Efficient generation of complex vectorial optical fields with metasurfaces

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I. Backgrounds & Motivations

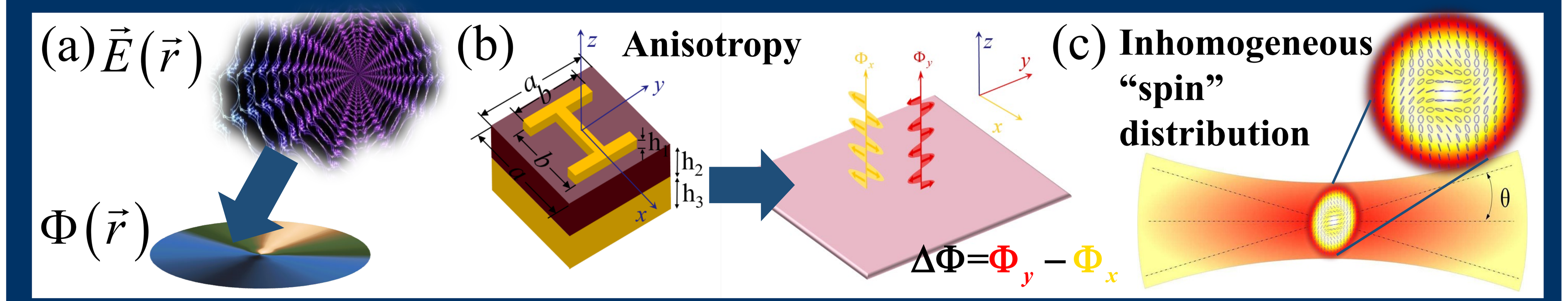

Fig. 1 Previous metasurfaces using either (a) $\Phi(\vec{r})$ (Wave-front) or (b) $\Delta\Phi$ (Spin/polarization) and (c) real VOF with both complex wavefront & spin distribution

- **Motivations**

1. Propose a **general platform** to generate **complex VOF** with both ***arbitrary wave-front*** & ***polarization distribution***
2. Use the meta-platform to explore **new physics** and realize more **fancy functionalities**: Far-field VOF, Near-field VOF, Bifunctional VOF etc.

II. Basic idea & Theoretical analysis

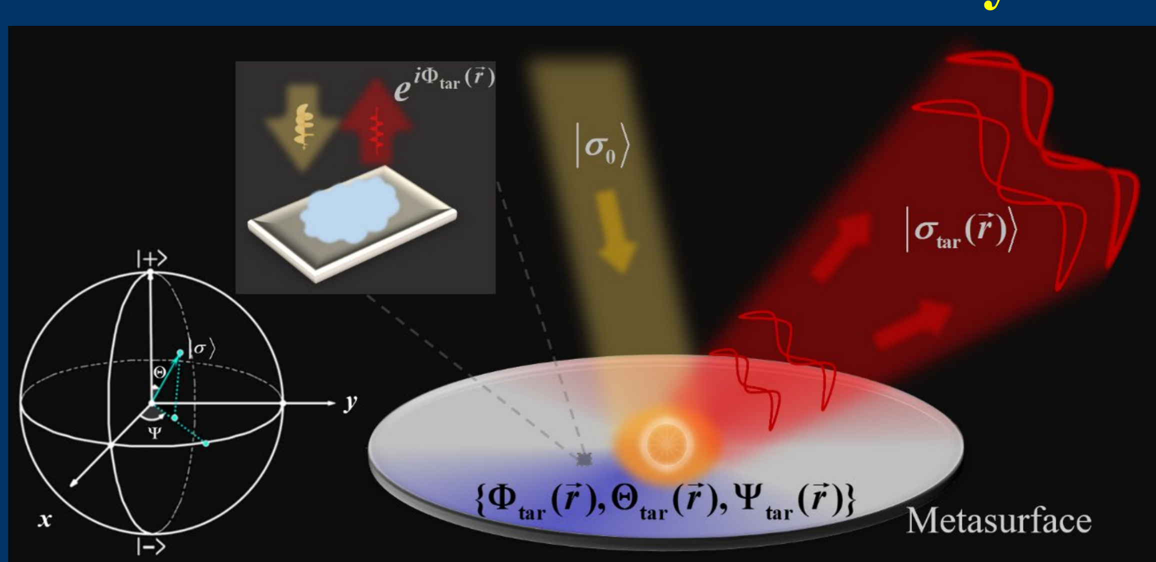

Fig. 2 Schematic of generating arbitrary VOFs with metasurfaces

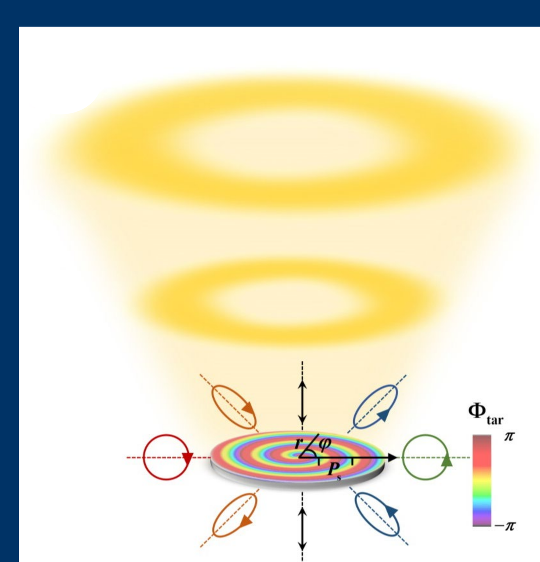

Fig. 3 DMT model calculation

- **Key Points**

A set of meta-atoms, each of which can:

1. Convert the local spin-state of incident light to an arbitrary state $(\Theta_{tar}(\vec{r}),\Psi_{tar}(\vec{r}))$
2. Possess any required extra phases $\Phi_{tar}(\vec{r})$

- **Dipole-Model Calculations**

Treat each meta-atom as a pair of dipoles and calculate : Radiative pattern seen as a **Diverging Vector Vortex** beam

$\rightarrow \{\Theta_{tar},\Psi_{tar},\Phi_{tar}\}$ ⬌ Desired VOF

III.Meta atom design strategy & Benchmark Cases

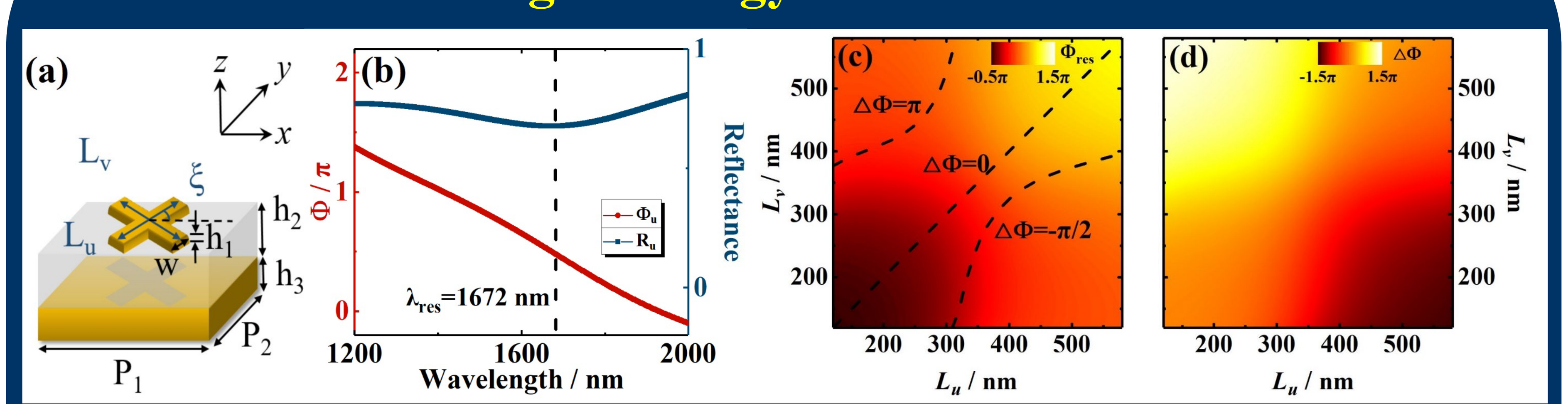

Fig. 4 Meta-atom design: MIM tri-layer meta-atom for reflection geometry

- **Design Strategy**

Three geometrical degrees of freedom (L_u,L_v,ξ)

→considerably **large variation range** $(\Phi_{res},\Delta\Phi,\xi)$

→unprecedented ability to freely manipulate $(\Phi_{tar},\Theta_{tar},\Psi_{tar})$

i.e. **arbitrary local spin state** and **initial phase** for each meta-atom

$$\begin{pmatrix}L_u\\L_v\\\xi\end{pmatrix}\Leftrightarrow\begin{pmatrix}\Phi_{res}\\\Delta\Phi\\\xi\end{pmatrix}\Leftrightarrow\begin{pmatrix}\Phi_{tar}\\\Theta_{tar}\\\Psi_{tar}\end{pmatrix}$$

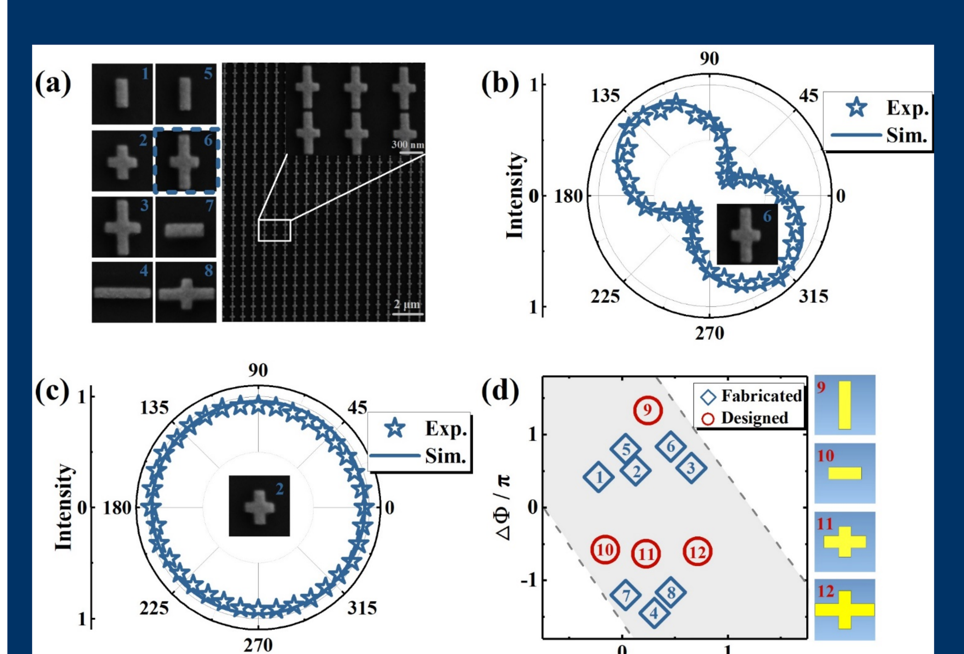

Fig. 5 Meta-atoms functioning as different wave plates

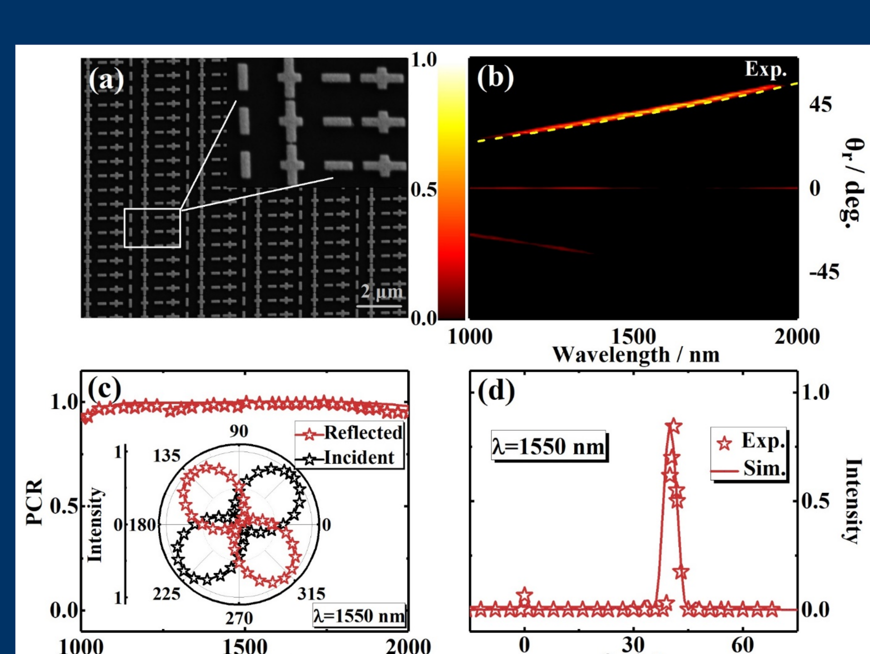

Fig. 6 Anomalous-reflection half-wave plate

- **Benchmark cases**

1. Designed meta-atoms functioning as different wave plates & processing different phases
2. Anomalous-reflection half-wave plate:
   Linear initial phase distribution → Anomalous reflection
   Each meta-atom as HWP → Desired uniform polarization conversion

IV. Far-field VOF Generator

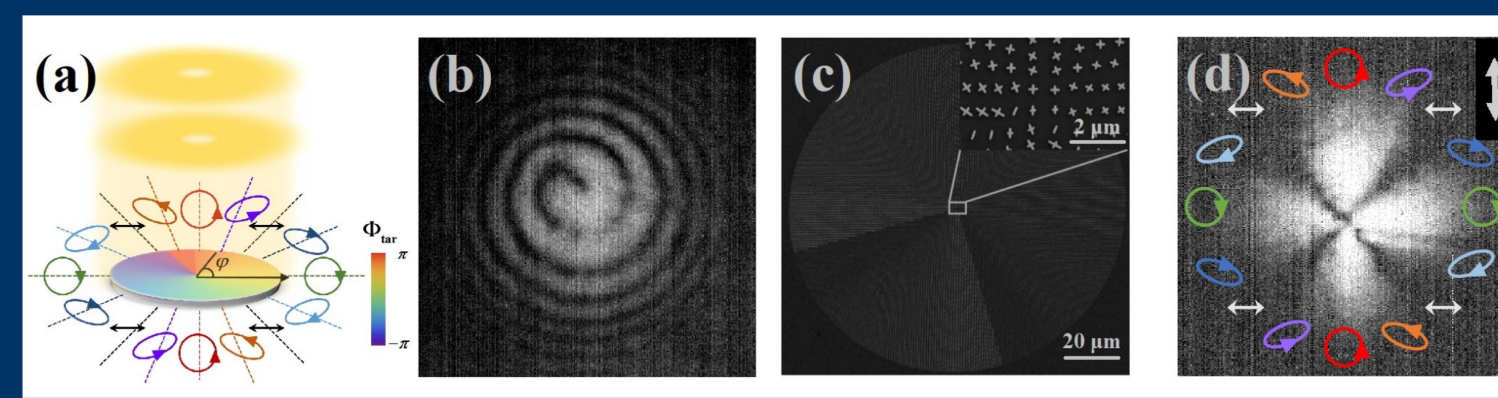

Fig. 7 A far-field vortex beam with varying ellipticity

- $\Phi_{tar}(\vec{r})=\varphi+\frac{\pi}{4}$: Uniform beam → l=1 vortex
- $\Theta_{tar}(\vec{r})=\pi-2\varphi$: Homogeneous LP → Varied ellipticity
- $\Psi_{tar}(\vec{r})=2\varphi-\frac{\pi}{2}$: Homogeneous LP → Varied orientation

V. Near-field VOF Generator

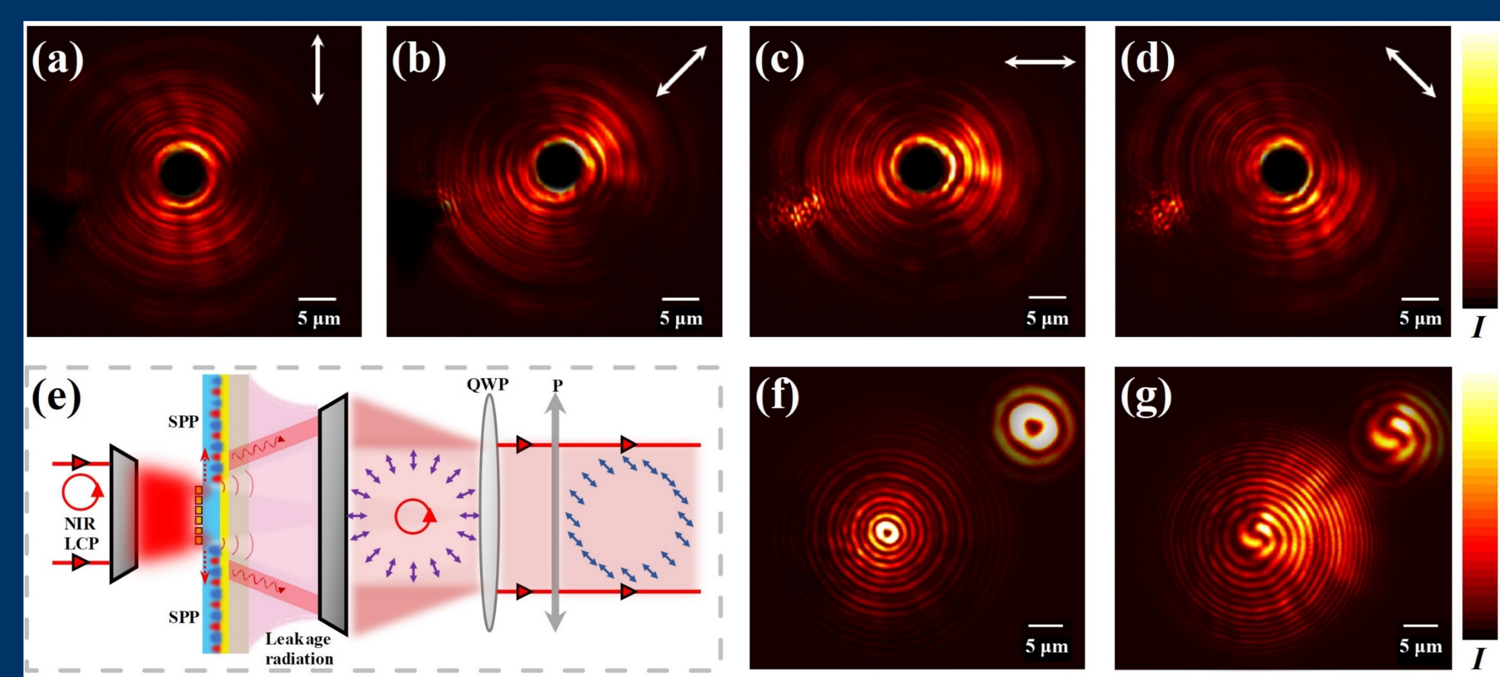

Fig. 8 A vectorial vortex surface plasmon coupler

- $\Phi_{tar}(\vec{r})=\zeta_r r+\varphi,\ \zeta_r>k_0$: Propagating wave → Radial SPP
- $\Phi_{tar}(\vec{r})=\zeta_r r+\varphi,\ \xi_\varphi=1$: Uniform beam → l=1 vortex
- $\Theta_{tar}(\vec{r})=\frac{\pi}{2},\Psi_{tar}(\vec{r})=2\varphi$: Homogeneous LCP → LP along r direction
- Experimentally efficiency : 34 ± 6%

VI. Bi-functional VOF Generator

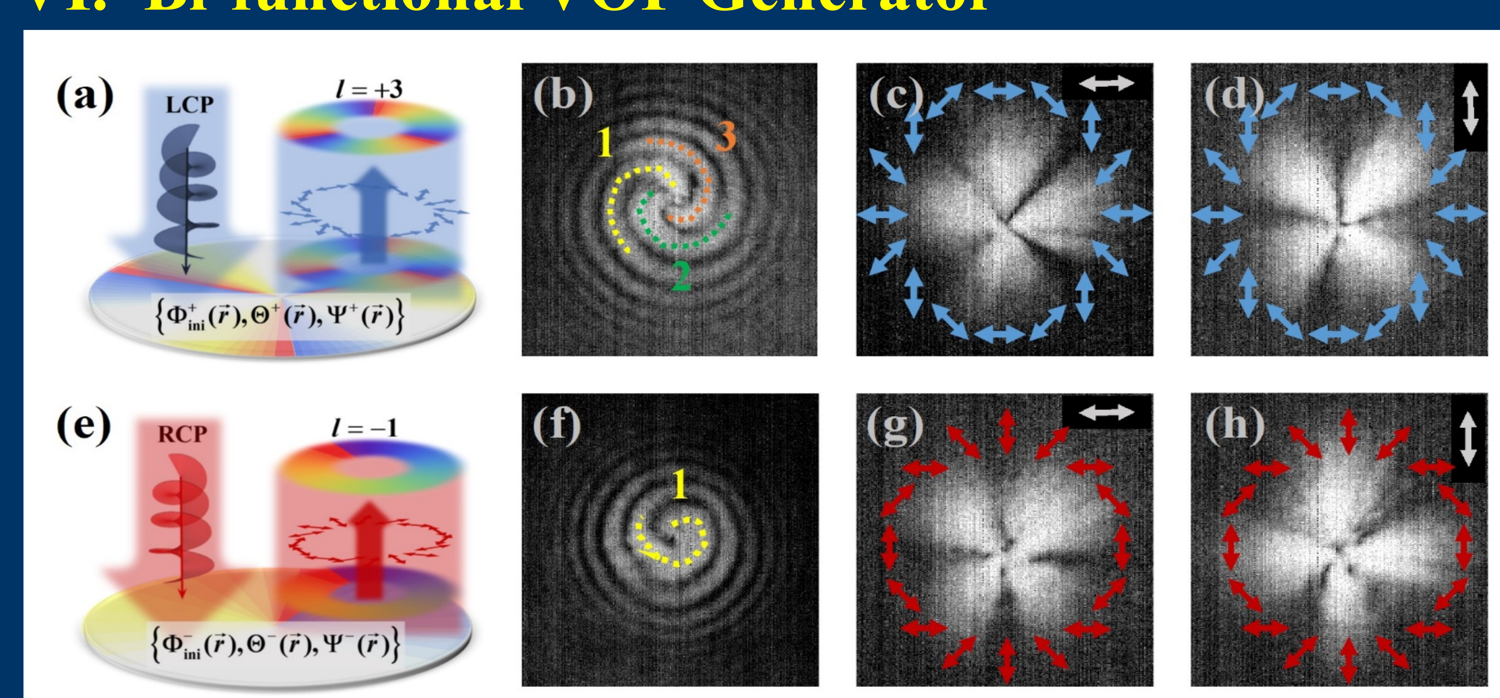

Fig. 9 A Bi-functional VOF generator

$$\Phi_{tar}^{\sigma}=\Phi_{res}+\sigma\cdot\Phi_{geo}$$

Spin –independent Resonance Phase
Spin–dependent Geometric Phase

LCP Incidence	RCP Incidence
$\Phi_{ini}^{+}(\vec{r})=3\varphi$:Uniform → l=+3 vortex	$\Phi_{ini}^{-}(\vec{r})=-\varphi-\frac{\pi}{2}$:Uniform → l=-1 vortex
$\Theta^{+}(\vec{r})=\frac{\pi}{2}$:LCP → LP	$\Theta^{-}(\vec{r})=\frac{\pi}{2}$:RCP → LP
$\Psi^{+}(\vec{r})=4\varphi$:LCP →Varied orientation	$\Psi^{-}(\vec{r})=4\varphi+\pi$:RCP →Varied orientation

VII. Conclusions & Perspectives

1. A **general meta-platform** is proposed for **arbitrary VOF** with **desired wave front** and **inhomogeneous local spin state**.
2. Both **far-field** and **near-field** VOF generators are designed and characterized to demonstrate the concept.
3. **Bi-functional VOF generators** are also designed and characterized based on **two different mechanisms induced phases.**
4. Even more fancy physics and functionalities **to be explored** based on this platform…

References

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