Chiral Optics Miracle | Ultra-High-Q Cavity via BIC-GMR Degeneracy Boosts Chiral Sensing

Experimental results demonstrate that the BIC-GMR degenerate state enables near-perfect transmission CD up to 0.99, without requiring symmetry breaking.

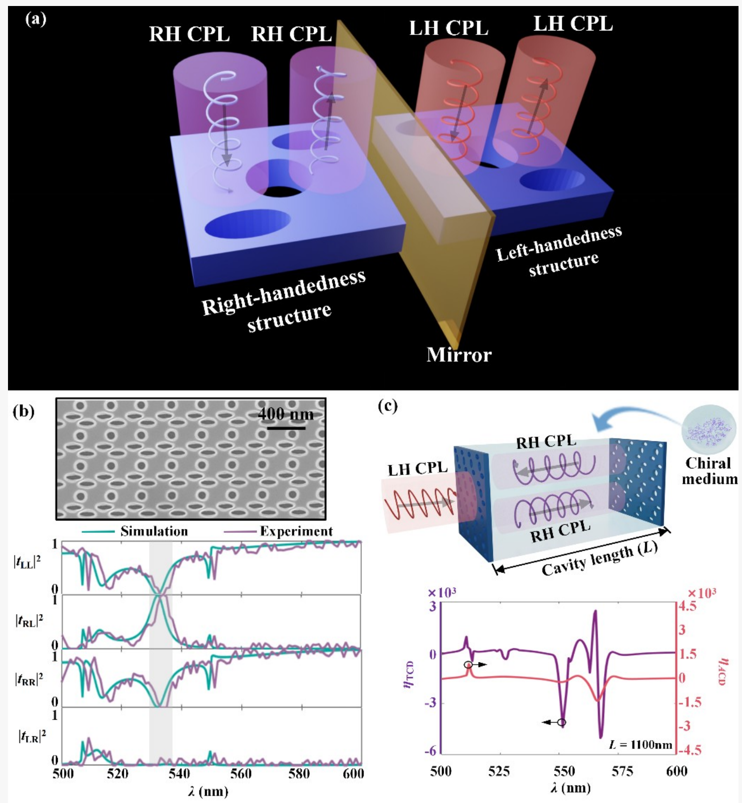

Fig. 1 (a) Schematic diagram of different chiral spin-preserving metamirror (b) Simulated and measured transmission coefficients spectra for CPL with different handedness. The insets illustrate SEM image of the spin-preserving metamirror (c) Schematic of a chiral...

CHENGDU, SICHUAN, CHINA, October 9, 2025 /EINPresswire.com/ -- In nature, many molecules exhibit chirality, meaning their spatial structures are non-superimposable mirror images of each other, just like human left and right hands. Such subtle structural differences can lead to significant variations in pharmacological activity, biological recognition, and metabolic pathways. Therefore, the identification and detection of chiral molecules hold great scientific importance and practical value. Circular Dichroism (CD) spectroscopy is a key optical technique for probing molecular chirality. It operates by measuring the differential absorption of left- and right-handed (LH and RH) circularly polarized light (CPL) as it passes through chiral substances, thereby revealing information about the molecule's chirality and conformational structure. In particular, for biological macromolecules such as proteins, CD spectra provide rich insights into their secondary structures (e.g., α-helices and β-sheets), making this technique widely used in structural biology, drug development, and biomedical diagnostics.

Despite its long-standing use and significant achievements, conventional CD spectroscopy faces a fundamental challenge: while molecular dimensions are on the nanometer scale, the wavelengths of probing light are typically hundreds of nanometers. This scale mismatch leads to extremely weak light–matter interactions, and the resulting CD signals are often near the detection limit. As a result, traditional CD measurements typically require high-concentration or large-volume samples, which hinders trace analysis and limits applications involving minute biological specimens. To overcome this limitation, researchers have turned to advances in nanophotonics to design novel nanostructures and optical cavities that can enhance light–matter interactions and amplify CD signals.

For instance, metasurfaces can locally intensify electromagnetic fields and boost the optical chirality density, thereby significantly enhancing CD responses. However, such structures often suffer from material absorption and scattering losses, which degrade the resonance quality factor (Q-factor) and reduce the signal-to-noise ratio, ultimately restricting their use in high-sensitivity detection. A promising new optical mechanism, known as Bound States in the Continuum (BIC), has emerged in recent years. BIC allow for theoretically infinite Q-factors, enabling light to remain confined within a structure for extended durations, and thus substantially increasing interaction with chiral molecules. If BIC can be combined with traditional Guided Mode Resonances (GMR) and carefully engineered to maintain the handedness purity of circularly polarized light, it becomes possible to fundamentally overcome the trade-off between high optical chirality density and low-loss operation. This synergy holds the potential to drastically enhance CD signals, paving the way for ultrasensitive chiral detection.

Recently, Professor Guanghao Rui from Southeast University and Professor Junsuk Rho from Pohang University of Science and Technology in South Korea conducted a collaborative study and proposed a high-Q-factor chiral optical cavity structure that breaks the traditional trade-off between optical chirality density and mode loss. This work, titled “Superchirality induced ultrasensitive chiral detection in high-Q optical cavities”, was published in the 9th issue of Opto-Electronic Advances in 2025.

The research team employs a spin-preserving chiral metasurface to realize a BIC–GMR degenerate mode, achieving a high Q-factor while maintaining the chirality purity of circularly polarized light propagating within the cavity via spin-locking mechanism. Experimental results demonstrate that the BIC-GMR degenerate state enables near-perfect transmission CD up to 0.99, without requiring symmetry breaking. Full-wave simulations further predict that this synergistically enhanced system can achieve a Q-factor as high as 104 and generate a localized field in the molecular interaction region with an optical chirality density enhancement of up to 400-fold, leading to 5025-fold amplification of the CD signal.

This breakthrough provides a powerful tool for detecting low-concentration chiral molecules and paves the way for CD spectroscopy to approach single-molecule sensitivity. The proposed technology holds significant promise for applications in biomolecular analysis, drug screening, and environmental monitoring, enabling precise identification of chiral molecules even at ultra-low concentrations. More broadly, this approach could have far-reaching impacts across multiple disciplines, including life sciences, medical diagnostics, and materials science.

About the Research group:

Guanghao Rui is a Professor and Ph.D. advisor at Southeast University. His research has long focused on light field manipulation and nanophotonics. He has published over 100 SCI-indexed papers, holds more than 10 authorized Chinese patents, and has contributed two book chapters. He has received several honors, including the Jiangsu Young Optical Scientist Award and the Zhishan Young Scholar Award from Southeast University.
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Junsuk Rho is the Mu-Eun-Jae Endowed Chair Professor and a Young Distinguished Professor in the Departments of Mechanical Engineering and Chemical Engineering at Pohang University of Science and Technology (POSTECH), South Korea. He also serves as the Director of the POSCO-POSTECH-RIST Convergence Research Center for Flat Optics and Metaphotonics. He earned a degree in English, French, and Chinese from Myeongdeok Foreign Language High School in Korea, and went on to receive his B.S. from Seoul National University (2007), M.S. from the University of Illinois at Urbana-Champaign (2008), and Ph.D. from the University of California, Berkeley (2013). He has previously worked as a postdoctoral researcher in the Materials Sciences Division at Lawrence Berkeley National Laboratory and as a Ugo Fano Fellow, one of the highest honors supported by the U.S. Department of Energy, at the Center for Nanoscale Materials, Argonne National Laboratory.
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Tianxu Jia is a Ph.D. candidate at Southeast University, specializing in nanophotonics. His research focuses on metasurface design and control, as well as light–matter interactions. He has published three first-author papers in JCR Q1 journals and led a scientific innovation project funded by Jiangsu Province. He has received several honors, including the First-Class Academic Scholarship, Outstanding Graduate Student, Nanshan Zhishan Award, Excellent Communist Party Member among Graduate Students at Southeast University, and the Excellent Presentation Award at a Jiangsu Provincial Academic Conference. In 2024, he was awarded a Chinese Government Scholarship for joint Ph.D. training at Pohang University of Science and Technology (POSTECH), South Korea.

Read the full article here: www.oejournal.org/oea/article/doi/10.29026/oea.2025.250079

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