Multiplexing near- and far-field functionalities with high-efficiency bi-channel metasurfaces

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INTRODUCTION

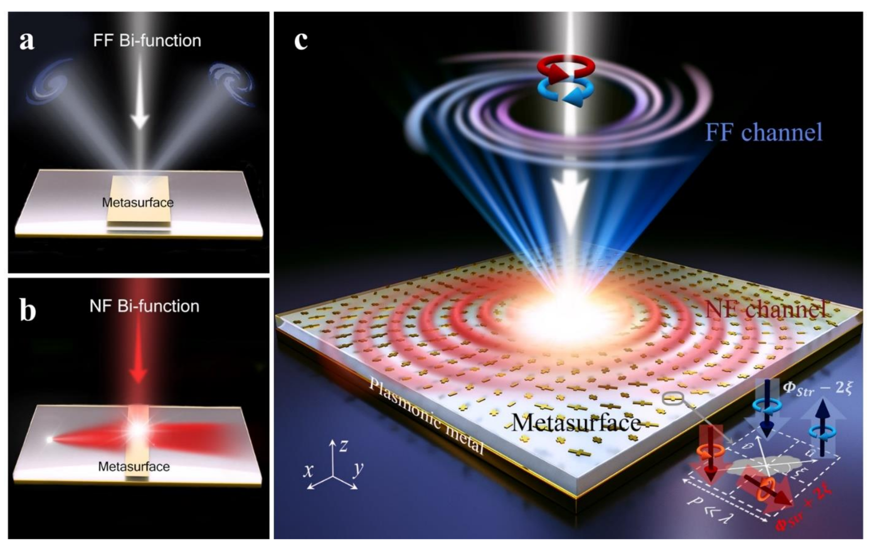

Fig. 1 Working principle of the bi-channel meta-surface. Schematics of (a) a FF bi-functional meta-device and (b) a NF bi-functional meta-device realized previously, and schematics of (c) the bi-channel meta-device proposed in this article which exhibit distinct pre-designed wave-control functionalities in NF and FF channels, respectively, under excitations of circularly polarized light with opposite helicities.

- **Motivations**

Propose a general approach to design bi-channel metasurfaces that can multiplex two distinct light-manipulation functionalities in near-field (NF) and far-field (FF) channels, respectively.

- **Key Points**

1. a bi-channel metasurface should exhibit two different phase profiles $\Phi_{NF}(\vec{r})$ and $\Phi_{FF}(\vec{r})$ as shined by CP lights with opposite helicity.

2. $\Phi_{NF}(\vec{r})$ must contain a phase gradient term to help convert PW to SW while $\Phi_{FF}(\vec{r})$ does not need to have such a term.

DESIGN STRATEGY

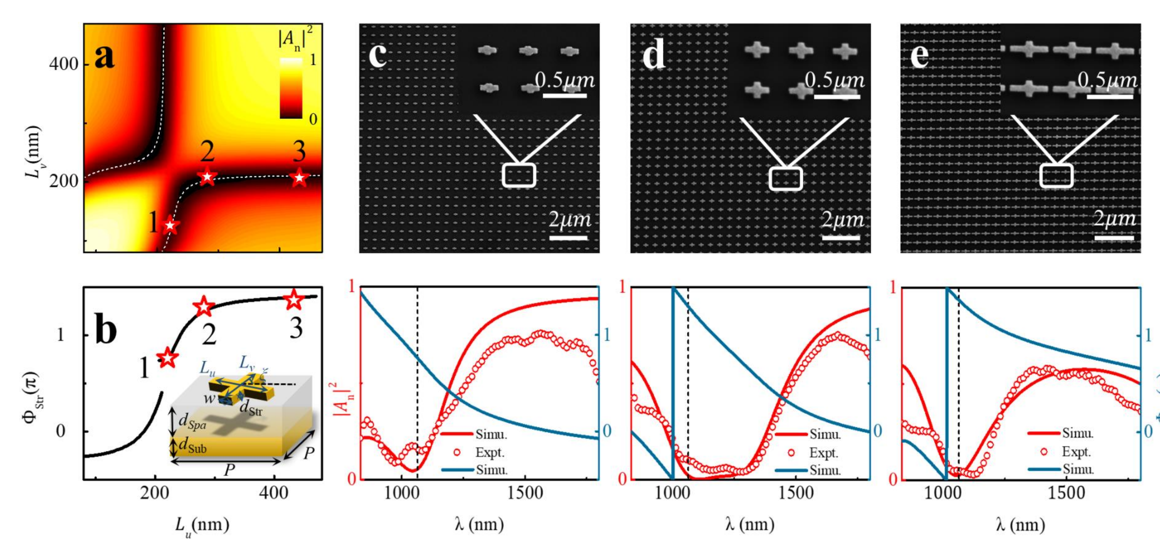

Fig. 2 Meta-atom design strategy and characterizations of three typical meta-atoms. (a) Simulated normal-mode intensity $|A_n|^2$ of the MIM meta-atom against their bar lengths L_u and L_v, with the dashed curve marking Min($|A_n|^2$) for each L_u. (b) Simulated structural phase Φ_{Str} of the MIM meta-atom as a function of the bar length L_u with L_v taking the values on the Min($|A_n|^2$) curve in (a) correspondingly. Inset in (b) illustrates the basic structure of an MIM meta-atom. (c,d,e) Upper panels are SEM pictures of three meta-atoms labelled as "1, 2, 3" in (a) and (b), respectively; Lower panels depict the $|A_n|^2$ spectra obtained by simulations (red line) and measurements (red circle) and the simulated spectra of Φ_{Str} (blue line) for three meta-atoms.

A set of atom, each of which could:

1. Designed meta-atoms functioning as half-wave plates satisfying: $A_n = \frac{|r_{uu}+r_{vv}|}{2} = 0$

2. Convert the incident polarization $|\sigma_0\rangle$ into an anomalous mode with coefficient $(r_{uu} - r_{vv})e^{i\sigma 2\xi}/2$

3. Providing an extra phase $\Phi_{Tot} = \Phi_{Str} + \sigma\Phi_{Geo}$ (spin − dependent Geometric phase) by such an atom, the whole device are thus allowed to exhibit two different phase distribution:

$$\begin{cases}\Phi_{NF}(\vec{r}) = \Phi_{Str}(\vec{r}) + 2\xi(\vec{r}) \\ \Phi_{FF}(\vec{r}) = \Phi_{Str}(\vec{r}) - 2\xi(\vec{r})\end{cases}$$

RESULTS

Bi-channel meta-devices I : Multiplexing NF & FF vortex generations

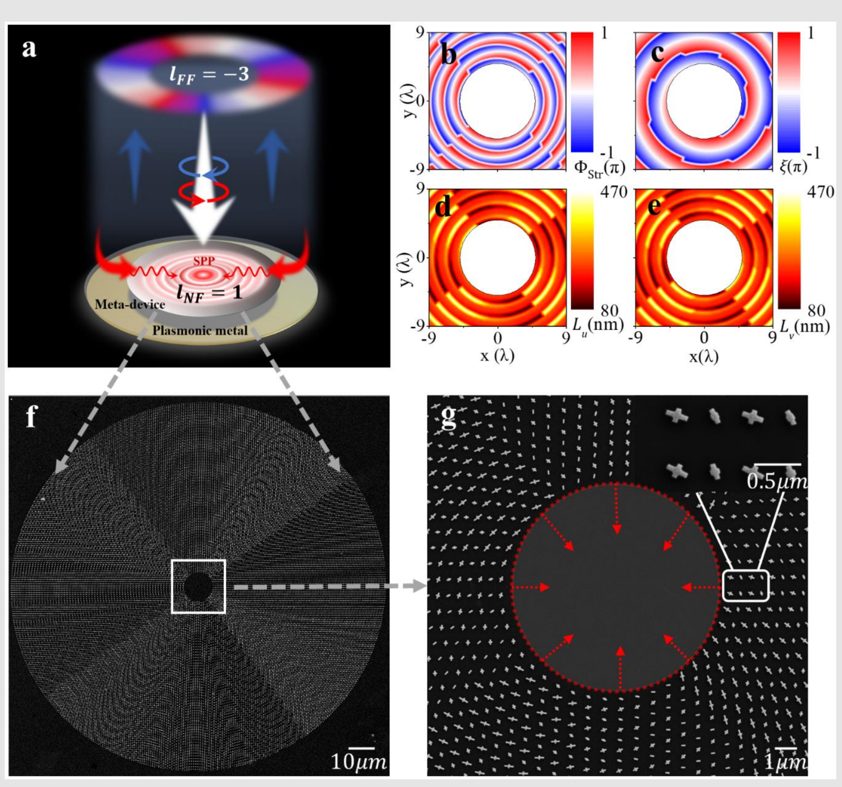

Fig. 3 Expected functionality, structural parameters and sample pictures of the meta-device I. (a) The proposed meta-device I is expected to covert the incident LCP light to a focused vortex SPP in the NF channel and reflect the incident RCP light to a spatial vortex beam in the FF channel, with topological charges of two vertices being -1 and 3, respectively. Distributions of (b) $\Phi_{Str}(\vec{r})$, (c) $\xi(\vec{r})$, (d) $L_u(\vec{r})$ and (e) $L_v(\vec{r})$ of the meta-device under design. (f) SEM image of the fabricated sample, with its zoomed-in images shown in (g) and the inset.

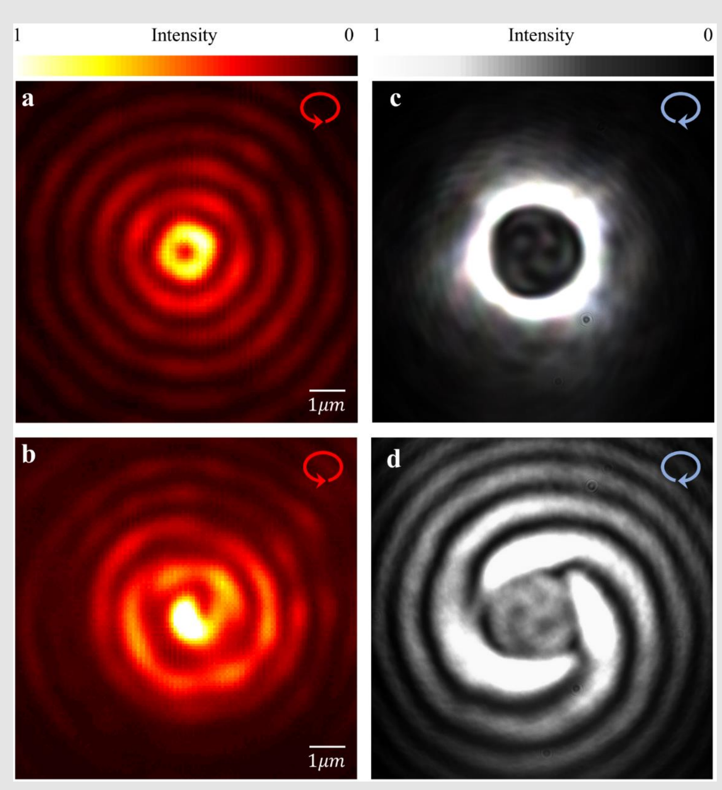

Fig. 4 Experimental characterizations of the bi-channel meta-device I. As shined by LCP light at 1064 nm, (a) the LRM-recorded field pattern of the vortex SPP generated on the sample surface and (b) the CCD-captured field pattern as the vortex SPP interferes with a spherical wave. As shined by RCP light at 1064 nm, (c) the CCD-captured field pattern of the vortex beam reflected by the device and (b) the CCD-captured field pattern as the vortex beam interferes with a spherical wave.

Bi-channel meta-devices II: Multiplexing NF & FF vortex generations

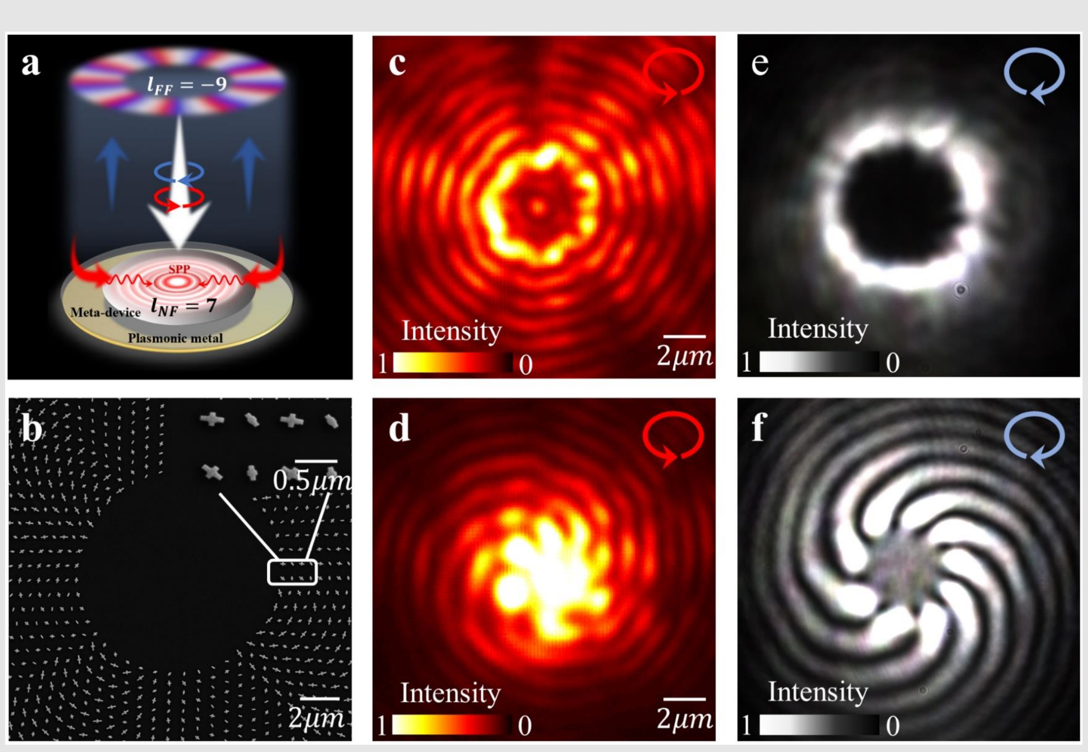

Fig. 5 Expected functionality, sample picture, and experimental characterization of the bi-channel meta-device II. (a) The proposed meta-device II is expected to covert the incident LCP light to a focused vortex SPP in the NF channel and reflect the incident RCP light to a spatial vortex beam in the FF channel, with vertices' topological charges being 7 and -9, respectively. (b) SEM image of the fabricated sample, with its zoomed-in images shown in the inset. As the meta-device is shined by LCP light at 1064 nm, (c) the LRM-recorded field pattern of the vortex SPP generated on the metallic surface and (d) the CCD-captured field pattern as the vortex SPP interferes with a spherical wave. As the meta-device is shined by RCP light at 1064 nm, (e) the CCD-captured field pattern of the vortex beam reflected by the device and (f) the CCD-captured field pattern as the vortex beam interferes with a spherical wave.

Bi-channel meta-device III: Multiplexing NF anomalous focusing SPP and FF hologram

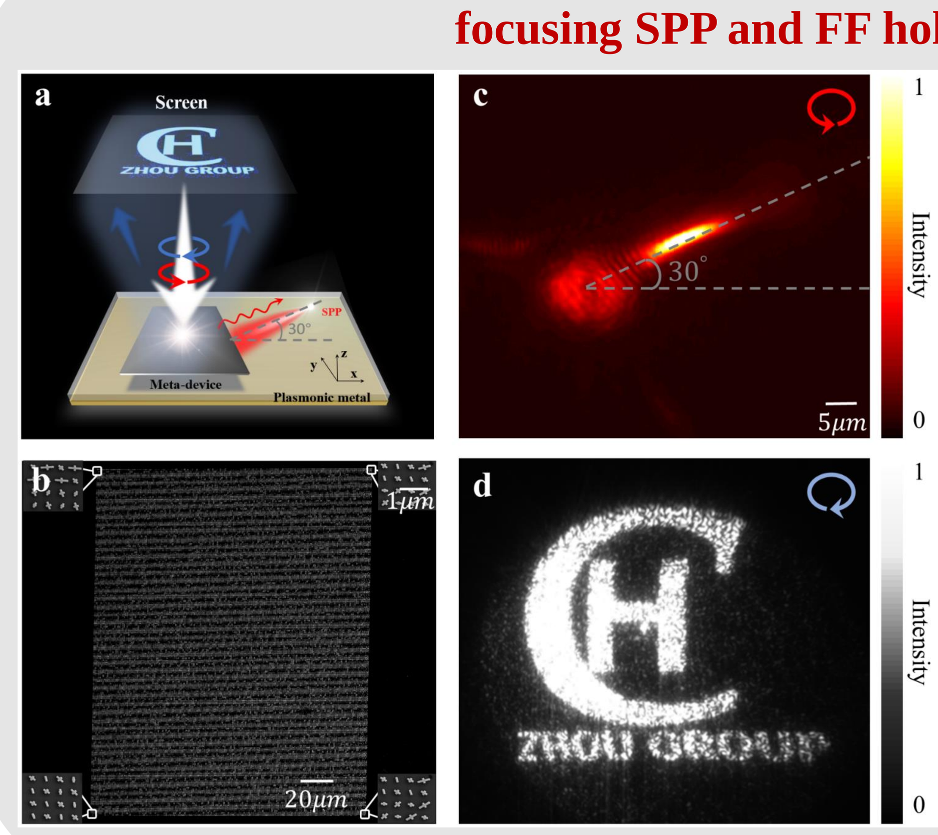

Fig. 6 Expected functionality, sample picture, and experimental characterizations of the bi-channel meta-device III. (a) The proposed meta-device III is expected to covert the incident LCP light to an anomalously focused NF SPP beam and generate a pre-designed FF hologram as the device is shined by an RCP light. (b) SEM image of the fabricated sample. (c) The LRM-recorded near-field pattern generated on the metallic surface, representing an anomalously deflected SPP beam which is then focused to a pre-designed focal point, as the meta-device is shined by LCP light at 1064 nm. (d) The CCD-captured hologram image in the far field as the meta-device is shined by RCP light at 1064 nm.

Experimental setup

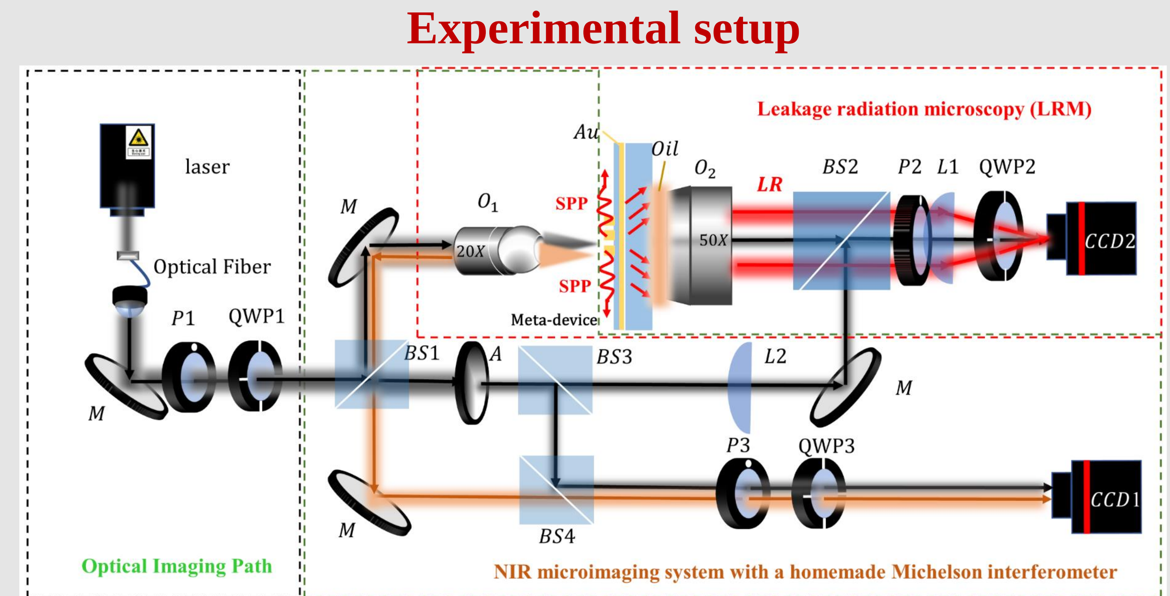

Fig. 7 The micro-imaging system with a home-made Michelson interferometer for far-field characterization and leakage radiation microscopy system for near-field SPP characterization in the NIR regime. M represents Mirror, A represents Attenuator, L represents Lens, and QWP represents Quarter-Wave Plate.

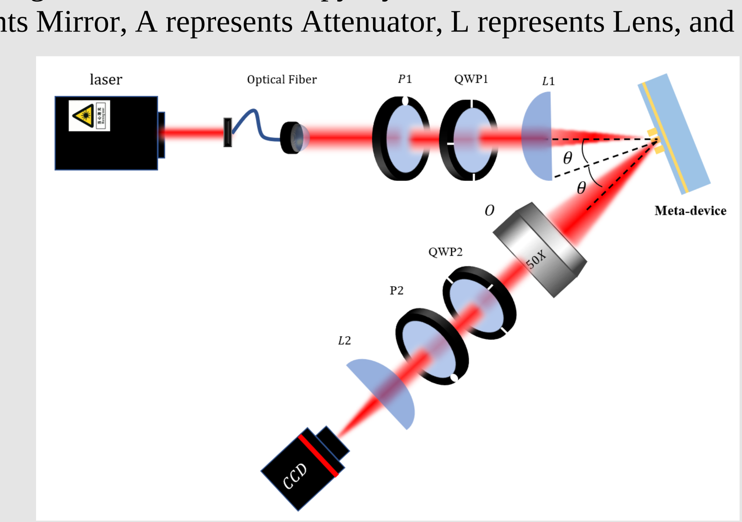

Fig. 8 The micro-imaging system for far-field hologram characterization.

CONCLUTION

1. we propose a generic strategy to realize meta-devices that can multiplex wave-manipulation capabilities in two spatially non-overlapping channels (i.e., NF and FF channels).
2. After experimentally characterizing the optical properties of several typical meta-atoms, we follow the proposed scheme to design/fabricate three meta-devices and then experimentally demonstrate their bi-channel wave-manipulation functionalities.
3. Our results open a new avenue for achieving multi-functional optical devices working for spatially non-overlapping spaces.

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