Berry Phases in Optical Möbius-Strip Microcavities

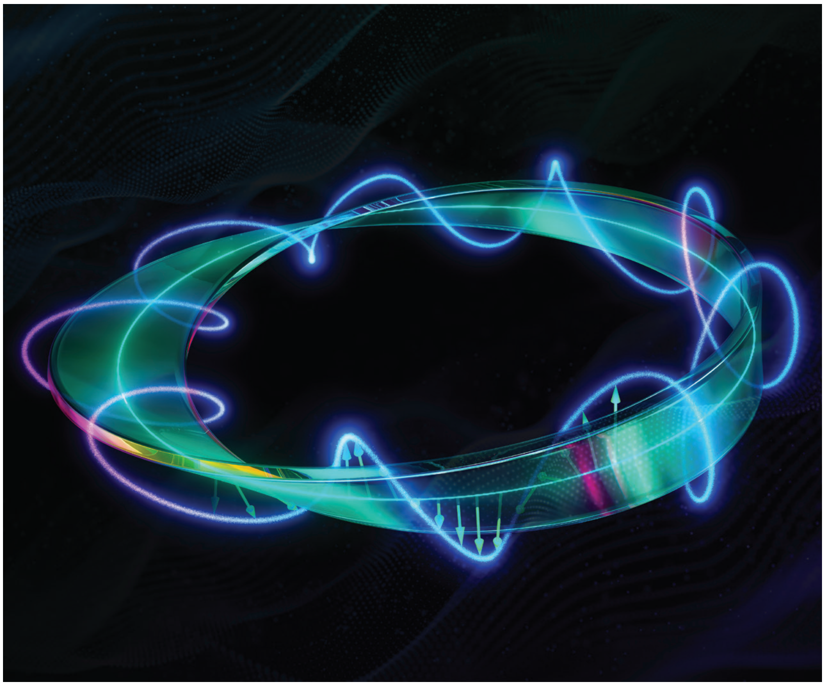
Curving a microscale optical waveguide into a closed loop generates a microring that can support optical resonances in the form of whispering-gallery modes (WGMs). In a regular ring resonator, neither the wavevector nor the electric-field vector experiences a nontrivial evolution and thus has no spin-orbit coupling. For that reason, it also lacks an optical Berry phase—the geometrical phase shift, $\Delta\varphi$ (in addition to the conventional dynamical phase), that arises from the evolution of polarization, and that was anticipated by Pancharatnam in 1956[1] and rediscovered by Berry in 1984.[2]

Via introducing topology into a WGM cavity, spin-orbit coupling embarks on a fascinating journey.[3] For example, diverging from conventional "orientable" cylindrical ring resonators with definite sides, the Möbius strip is well known for its non-orientable surface. In an ideal Möbius strip cavity, although the wavevector experiences a trivial evolution, the electric field is twisted to preserve its orientation parallel to the strip surface. Therefore, the twisted electric field along the Möbius strip creates orbital angular momentum and enables optical spin-orbit coupling through the Möbius topology. The effect can be presented as an adiabatic and cyclic evolution on the Poincaré sphere—and should give rise to an optical Berry phase.

Recently, we reported the experimental observation of just such optical Berry phases in dielectric Möbius strip cavities with finely adjusted transverse cross-sections.[4] By changing the ratio between the thickness and width in the strip cross-section, linearly and elliptically polarized light can be supported, generating Berry phases ranging from π to 0, which can be directly depicted by the corresponding evolution path on the Poincaré sphere. Owing to the existence of this variable Berry phase, the resonances do not occur exactly at odd multiples of the half wavelength, but quite generally at non-integer multiples.

We fabricated these Möbius strip microcavities using direct laser writing with two-photon polymerization. To extract the Berry phase determined by Möbius topology, we compared the Möbius strip cavity's resonance spectra with those of a different 3D strip cavity that showed the identical transverse cross-section dimensions, but without the Möbius topology. Experimental results also suggested that the Berry phase is "programmable." The latter finding contrasts with previous theoretical predictions in optical, electronic and magnetic systems with Möbius topology, for which a sole Berry phase of π occurs.

Beyond the fundamental implications, we believe the realm of optical Möbius strip cavities unveils exciting technological horizons. These cavities stand as a topologically elegant and, more importantly, practically accessible, integrable and miniaturizable building block with unlimited possibilities for optics and photonics in both the classical and quantum regimes. OPN



Schematic showing twisting elliptically polarized light with a non-integer number of wavelengths supported by a Möbius-strip microcavity.

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