+T_{22}}{2}.\vec{E}_L + \frac{T_{11}-T_{22}}{2}e^{i2\vec{\varphi}_2}.\vec{E}_R\right]$$

$$\overleftarrow{E}_t = \overleftarrow{E}_{t1} + \overleftarrow{E}_{t2} = \left[\frac{T_{11}+T_{22}}{2}.\overleftarrow{E}_L + \frac{T_{11}-T_{22}}{2}e^{i2\overleftarrow{\varphi}_1}.\overleftarrow{E}_R\right] + \left[\frac{T_{11}+T_{22}}{2}.\overleftarrow{E}_L + \frac{T_{11}-T_{22}}{2}e^{i2\overleftarrow{\varphi}_2}.\overleftarrow{E}_R\right]$$

$$\vec{E}_t \approx \frac{T_{11}-T_{22}}{2}e^{i2\vec{\varphi}_1}.\vec{E}_R + \frac{T_{11}-T_{22}}{2}e^{i2\vec{\varphi}_2}.\vec{E}_R$$

$$\overleftarrow{E}_t \approx \frac{T_{11}-T_{22}}{2}e^{i2\overleftarrow{\varphi}_1}.\overleftarrow{E}_R + \frac{T_{11}-T_{22}}{2}e^{i2\overleftarrow{\varphi}_2}.\overleftarrow{E}_R$$

Optical System: Polarization Multiplexing (1/2)

Design Methodology

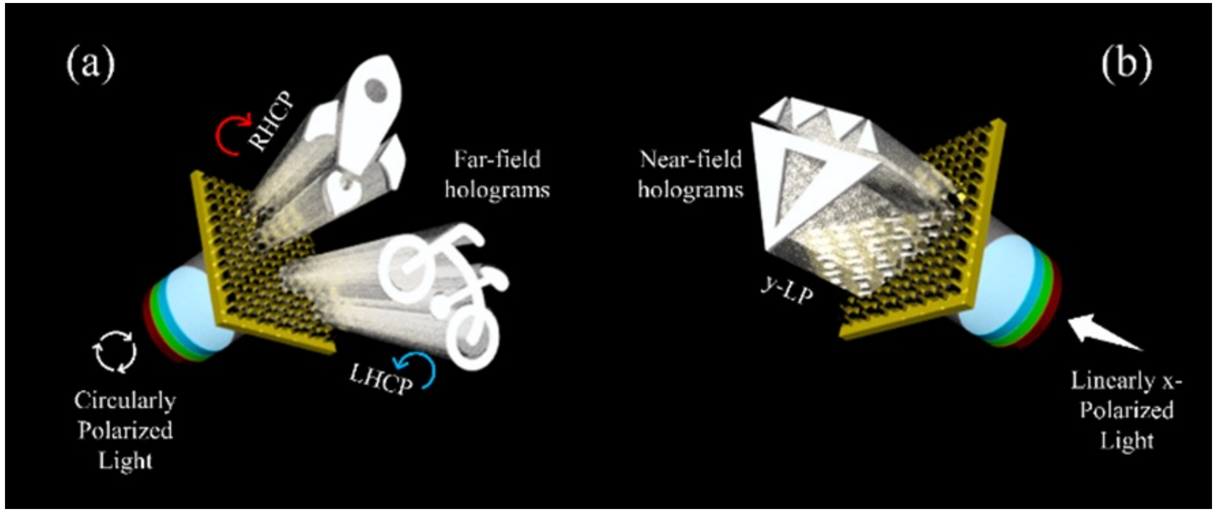
Geometric phase modulation of the LHCP and RHCP:

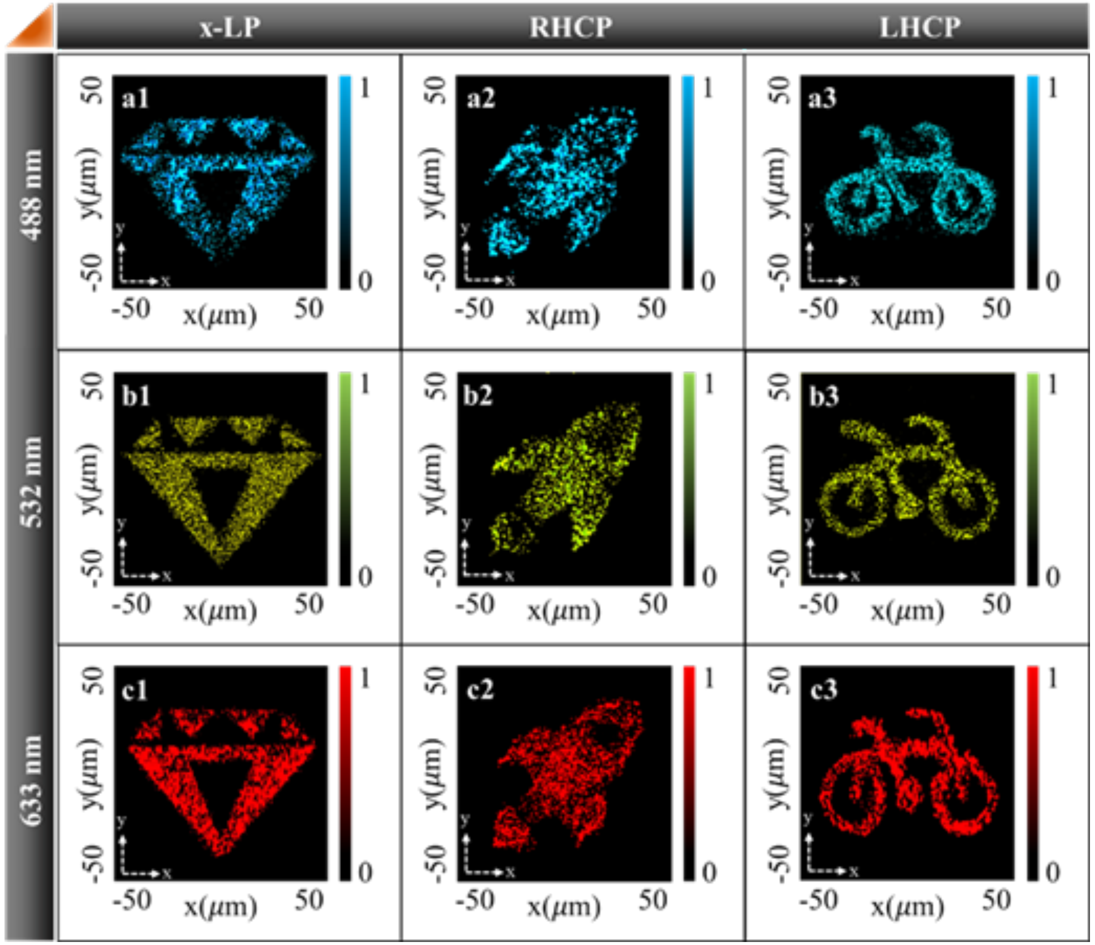
$$\varphi_m = \arg[\cos\varphi_{iR} + \cos\varphi_{iL} + i.(\sin\varphi_{iR} - \sin\varphi_{iL})],$$

$$\varphi_t = \arg\left[\exp i.\left(\tan^{-1}\left[\tan\left(\frac{\varphi_{iL} - \varphi_{iR}}{2}\right)\right]\right)\right].$$

The near-field amplitude modulation:

$$I(\zeta) = I_0 Cos^2 2\zeta$$

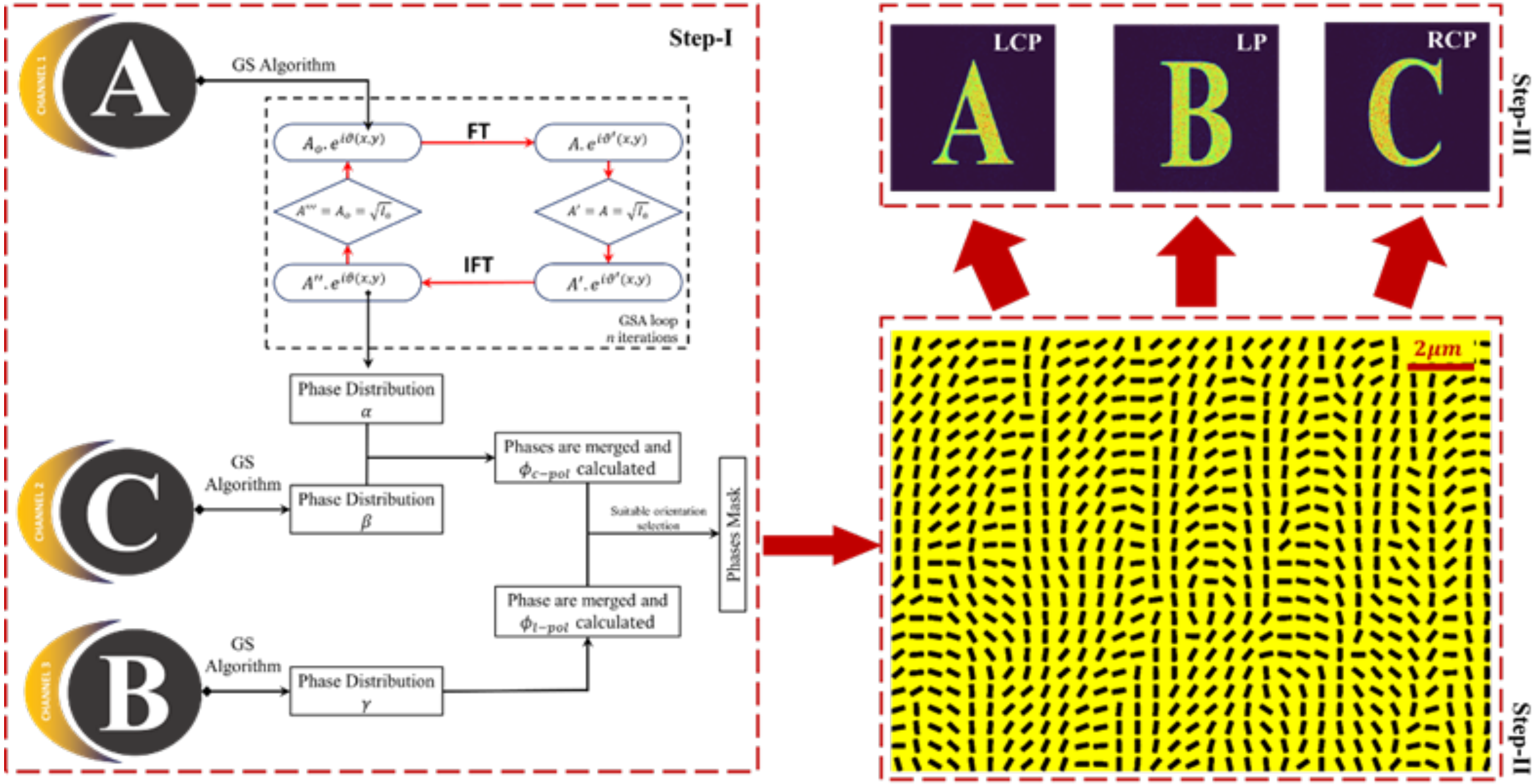




Aberrations

Optical System: Multi-operational Metasurfaces

Design Flow



Aberrations

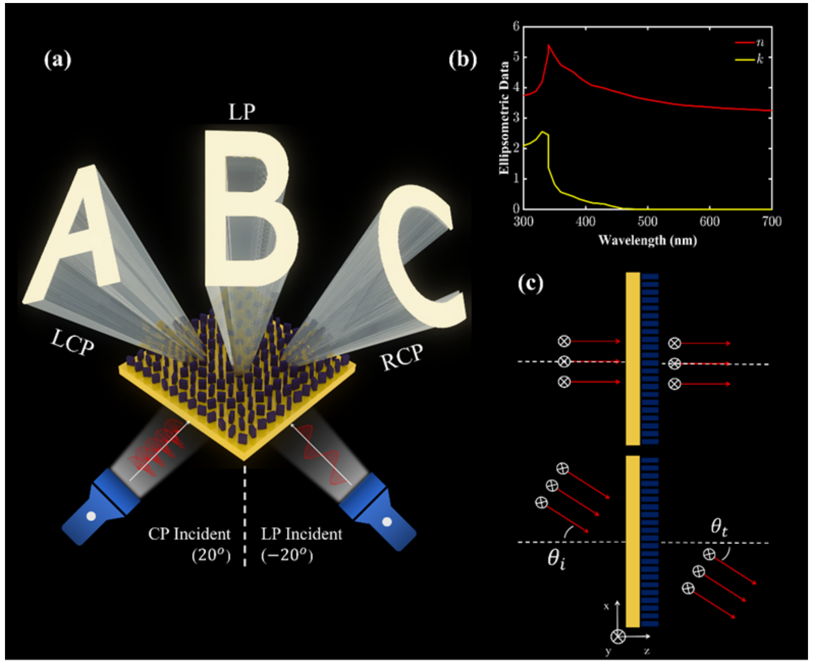
Optical System: Multi-operational Metasurfaces

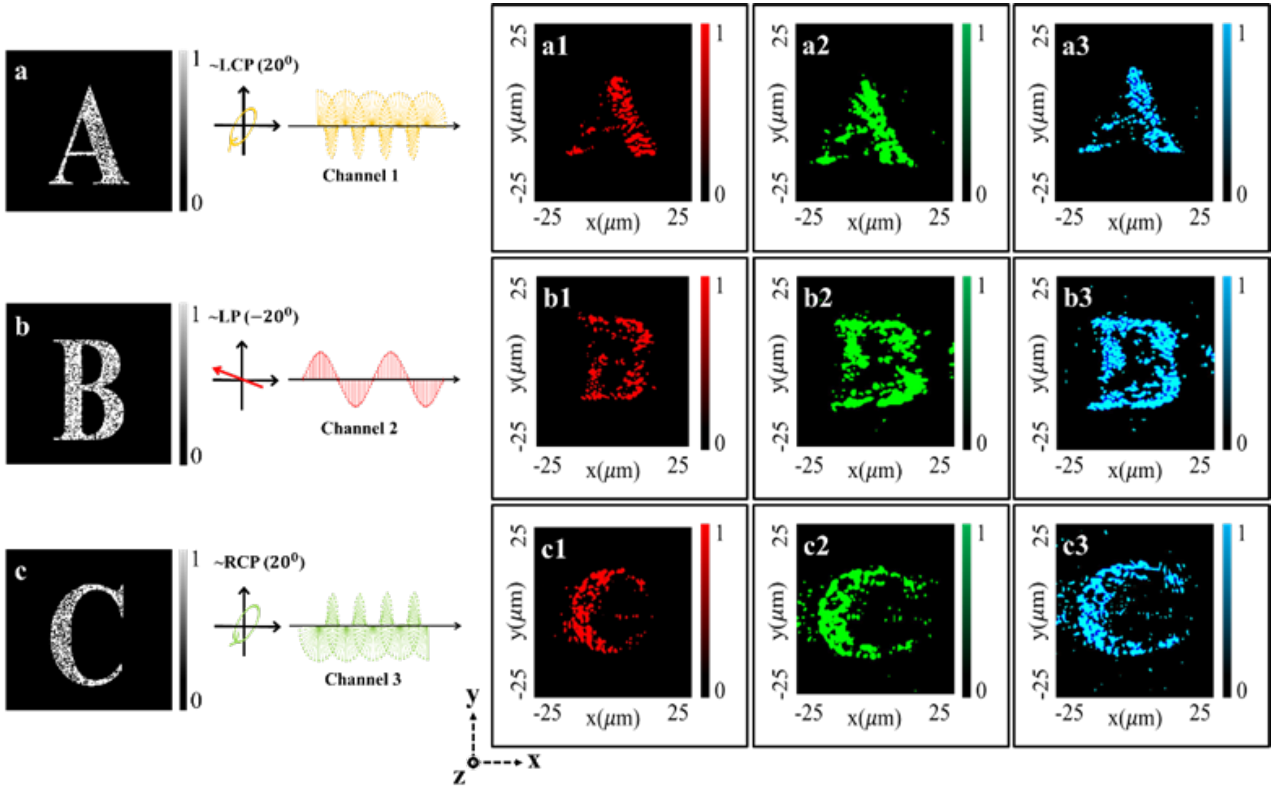
Design Scheme

$\phi_{c-pol} = \arg[\exp(i\alpha) + \exp(-i\beta)]$. >> circular polarization

$\phi_{l-pol} = \arg[\exp(i\gamma) + \exp(-i\gamma)]$. >> liner polarization

$$\phi_{net}(x,y) = \arg[\exp(i\phi_{l-pol}) + \exp(i\phi_{c-pol})]$$





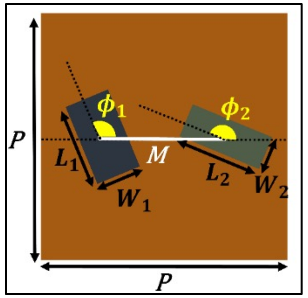
Metadevices

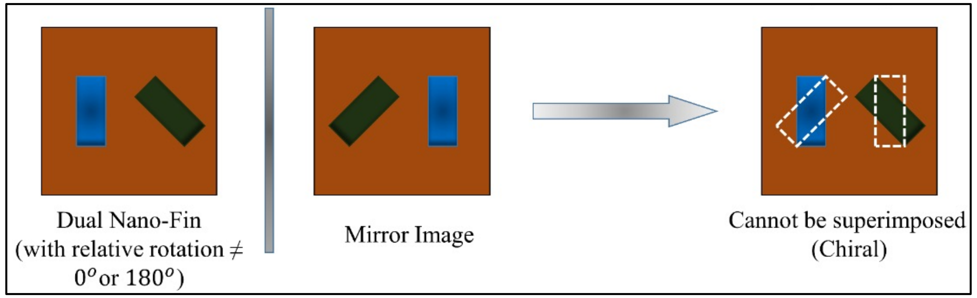
Broadband Chirality & Polarization Insensitiveness

Adv. Optical Mater. 2021, 9, 2002002.

Nanophotonics, vol. 9, no. 4, 2020, pp. 963-971

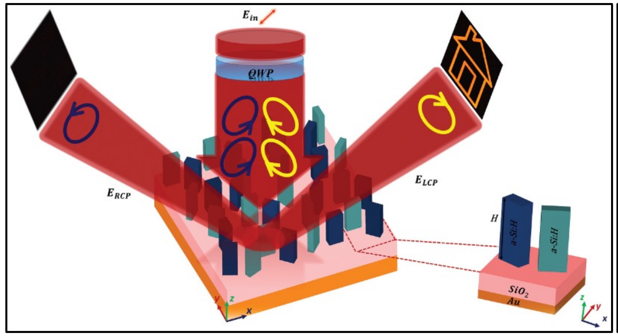
Diatomic Structures for Broadband chirality & Polarization Insensitiveness):

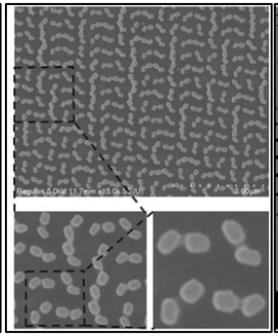


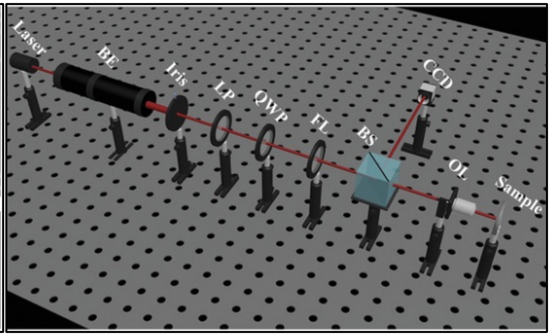


$$R_T = \frac{1}{2} e^{i2\pi M/P_x} \begin{bmatrix} 0 & e^{-i(2\phi_1-\tau_1)} + e^{-i(2\phi_2-\tau_2)} \\ e^{i(2\phi_1+\tau_1)} + e^{i(2\phi_2+\tau_2)} & 0 \end{bmatrix}$$

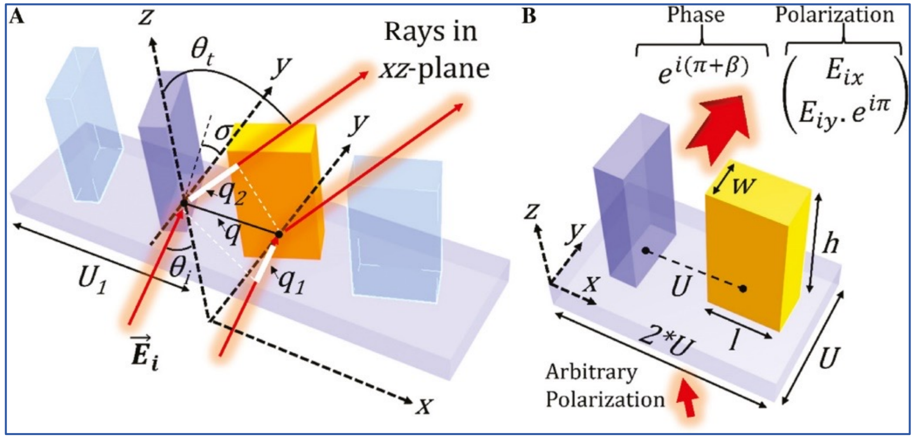
Assuming $\tau_1 - \tau_2 = \frac{\pi}{2}$, $\Delta\phi = \phi_1 - \phi_2 = -\frac{\pi}{4}$ and $P_x = 2M$

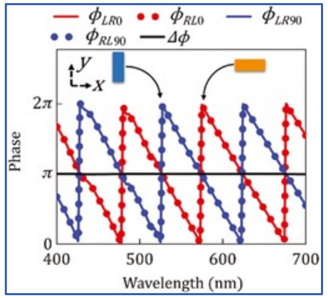


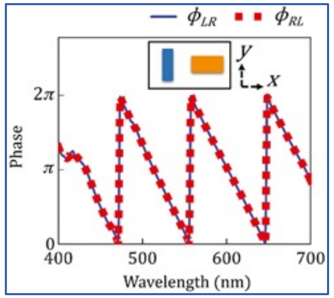


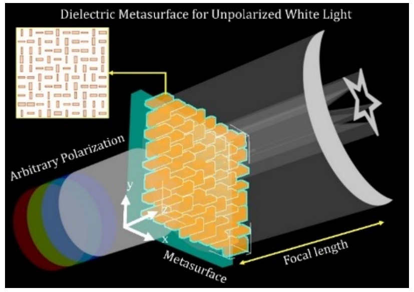


$$\vec{\boldsymbol{E}}_t(z,t) = J(\sigma).\widehat{\boldsymbol{E}}_{\pm inc} = \frac{t_p + t_s}{2}\begin{pmatrix} 1 \\ \pm i \end{pmatrix} \mp \frac{t_p - t_s}{2} e^{i\gamma}\begin{pmatrix} 1 \\ \mp i \end{pmatrix}$$









Meta-optics @ MicroNano Lab

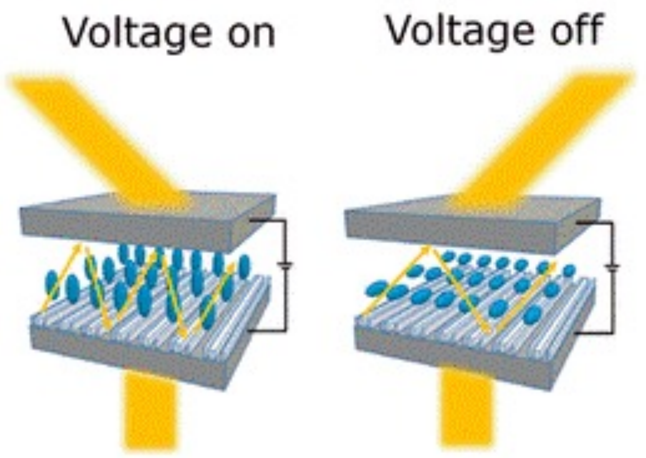
Tuneable Meta-optics

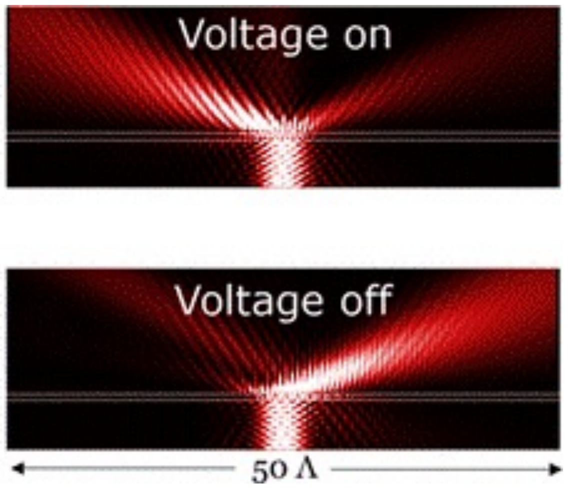
MicroNano Lab

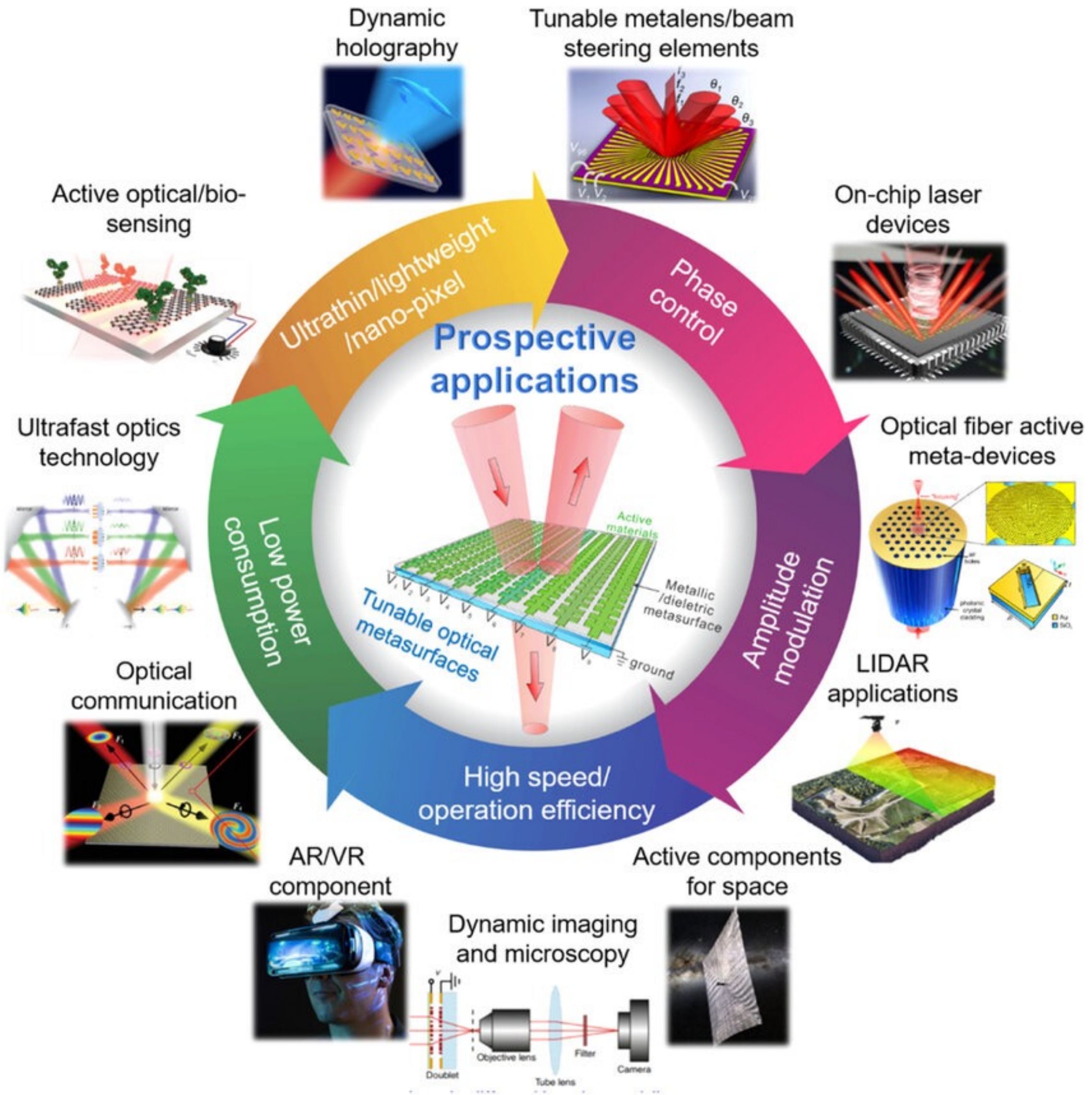
IU micronano

Introduction to Tunable Metasurfaces

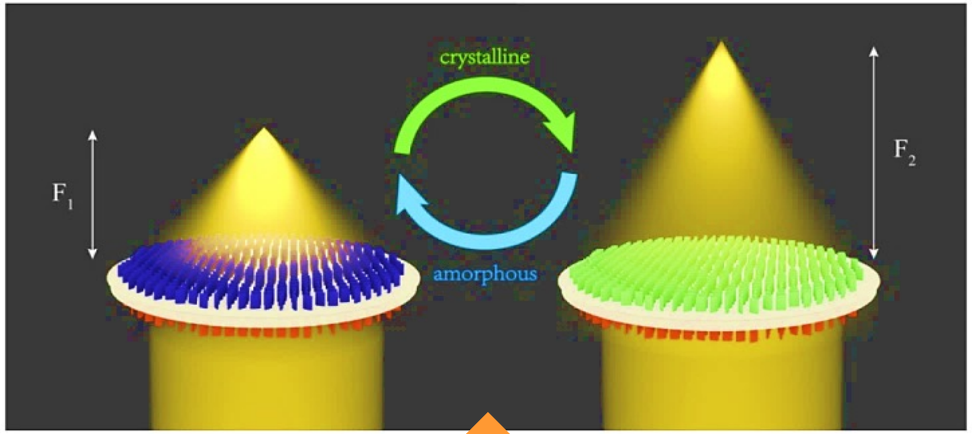
- The Tunable metasurfaces are a remarkable class of artificial materials that can dynamically control the properties of electromagnetic waves.
- By precisely engineering their structure and composition, these surfaces can achieve unprecedented control over the propagation, reflection, and absorption of light, enabling a wide range of advanced applications.



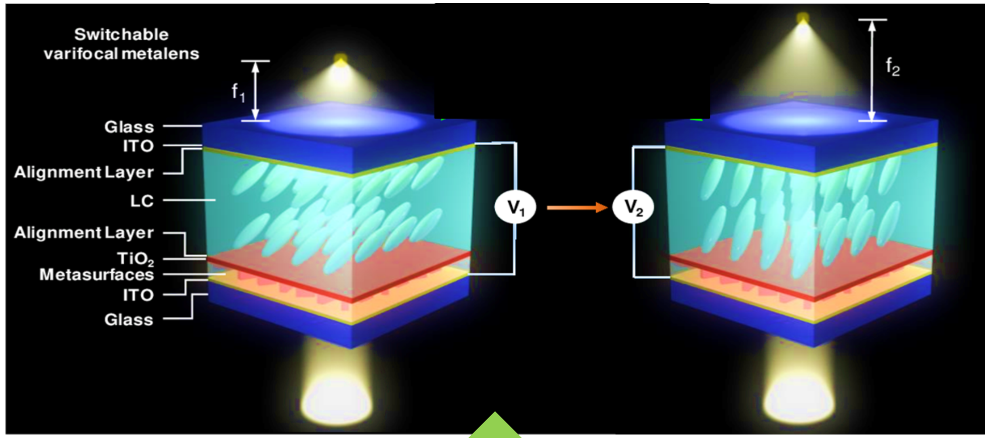




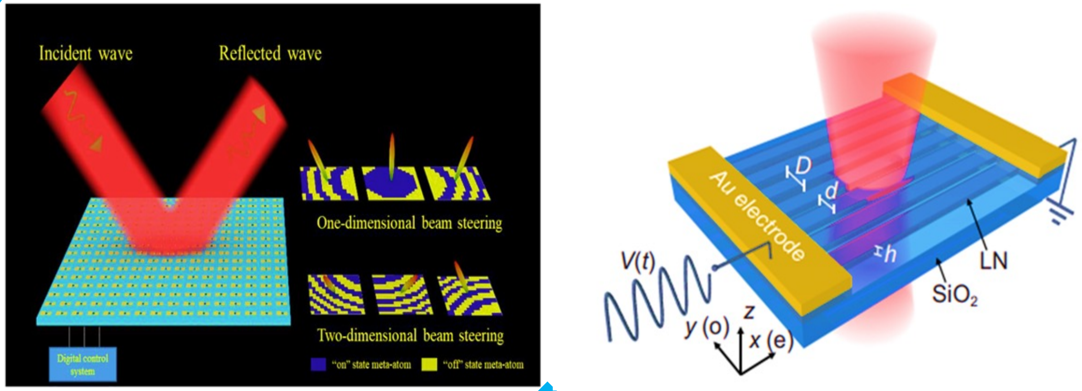
Tunability in Metasurfaces



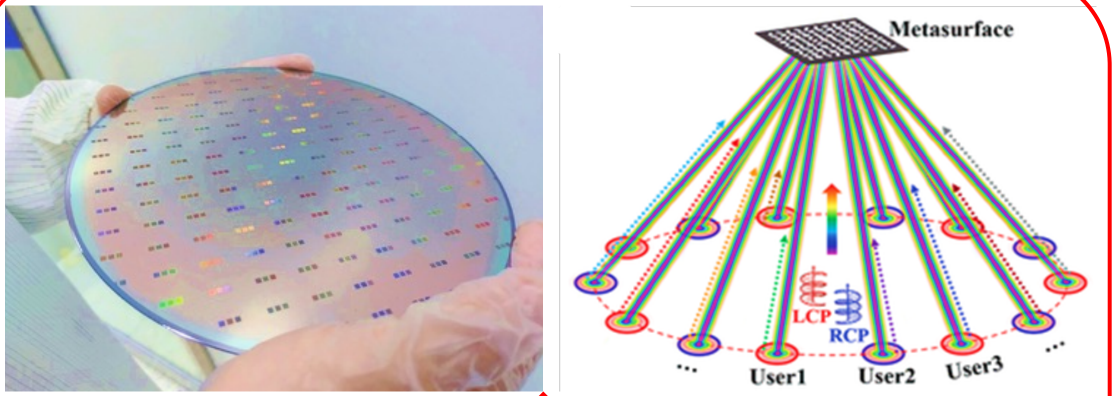
Tunable Metasurfaces by Phase Change Materials



Liquid crystal based Tunable Metasurfaces



Tunable Metasurfaces Using Lithium Niobate

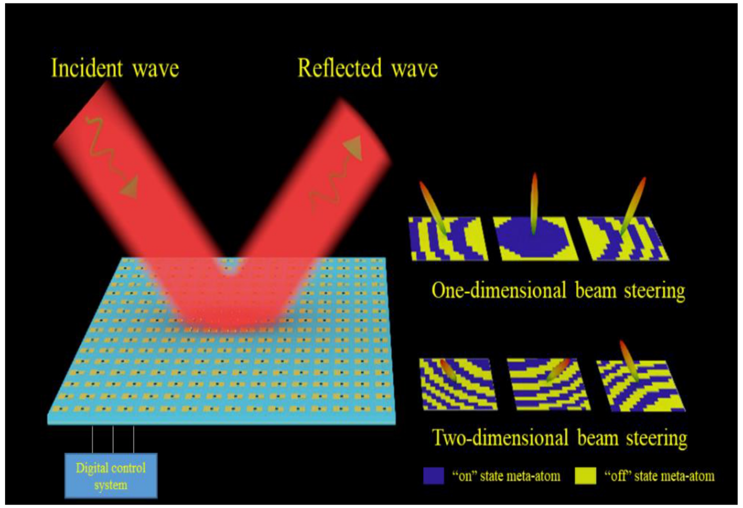


Mass manufactured tunable metasurface

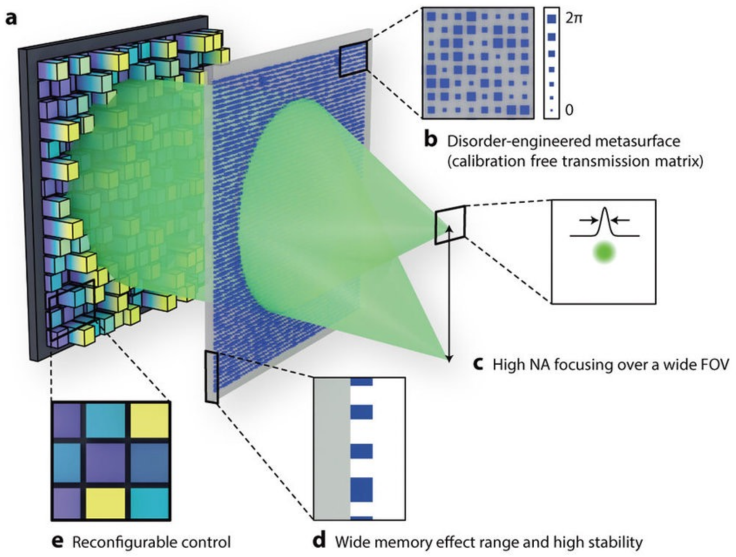
MicroNano Lab

Applications of Tunable Metasurface

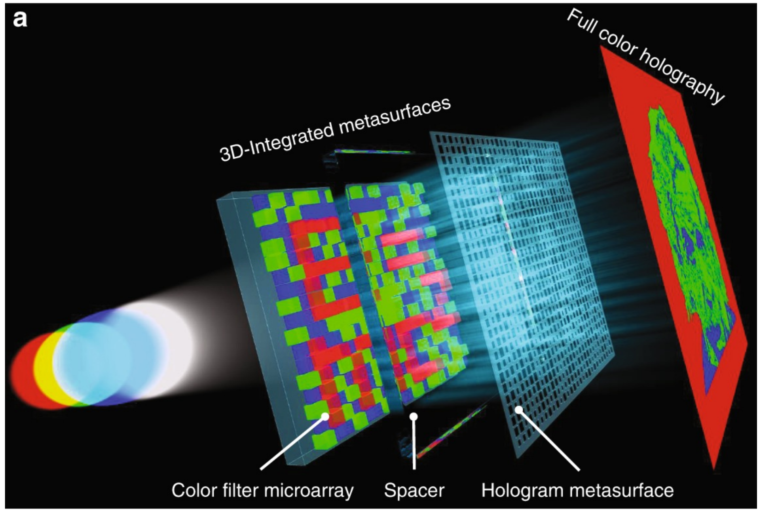
Beam Steering



Wavefront Shaping

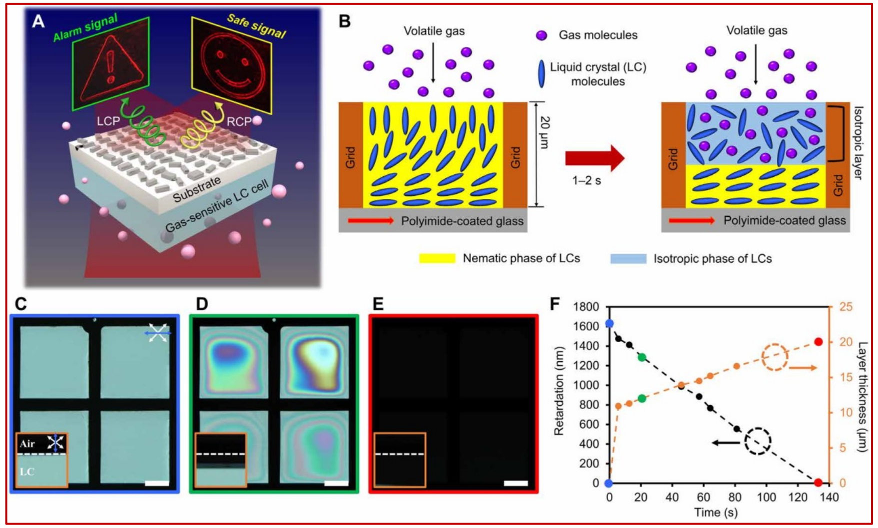


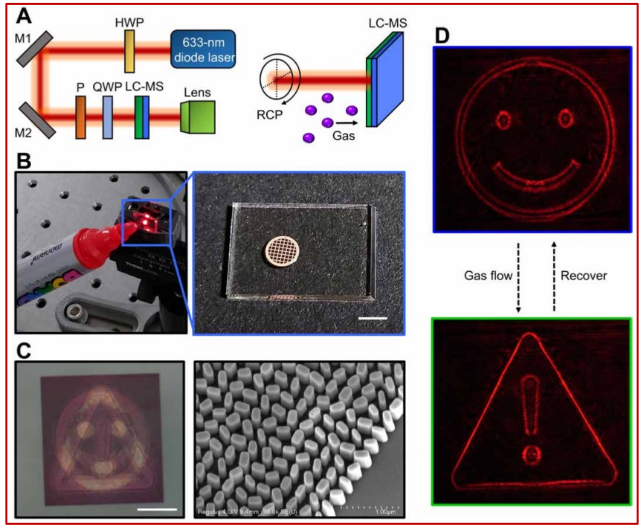
Holography

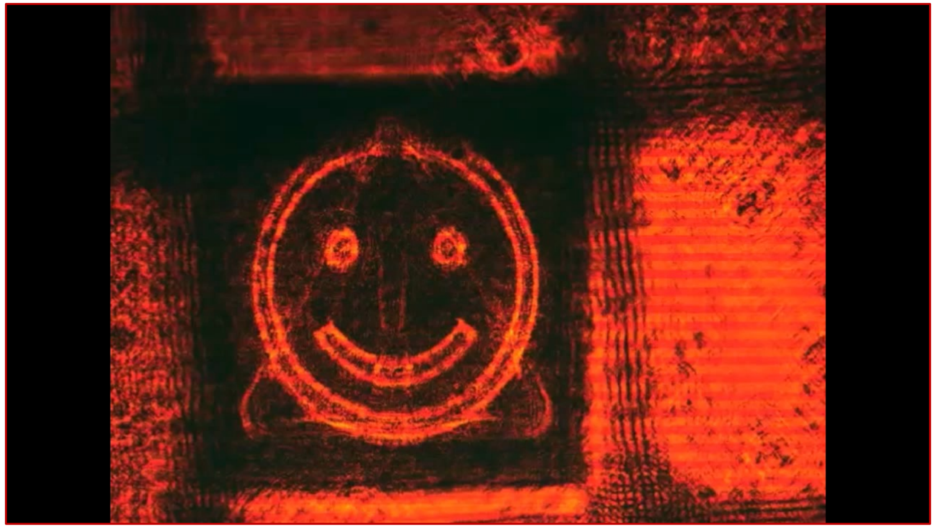


Metasurface based Visual Gas Sensor

- Our group has presented a **compact sensor platform** that integrates **liquid crystals (LCs)** and holographic metasurfaces (MSs) to promptly **sense a volatile gas** and provide instantaneous feedback **through a visual holographic alarm**.
- **Demonstration of an LC-MS gas sensor:** Optical setup for an LC-MS gas sensor is shown below.
- In the **absence of IPA gas**, the **RCP light** illuminated on the LC-MS sensor **passes the LC** layer **without any polarization conversion** and is transmitted into the metasurface.
- In contrast, the **LC** layer **converts the incoming RCP into LCP light** upon the **exposure of IPA gas**.



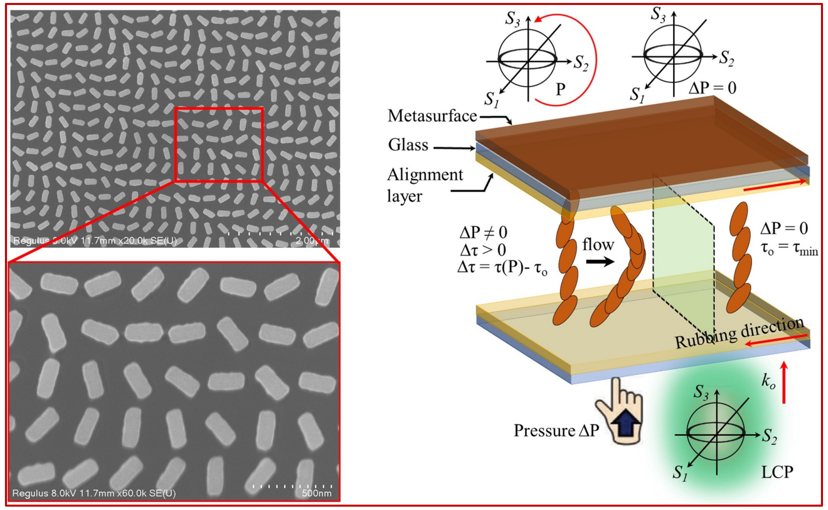


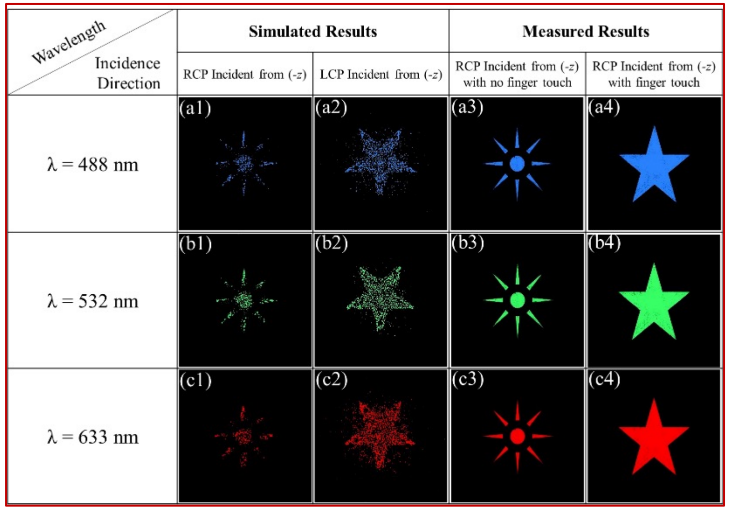


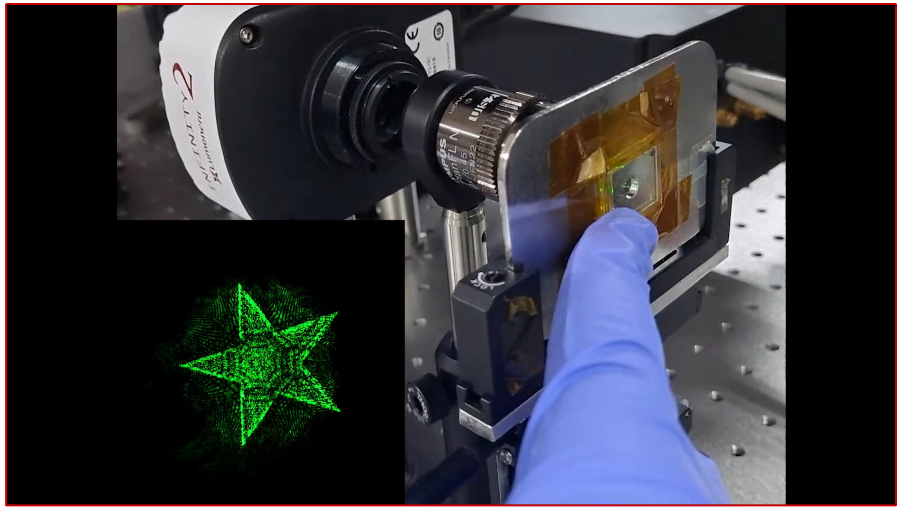
Inki et al., Science Advances, Vol 7, Issue 15, 2021

Metasurface based Visual Pressure Sensor

- Two separate on-axis and off-axis holographic metasurfaces are designed and integrated with **pressure-sensitive liquid crystal (LC)** cells to demonstrate **actively tunable meta-holography**.
- The simple design technique, cost-effective fabrication, and **finger touch-enabled** holographic output switching make this integrated setup a potential candidate for many applications like smart safety labeling, motion or touch recognition, and interactive displays for impact monitoring of precious artworks and products.







Ashar et al., Advanced Science, 2021 (under review)

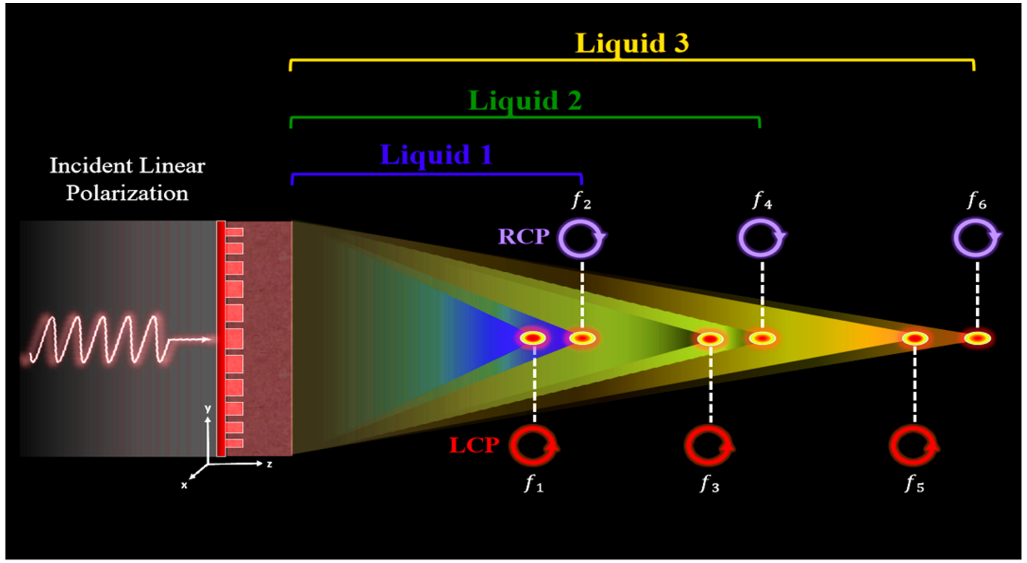
RECONFIGURABLE METASURFACES FOR WIRELESS COMMUNICATION

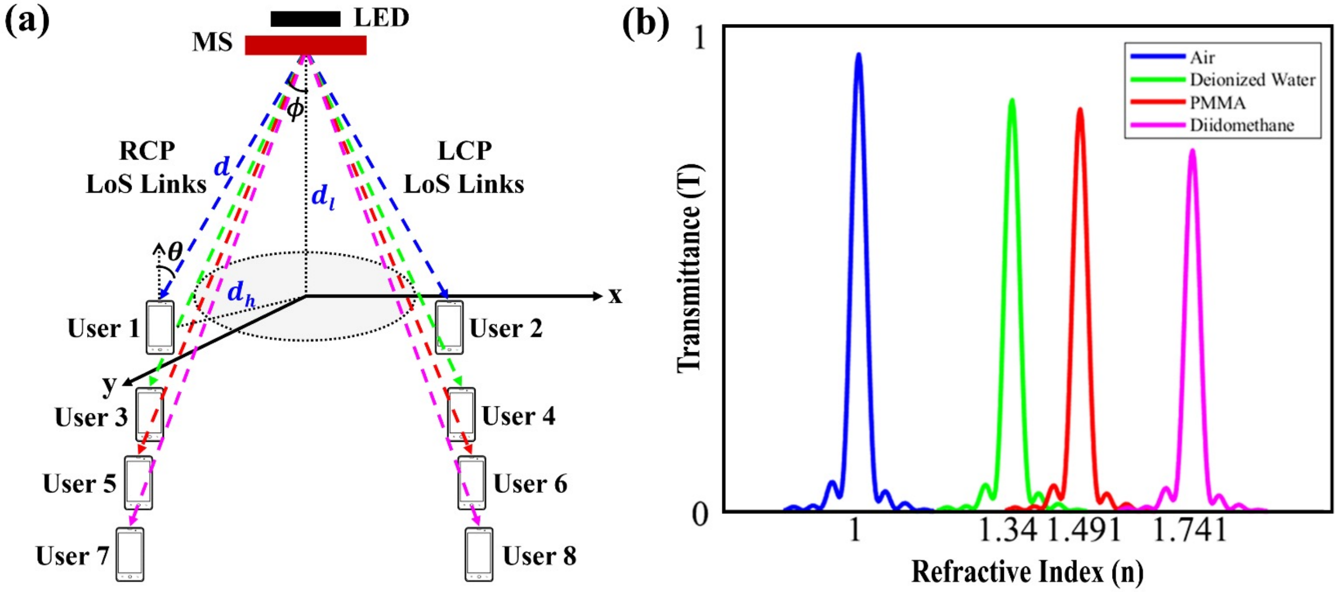
Fluid Responsive Tunable Metasurface

Fluid-Responsive Tunable Metasurfaces for High-Fidelity Optical Wireless Communication

Reconfigurability → Run-time fluids transition

- Developed **fluid-responsive metasurfaces** for **real-time beam steering and variable focusing** through integration with isotropic fluids.
- Demonstrated **polarization-based switching** to enhance productivity and signal quality.

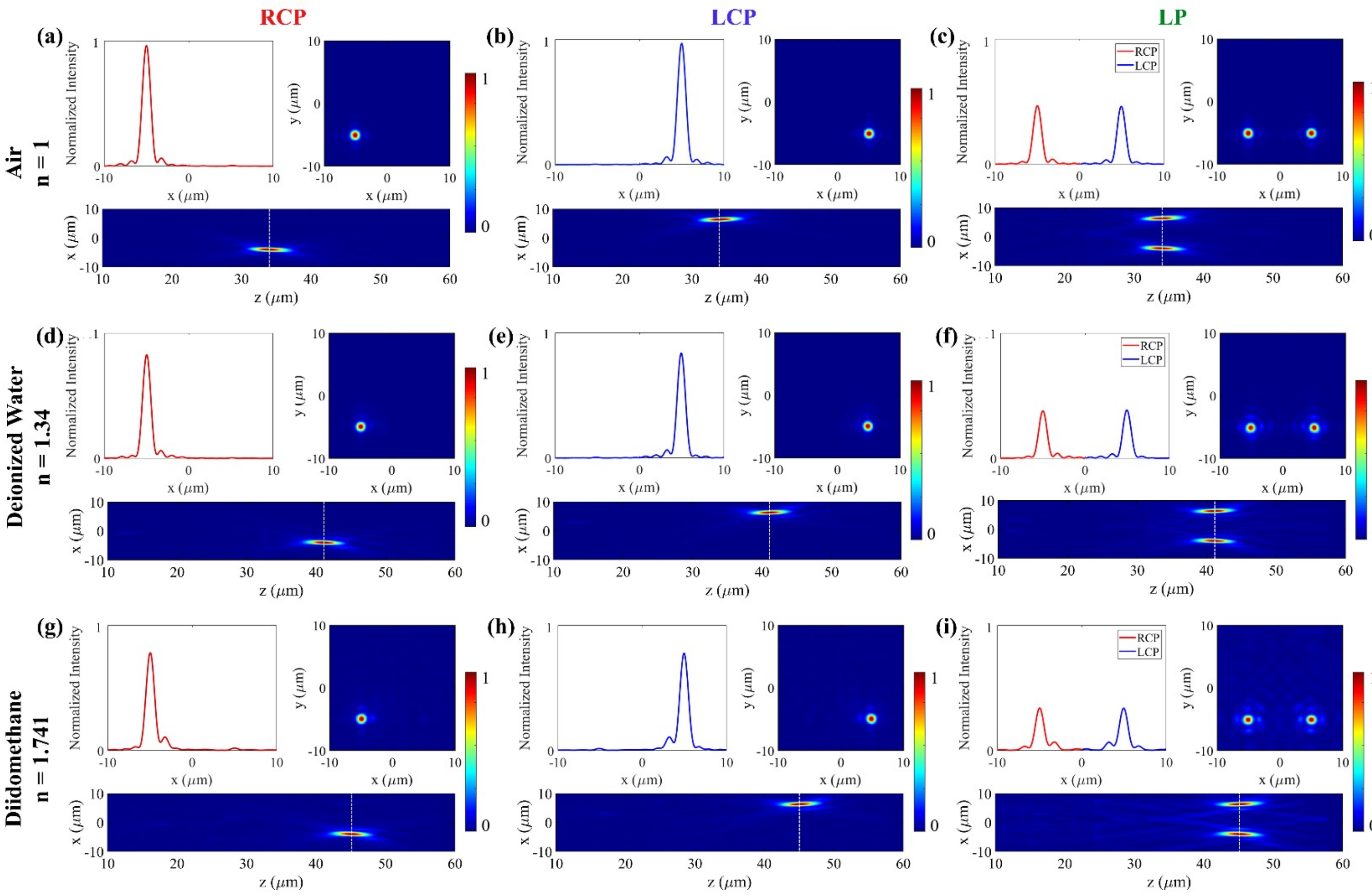




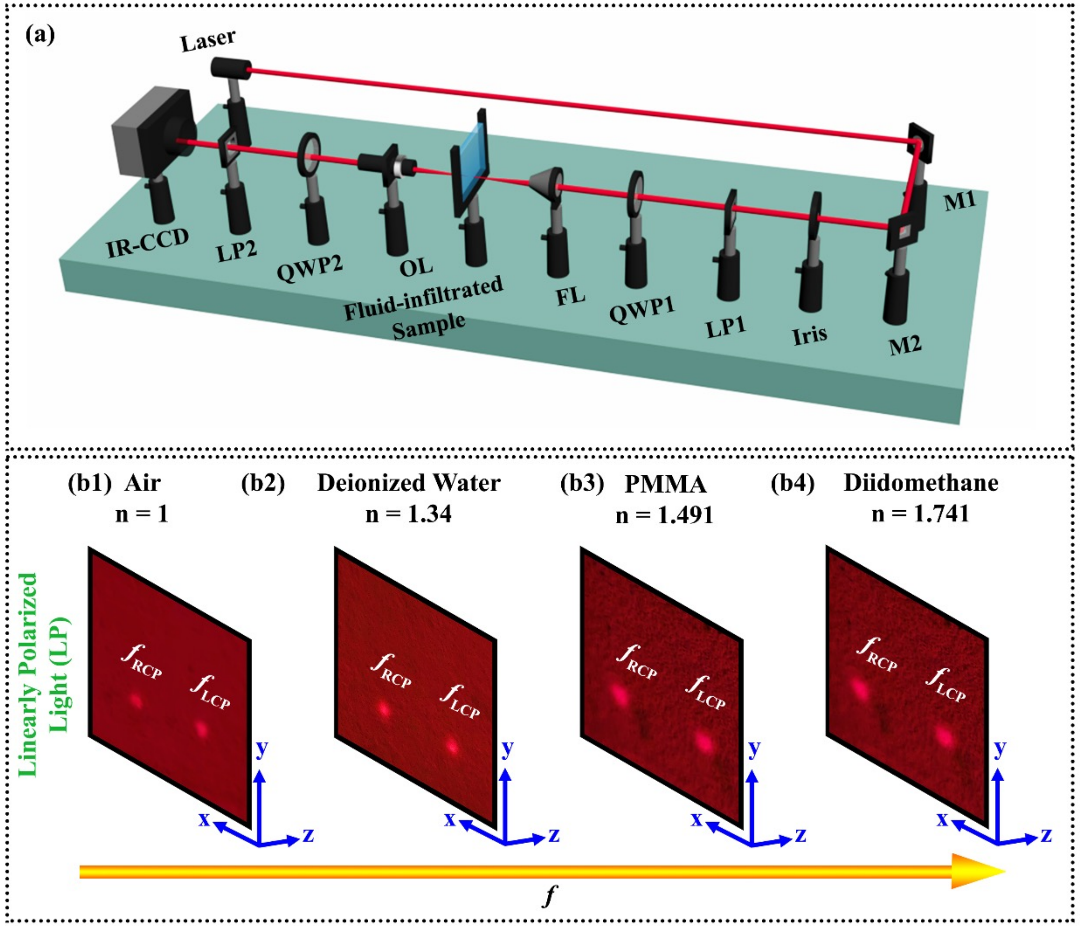
Our Work: Tunable Metasurface

Fluid-Responsive Tunable Metasurfaces for High-Fidelity Optical Wireless Communication

Simulated Results



Experimental Results



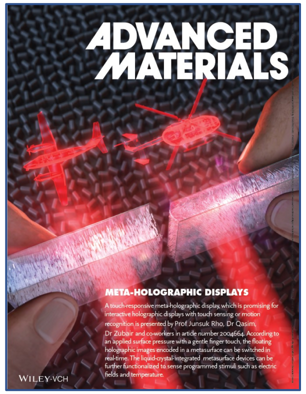
Publications

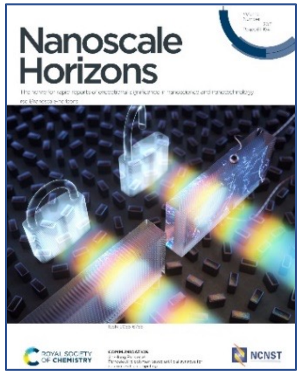
Research Output

ITU micronano

- nature.com
- nature COMMUNICATIONS
- Light Science & Applications
- ACS Publications
- ACS NANO
- NANO LETTERS
- ACS APPLIED MATERIALS & INTERFACES
- ACS OMEGA
- APS Advancing Physics
- Wiley Online Library
- ADVANCED MATERIALS
- ADVANCED FUNCTIONAL MATERIALS
- ADVANCED OPTICAL MATERIALS
- ADVANCED SCIENCE Open Access
- LASER & PHOTONICS REVIEWS
- Physical Review A atomic, molecular, and optical physics
- OPTICA PUBLISHING GROUP Formerly OSA
- PHOTONICS Research
- Optics EXPRESS
- Optical Materials EXPRESS
- ROYAL SOCIETY OF CHEMISTRY
- Nanoscale
- Nanoscale Horizons
- IET The Institution of Engineering and Technology
- IET Microwaves, Antennas & Propagation
- IEEE Sensors Letters
- ELSEVIER
- RENEWABLE AND SUSTAINABLE ENERGY REVIEWS
- nano energy
- IEEE Advancing Technology for Humanity
- IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION — A PUBLICATION OF THE IEEE ANTENNAS AND PROPAGATION SOCIETY
- IEEE Antennas and Wireless Propagation Letters
- IEEE SENSORS JOURNAL — A PUBLICATION OF THE IEEE SENSORS COUNCIL — WWW.IEEE.ORG/SENSORS
- IEEE OPEN JOURNAL OF THE COMPUTER SOCIETY
- J-FLEX IEEE Journal on Flexible Electronics

Cover Pages





Strengths

INFORMATION TECHNOLOGY
UNIVERSITY OF THE PUNJAB

Strengths: Research Output

THE NATION

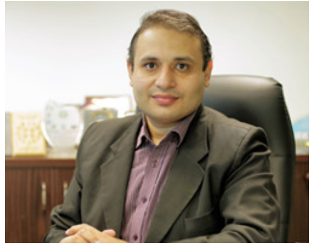
E-PAPER TODAY'S PAPER EDITOR'S PICKS OPINION

Ahsan inaugurates three centers of excellence

ITU's Nano-Metamaterials (Nano-Meta) Lab @ National Centre for Nanoscience & Nanotechnology.

Lead-PI
Dr. M. Qasim

Co-PI
Dr. M. Zubair

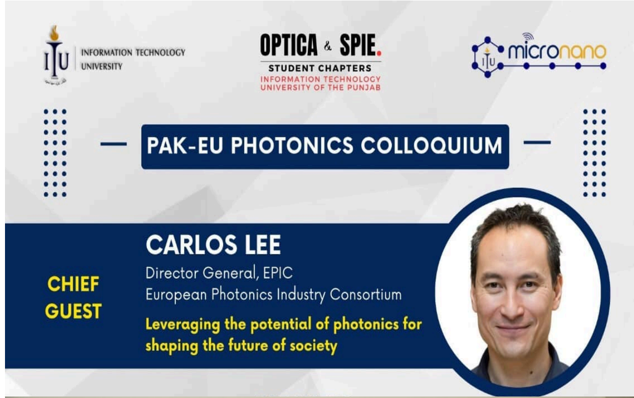


Co-PI
Dr. Tauseef

Co-PI
Dr. Haris

STEM University Level-Knowledge Sharing & Dissemination

Symposiums: Seminars/Workshops/Trainings



International Society Chapters

IEEE APS/CAS/MTT/SSC
Joint Chapter Lahore Section

OPTICA & SPIE.
STUDENT CHAPTERS
INFORMATION TECHNOLOGY UNIVERSITY OF THE PUNJAB

STEM University Level-Knowledge Sharing & Dissemination

Symposiums: Seminars/Workshops/Trainings

STEM Promotion

STEM Outreach,Promotion & Trainings

Outreach, Symposiums, Seminars, Workshops, Trainings

MicroNano Lab

Gap Analysis for Pre-University Education

Building Bridges: Outreach for Educational Excellence

2. Visit to Aligarh Public School for International Day of Light







Building Bridges: Outreach for Educational Excellence

1. Visit to Railway High School for Optics Workshop









MicroNano Lab

Gap Analysis for Pre-University Education

Building Bridges: Outreach for Educational Excellence

3. STEM Outreach Activity in Jhelum

Building Bridges: Outreach for Educational Excellence

4. Next Stop → Umarkot Optics Empowerment Initiative

Total Population	1,073,469
Urban Areas Population	243,537 (22.69%)
Gender Ratio	929 women per 1,000 men
Total Literacy Rate	35.07%

Collaboration

Welcome to Collaborate

Science for Peace & Harmony; beyond religious and territorial boundaries.

Novel Theories to Break limits

Academia

Mentors

Industry

Humanitarians

Technology Readiness

Smart Design & Optimization Tools

Device-level Innovation

System-level Integration & Development

R &D for Innovative Solutions

Thank You