Optical Isolation Based on Angular-Momentum Biasing

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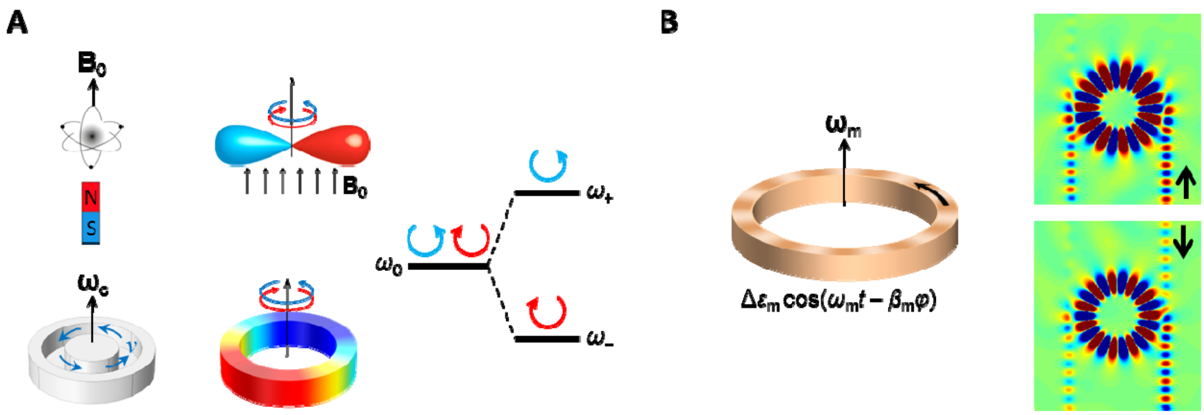
Breaking reciprocity is of essential importance in optical networks: isolators and circulators can protect sources, suppress the spurious coupling between different portions of a network, and guarantee its smooth operation. To date, non-reciprocal optical components have been largely based on magneto-optical effects. However, these solutions are unsuited for integrated photonics, as they rely on bulky external biasing devices and the lattice of the required magnetic materials is typically incompatible with conventional semiconductor technology. Magnetic-free non-reciprocity may therefore revolutionize integrated photonic circuit technology. Past attempts in this direction were based either on non-linear effects [1], imposing significant restrictions on the signal intensity, or spatiotemporal modulation [2], leading to bulky structures due to the weak nature of electro-optical effects. In contrast, we have recently proposed a new way to break reciprocity and achieve large, linear optical isolation over a subwavelength footprint, based on biasing a nanoresonator with angular momentum.

Like magneto-optical materials, an azimuthally symmetric ring cavity supports pairs of degenerate counter-rotating resonant states (a). Appropriate biasing can lift this degeneracy and induce non-reciprocity [3-5]. The angular momentum vector, being odd-symmetric under time reversal, can mimic the effect of a magnetic bias on a ferromagnetic molecule and efficiently break reciprocity (a). For sound, we successfully applied this concept by mechanically spinning a fluid in a resonant ring cavity [3], but this solution is obviously impractical for nanophotonic applications. For this reason, we recently proposed to impart an effective electronic spinning to a suitably designed nanophotonic resonant ring through appropriate spatiotemporal modulation in the form of an azimuthally traveling wave (b) [5]. Contrary to other approaches based on spatiotemporal modulation, the enhanced light-matter interaction in the resonant rings significantly boosts modulation effects, allowing the realization of compact devices requiring limited modulation amplitudes and frequencies. Proper selection of the nanoring quality factor and coupling to the incoming signal leads to giant isolation for modulation frequencies significantly smaller than the signal frequency and small values of the modulation amplitude, as shown in (b) for the case of an optical isolator designed in silicon-photonic technology. The proposed approach can be applied to different frequency bands and photonic circuit technologies, opening a path towards compact and efficient non-reciprocal integrated optical components.

[1] L. Fan, et al., Science **335**, 447–50 (2012).
[2] Z. Yu, et al., Nature Photon. **3**, 91–94 (2009).
[3] R. Fleury, et al., Science **343**, 516-519 (2014).
[4] D. L. Sounas, et al., Nat. Commun. **4**, 2407 (2013).
[5] D. L. Sounas, et al., ACS Photon. 1, 198–204 (2014).



(a) (Adapted from [3]) Non-reciprocity induced by a static magnetic bias in ferromagnetic molecules (top) and by angular momentum bias in a circular cavity (bottom). (b) (Adapted from [5]) Optical implementation of angular-momentum biasing through spatiotemporal modulation of a ring resonator. By coupling the ring to two waveguides, an isolator is realized: power propagate from top to bottom, but not in the opposite direction.