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Spin-directional coupling in hyperbolic shear metasurfaces

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The miniaturization and flattening of modern optical devices demand tunable control over highly localized electromagnetic fields. While there is progress in the control of group and phase velocities of localized light, its polarization properties and directivity pattern are still difficult to manage.

Optical spin angular momentum (SAM) defines polarization properties of light [1]. In particular, plane waves possess longitudinal SAM (parallel to the wave propagation direction), while conventional surface plasmon-polaritons at the metal-dielectric interface have purely transverse SAM (perpendicularly to the wave propagation direction). This phenomenon of strict connection between the wave propagation and SAM is known as spin-momentum locking [2], or robust spin-directional coupling [3]. The gap in the SAM manipulation between the purely longitudinal and transverse states limits polarization control and design flexibility in nanophotonic systems. Anisotropic metasurfaces were previously introduced to partially overcome this limitation by enabling hybrid TE-TM polarization modes and extended in-plane spin control via the nanostructures designing [2]. Nevertheless, the possible SAM directions remain limited.

The recent discovery of the shear hyperbolic metasurfaces [4] opens new opportunities for the in-plane SAM manipulation. Shear hyperbolic metasurfaces are two-dimensional (2D) structures engineered to support surface modes of hyperbolic dispersion with frequency-dependent optical axis. They are composed of a periodic array of two orthogonal sets of subwavelength dipole resonators rotated with respect to each other.

In this work, we show that shear hyperbolic metasurfaces provide broader control over the propagation direction and the angle between the SAM and wave propagation direction compared to other two-dimensional anisotropic systems. The improved tunability allows access to a wider range of polarization states and directional spin configurations, making them particularly promising for spin-based photonic applications.

In addition to spin control properties, shear hyperbolic metasurfaces also support canalization regimes, enabling diffractionless, highly directional energy propagation [5]. This dual functionality makes them a promising platform for next-generation photonic and opto-spintronic devices. Their ability to simultaneously route energy and tune polarization and spin states at the nanoscale is essential for the development of compact, highly integrated optical systems.

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