Efficient generations of complex vectorial optical fields with metasurfaces

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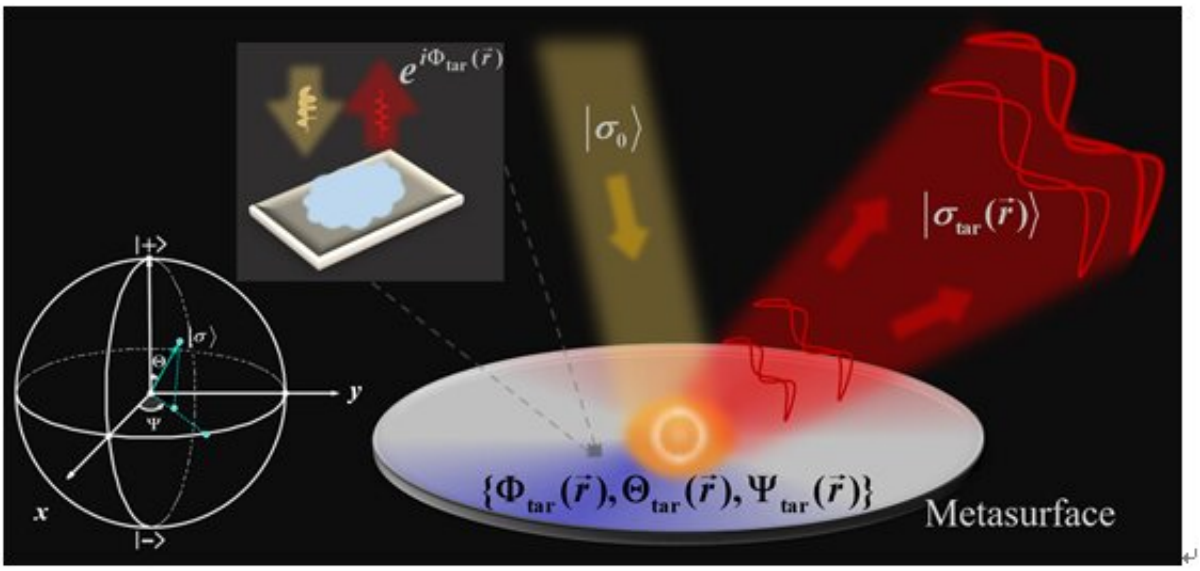


Figure | Schematics of generating arbitrary VOFs with metasurfaces.

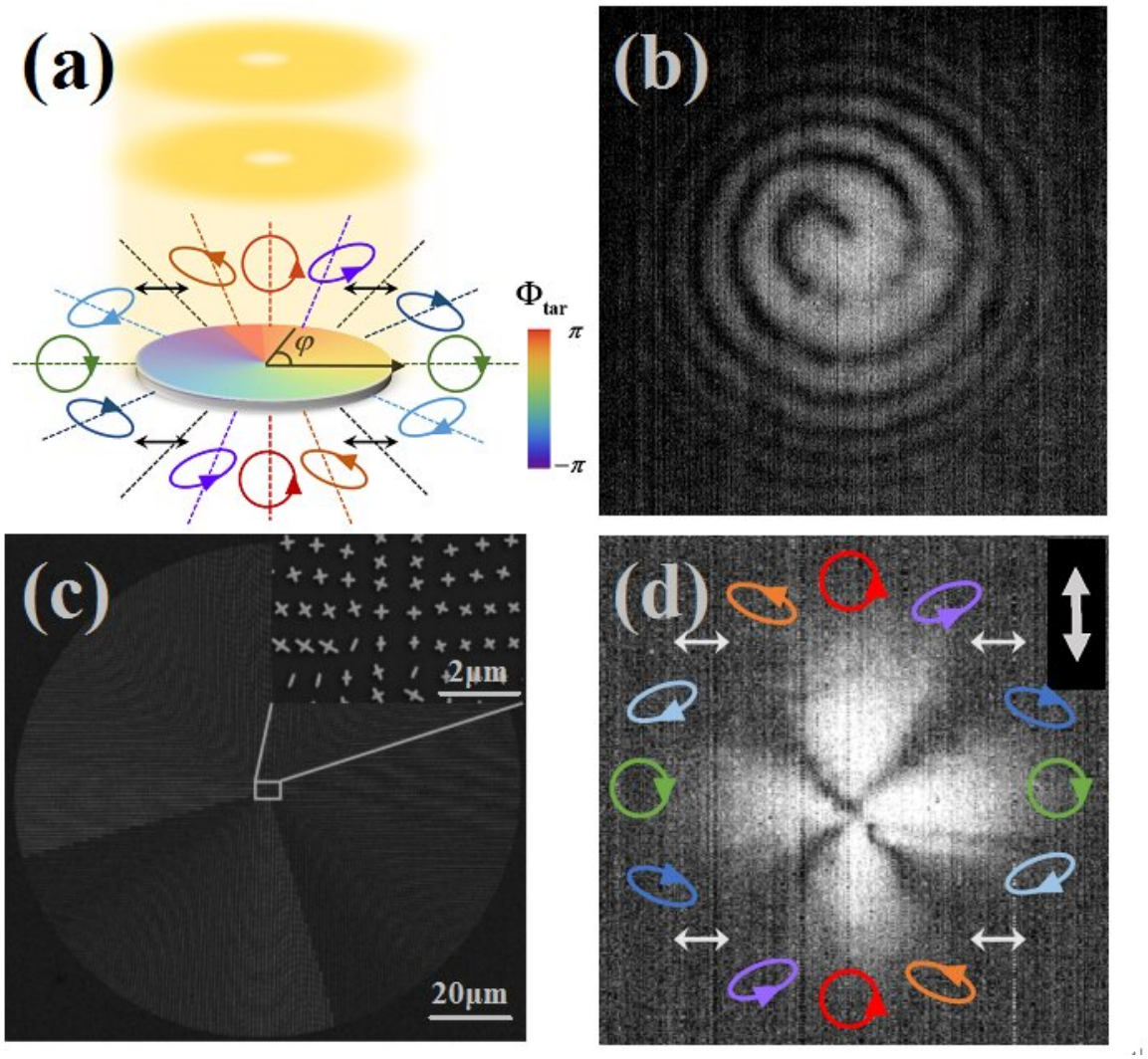
A specifically designed meta-atom can reflect normally incident light with polarization $|\sigma_0\rangle$ (described by a point (Θ_0,Ψ_0) on Poincare's sphere) to a light with a target polarization $|\sigma_{tar}\rangle$ (described by a point $(\Theta_{tar},\Psi_{tar})$ on Poincare's sphere) with a desired phase Φ_{tar}. Using a set of meta-atoms with different Φ_{tar} and $\{\Theta_{tar},\Psi_{tar}\}$ to form a metasurface and shining it by a normally incident light with polarization $|\sigma_0\rangle$, an VOF can be generated with wave-front determined by $\Phi_{tar}(\vec{r})$ and polarization distribution determined by $\{\Theta_{tar}(\vec{r}),\Psi_{tar}(\vec{r})\}$ on the designed metasurface.

Credit: Dongyi Wang, Feifei Liu, Tong Liu, Shulin Sun, Qiong He and Lei Zhou

Vectorial optical fields (VOFs) exhibiting arbitrarily designed wave-fronts and polarization distributions are highly desired in photonics. To efficiently generate arbitrary VOFs, scientists in China proposed a generic approach based on metasurfaces exhibiting full-matrix yet inhomogeneous Jones-matrix distributions. Based on their strategy, efficient generations of complex VOFs in both far- and near-field were experimentally demonstrated in the NIR regime. The proposed meta-platform opens new avenues for diversified photonic applications, such as optical trapping and super-resolution imaging.

Light beams are widely used in photonics applications and have attracted immense research interest. Compared to homogeneously polarized light beams, vectorial optical fields (VOFs) with tailored wave-fronts and inhomogeneous polarization distributions exhibit more advantages in applications compared to their scalar-wave counterparts, thanks to the added degree of freedom (DOF) of polarization. By tailoring the polarization distributions, special VOFs such as flap-top beams and radially polarized beams can be generated, being highly favored in super-resolution microscopy, optical manipulations, etc.

Despite great advances in applications, generation of such complex VOFs are far from satisfactory. Available methods based on conventional materials suffer from bulky size and low efficiency issues, due to the limited electromagnetic response of natural materials. And recently, metasurfaces have been widely used to generate VOFs in different frequency ranges, but mostly for far-field generation with certain limited polarization distributions (e.g. radial or azimuthal linear polarizations). In addition, complex VOFs in the near-field with arbitrary polarization distributions are so far rarely generated with metasurfaces.



a, Schematics of our proposed meta-device to generate a vortex beam with varying ellipticity. b, Interference pattern between transmitted light and a spherical wave, recorded by our CCD. c, The SEM image of fabricated sample. d, Optical images recorded by our CCD for the generated VOF after passing through a linear polarizer with tilting angle 90°. Credit: Dongyi Wang, Feifei Liu, Tong Liu, Shulin Sun, Qiong He and Lei Zhou

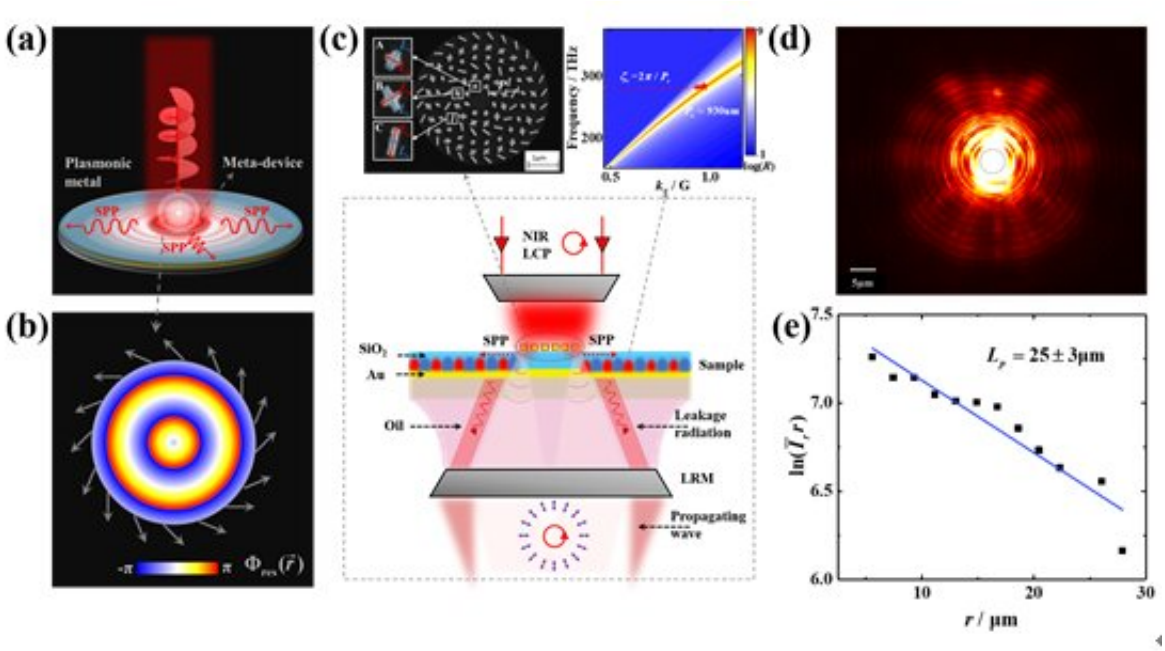


Figure | Concept, sample, experimental setup and partial characterizations of the vectorial vortex surface plasmon coupler.

a, Schematics of our proposed meta-device to generate a cylindrically polarized vortex SPP beam. **b**, Colour map represents the designed $\Phi_{res}(\vec{r})$ distribution on the meta-device with surrounding angles denoting the directions of ξ. **c**, Schematics of our leakage radiation microscopy (LRM) setup. Left-up inset is the SEM image of fabricated sample utilising three different meta-atoms A, B and C, and the right-up inset illustrates the dispersion of SPP supported by the guiding-out plasmonic metal. **d**, LRM-recorded image of surface wave generated by our meta-device which is shined by a normally incident LCP light at the wavelength of 1064 nm. **e**, Measured $\ln(\overline{I},r)$ versus r (solid squares), fitted with a linear relation (solid line) with slope determining the SPP propagation length.

Credit: Dongyi Wang, Feifei Liu, Tong Liu, Shulin Sun, Qiong He and Lei Zhou

In a newly published paper in *Light: Science & Applications*, Prof. Lei

Zhou's group from Physics Department of Fudan University in China, proposed a generic approach to efficiently generate arbitrary VOFs based on metasurfaces exhibiting full-matrix yet inhomogeneous Jones-matrix distributions. To illustrate the feasibility and power of their strategy, they elucidated their concept based on model-level analytical calculations, and experimentally demonstrated a meta-device as a benchmark that can simultaneously deflect light and manipulate its polarization in a controllable manner. Then, they further experimentally demonstrated the generations of far-field VOFs exhibiting a vortex wave front with an inhomogeneous polarization distribution and the generation of a near-field VOF with specially designed wave front and polarization distributions and even orbital angular momentum, i.e. a cylindrically polarized vortex surface plasmon wave. The excellent performance of realized meta-devices and the good agreement among the experimental results in the NIR regime, the simulations and analytical calculations well validated their approach, making such meta-platform as an alternative avenue to generate complex VOFs. These scientists summarize their VOF generation platform:

"we establish a generic strategy for designing ultra-thin meta-devices to efficiently generate arbitrary VOFs (including both far-field and near-field ones) as desired, and experimentally demonstrate the concept in the near-infrared (NIR) regime. The key idea is to assume the meta-device to exhibit an inhomogeneous full-matrix Jones matrix, thus possessing the control capabilities on both local spin and global wave-front of a light beam.The strategy proposed is so generic that we can design VOF-generation meta-devices working for impinging lights with arbitrary incident angles and polarizations in both reflection and transmission geometries," they added.

"In summary, by exploiting the full degrees of freedoms provided by full-matrix inhomogeneous Jones matrix, we establish a general strategy to realize meta-devices to generate VOFs both in the near- and far-field,

with any designed wave fronts and local polarization distributions. After illustrating our generic concept by both model-level analytical calculations and benchmark experiments on an anomalously-reflecting half-wave plate, we demonstrate the full capabilities of our approach by experimentally realizing two meta-devices...Our results offer a systematic approach to design ultra-compact optical devices to generate arbitrary VOFs under general conditions in different frequency domains, which are of great importance in both fundamental researches and photonic applications. Many future works can be expected along this line, such as extending the concept to transmission geometry, off-normal incidences, inhomogeneous amplitudes and arbitrary incident polarizations, and applying the generated VOFs to multi-channel communications, near-field sensing, optical trapping, and super-resolution imaging," the scientists conclude.

More information: Dongyi Wang et al, Efficient generation of complex vectorial optical fields with metasurfaces, *Light: Science & Applications* (2021). DOI: 10.1038/s41377-021-00504-x

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