Topologically Protected Plasmonic Phases in Randomized Aperture Gratings

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Abstract

Topological phases (TP) in optics have both the ability to serve as a photonic analogy for quantum systems and inherent usefulness in optic and photonic devices[1-3]. TPs are often achieved through periodic gratings[4], which lead to multiple diffraction orders, each carrying replicas of any desired phase information. Here we demonstrate how the randomization of grating periods diffracts all ordinary modes with uniform intensity[5], while still maintaining desired localization of plasmonic momenta, protected by topological phases. Polarization dependent directionality is shown due to a combined contribution of topological and dynamic phases and may be crucial in various fields of nanophotonics (such as optical communication, encoding, sensing etc.) where diffractionless propagation is paramount.

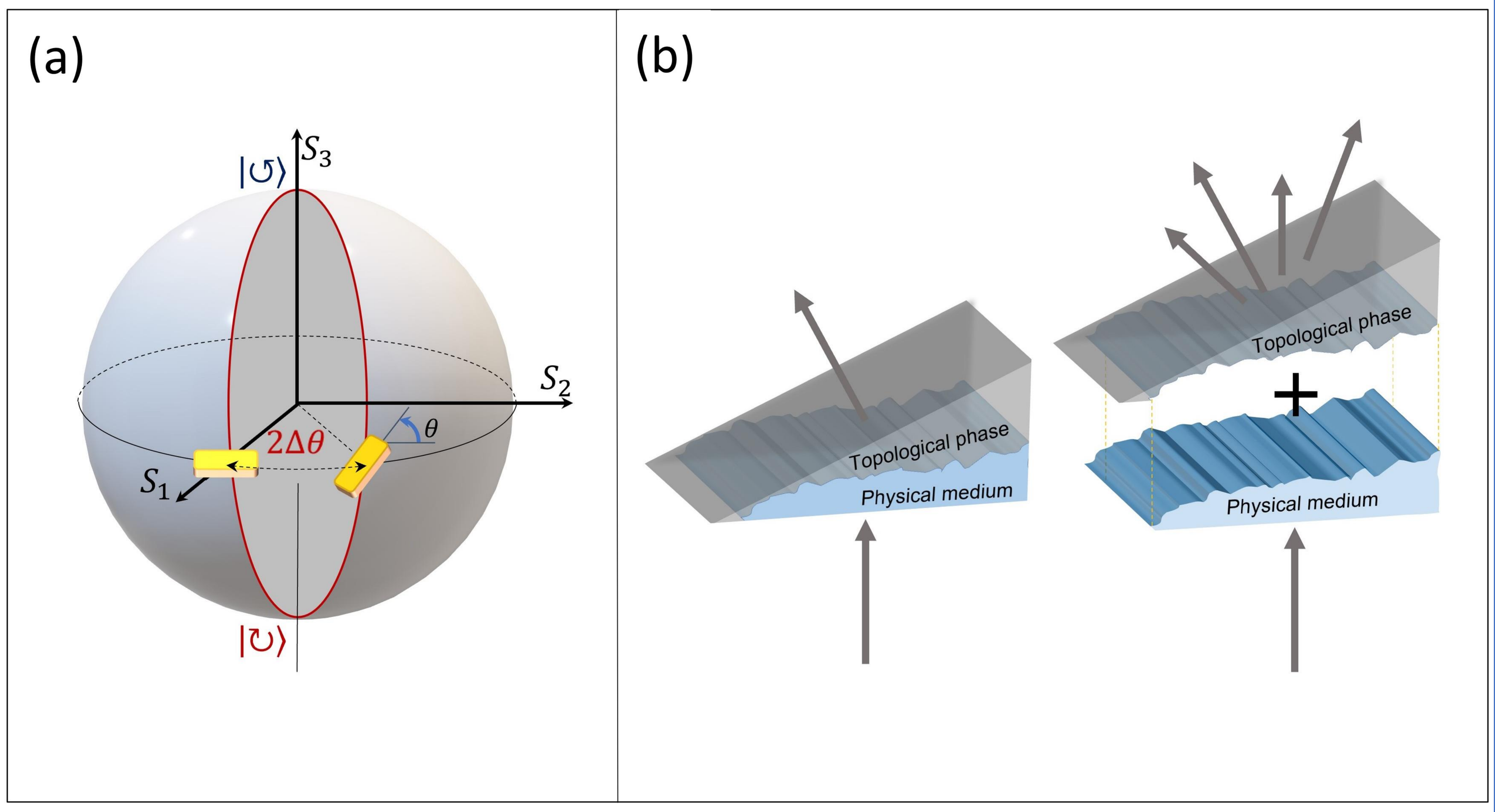

Figure 1: (a) Visualization of the TP on the Poincare sphere due to rotating apertures. The angle of the anisotropy axis, θ, corresponds to the longitudinal line of the sphere with the same angle. Subsequently, the solid angle subtended (in red) is then the topological phase accrued by coherent light passing through both apertures.
(b) Graphic presentation of the combined effect of the plasmonic grating and the topological phase. The randomized physical medium and the topological phase apart scatter incident light in all angles, but once coupled the light is diffracted in a topologically protected direction.

Results

Previous work[4] has shown that the total momentum of a topological diffraction mode from a periodic grating with spatial rotation of the unit-cell can be described via the following equation:

$$\boldsymbol{k}_t = \boldsymbol{k}_{in} + n\boldsymbol{k}_g + \sigma \boldsymbol{k}_\Omega \qquad (1)$$

Where $\boldsymbol{k}_{in}$ is the incident beam linear momentum, $n\boldsymbol{k}_g = 2\pi/\Lambda$ are the ordinary diffracted (OD) modes, $\sigma = \pm 1$ is the polarization of the incoming beam, positive for RCP and negative for LCP, and $\boldsymbol{k}_\Omega = 2\Omega$ is defined by the rotation rate of the apertures $\Omega = d\theta/d\xi$, where θ is the local orientation of the unit-cell and ξ is the coordinate along which the rotation is carried out. We now randomize the grating periodicity so that the equation can be only satisfied locally. For normal incidence ($\alpha = 0$) and $n = 1$ the local momentum delivered by the grating reads as:

$$\boldsymbol{k}_t = \frac{2\pi}{\Lambda_i} + \sigma \frac{2\Delta\theta_i}{\Lambda_i}$$

where Λ_i represents the local grating spacing and $\Delta\theta_i$ the local relative rotation between two apertures.
Setting the coupling condition $\boldsymbol{k}_t = \boldsymbol{k}_{SP}$ we obtain the requirement for the local grating period and rotation:

$$\boldsymbol{k}_{SP} \cdot \Lambda_i - \sigma \cdot 2\Delta\theta_i = 2\pi \qquad (2)$$

Equation 2 describes the condition for the constructive interference of plasmons at two adjacent apertures, taking into account the optical path and the TP contribution. We fabricated fully randomized gratings which maintained this relation between every two apertures, topologically protecting the polarization dependent plasmonic modes from randomness.

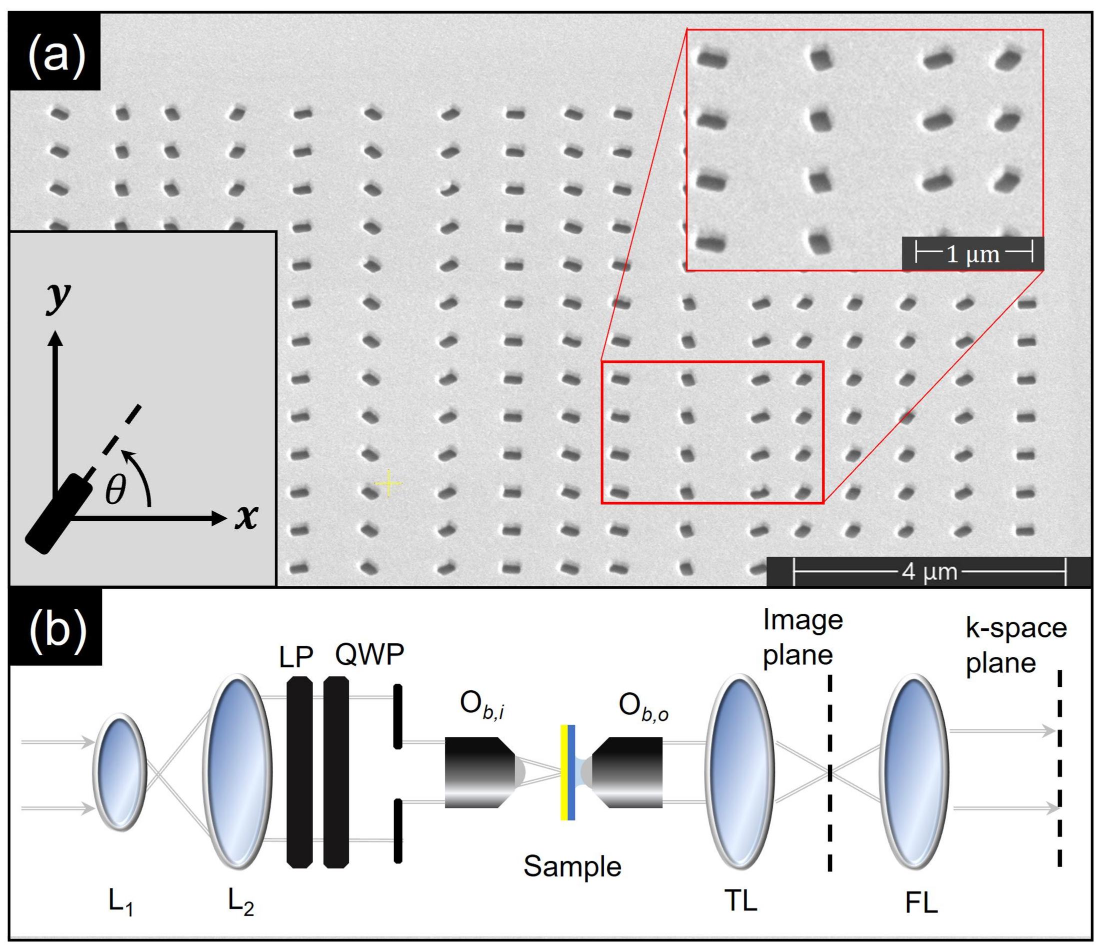

Figure 2: Randomized topological plasmonic structure. (a) SEM image of FIB milled apertures in gold. The inset schematically depicts an aperture orientation variation. Fifteen such structures were fabricated, with different randomized spacings. Five right-handed (RH) (shown) where the rotation of the cells is counterclockwise, five left-handed (LH) where the rotation is reversed and five ordinary (O) comprising circular apertures which should show no topological phenomena
(b) Optical leakage radiation microscopy setup.

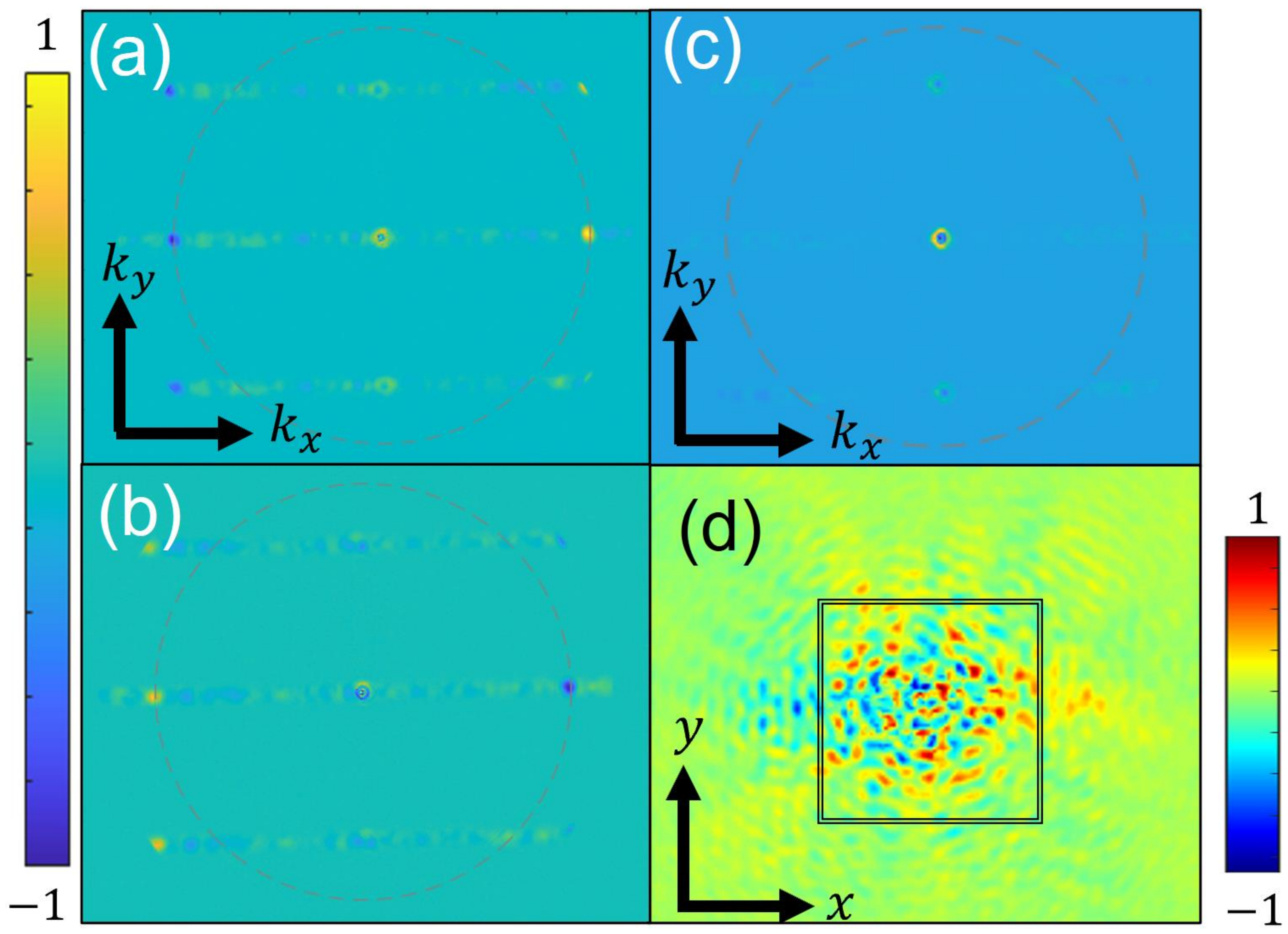

Fig. 3: Measured averaged circular dichroism *k*-space maps for RH structure (a), LH structure (b) and the circular structure (c). The averaged real space image corresponding to (a) is shown in (d), with the black outline denoting the structure boundaries. Colorbar is shown in arbitrary units.

Conclusions

- We have presented a method to topologically diffract polarization dependent plasmons independently from non-topological diffractions
- The randomized grating uniformly spreads the ordinary modes into *k*-space, but the topological phase-front couples to plasmons regardless of the precise arrangement of apertures
- This is a proof of concept for the ability to separate topological diffractions from their ordinary counterparts despite the use of aperture gratings, which would ordinarily couple them due to periodicity.
- This method of de-coupling of topological phases from ordinary ones may be useful in devices which need very fine separation of polarization dependent light, and may be applicable in analysis of other analogous solid-state systems.

References

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Acknowledgments

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