Radiationless anapole states in on-chip photonics

Resonant on-chip photonics via high-refractive-index nanoparticles has opened up the possibility to shape the functional response of photonic integrated circuits with wavelength-sized building blocks. The resulting flexibility in circuit design is allowing for the creation of ever more sensitive biosensors as well as nonlinear signal processing with greatly reduced power envelopes. By tailoring the interference between two modes of the nanoparticle, intriguing conditions such as quasi-bound states in the continuum and radiationless states known as anapoles arise. Specifically, the latter were shown under normal incidence to be widely tunable in wavelength while experiencing an enhanced energy concentration inside the particle. However, to exploit these striking states in on-chip circuitry, they have to be driven in-plane via integrated waveguides.

In a new paper published in Light Science & Application, a team of researchers led by Prof. A. Martínez from the Universitat Politècnica de València, Spain and Prof. L. Kuipers from Delft University of Technology in the Netherlands reports on a distinct spectral decoupling of the anapole condition from the near-field energy maximum in silicon disks when excited in exactly this on-chip configuration at telecom wavelengths.

To experimentally verify the two distinct spectral regions, they fabricate photonic chips with integrated nanodisk resonators on a silicon-on-insulator platform. The eigenmode spectrum of these disks shows a wavelength range where its electric and toroidal dipole moments cancel in the far field, and scattering is drastically reduced even for excitation from on-chip waveguides. By measuring the out-of-plane scattering of such waveguide-disk systems, the researchers were able to demonstrate the wide tunability of this reduced scattering condition for individual nanodisks.

The researchers further complemented this experimental far-field analysis by visualizing the electromagnetic mode profile at the anapole condition via phase- and polarization-resolved near-field optical microscopy. The team found that while the expected double-vortex fingerprint of the toroidal excitation is clearly visible even for in-plane geometries, the wavelength of maximum energy concentration inside the disks is red-shifted, and thus decoupled from the minimum scattering condition. This decoupling of the two phenomena that overlap under normal incident excitation was attributed to the enhanced retardation effects in the on-chip geometry as given by the longer interaction length between the disk and the exciting wave field.

The scientists predict that “similar phenomena might also occur for other states based on mode interference when excited in on-chip configuration. We believe that our finding may have important consequences when trying to employ anapole states for sensing or nonlinear applications in on-chip nanophotonics, either implemented in silicon or other high-index materials.”

E. Díaz-Escobar, T. Bauer, E. Pinilla-Cienfuegos, A. I. Barreda, A. Griol, L. Kuipers, and A. Martínez
Light: Science & Applications, **10**, 204 (2021). https://doi.org/10.1038/s41377-021-00647-x

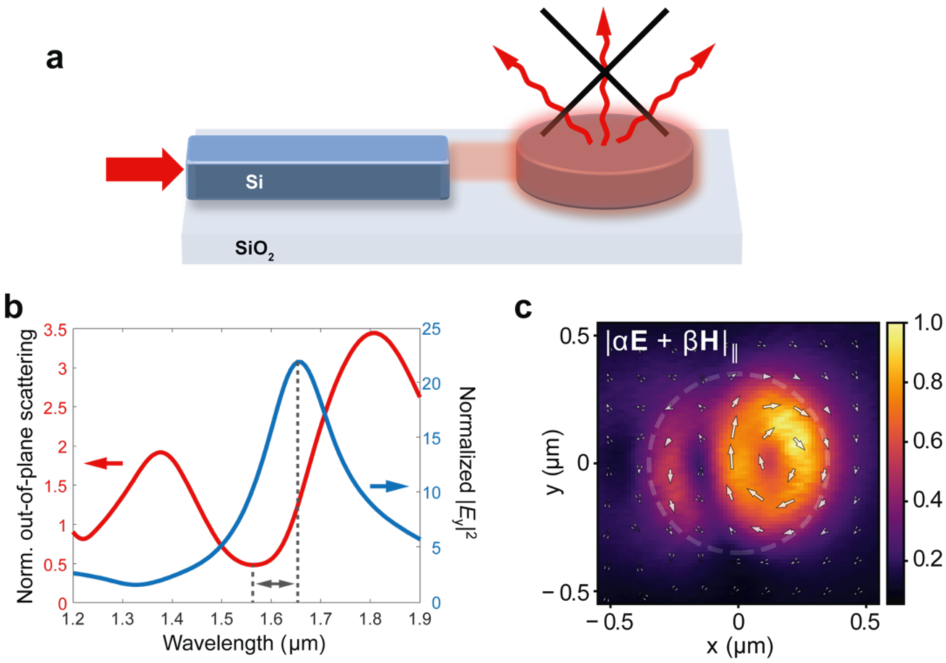

Figure | Decoupling of anapole condition and near-field energy maximum in on-chip excitation of high-index nanodisks.

a, Schematics of the on-chip geometry coupling light from an integrated feed waveguide to a high-index nanodisk. At the anapole condition, far-field scattering is drastically reduced while the excited mode allows to concentrate energy inside the nanodisk. **b**, Calculated far-field scattering response and near-field intensity for a disk of radius $r = 375\text{nm}$. The minimum of the normalized scattering and maximum of the field intensity inside the disk are distinctly shifted in wavelength. **c**, Experimentally retrieved in-plane near-field structure of the mode at the anapole condition, showing the double-vortex structure of the contributing toroidal moment. The white arrows represent the field direction at the time-snapshot where the field is maximized in the center of the disk.

Contact

Alejandro Martínez
Nanophotonics Technology Center, Universitat Politècnica de València, Camino de Vera s/n, 46022, Valencia, Spain
amartinez@ntc.upv.es

Kobus Kuipers
Kavli Institute of Nanoscience, Delft University of Technology, 2600 GA, Delft, The Netherlands
l.kuipers@tudelft.nl

E.D.E. acknowledges funding from Generalitat Valenciana under grant GRISOLIAP/2018/164. A.I.B. acknowledges financial support by the Alexander von Humboldt Foundation. T.B. and L.K. acknowledge support from the European Research Council (ERC) Advanced Investigator Grant no. 340438-CONSTANS. E.P.-C. gratefully acknowledges support from the Spanish Ministry of Science and Innovation under grant FJCI-2015-27228 and postdoctoral research stay grant CAS19/00349. A.M. thanks funding from Generalitat Valenciana (Grants No. PROMETEO/2019/123, BEST/2020/178 and IDIFEDER/2018/033) and Spanish Ministry of Science, Innovation and Universities (Grants No. PRX18/00126 and PGC2018-094490-BC22).