

From Optical Forces to Optical Spectroscopy: Recent Advances in Optical Sorting and Detection of Chiral Particles

A thorough review highlights optical, nanophotonic, and AI advances enabling more sensitive, selective, and practical sorting and detection of chiral particles

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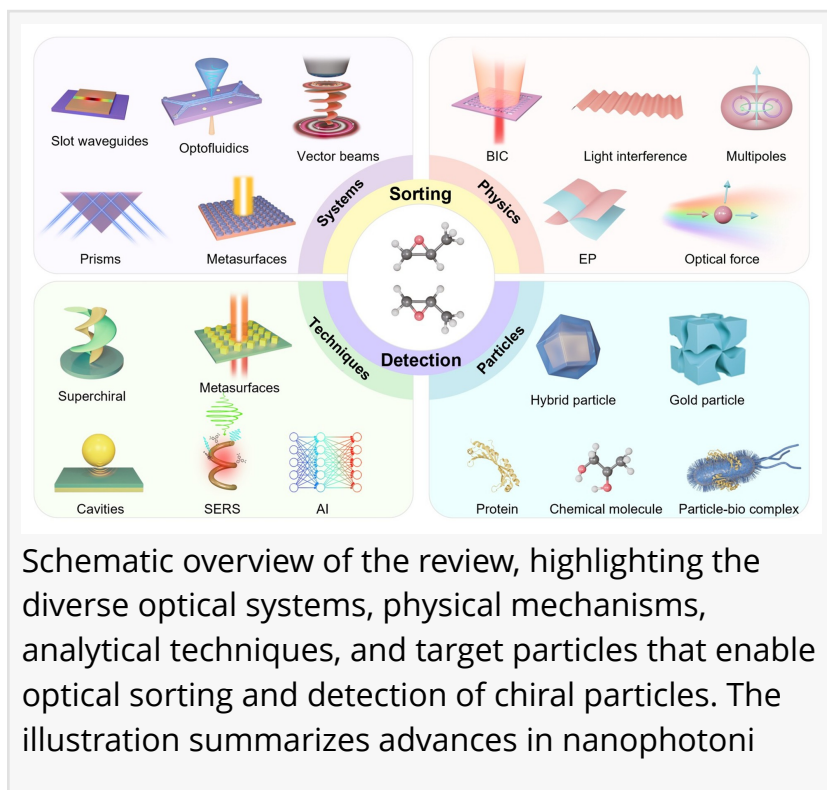
from Tongji University present a comprehensive review of emerging optical techniques for sorting and detecting chiral particles. The review highlights advances in engineered light fields, nanophotonic platforms, and artificial intelligence that enhance the sensitivity, selectivity, and efficiency of chiral analysis. By comparing optical sorting and detection strategies across diverse platforms, the work outlines current challenges and future

directions, providing a valuable roadmap for developing practical, high-performance optical technologies for chemistry, biomedicine, and materials science.

Research Background:

Chirality is a fundamental geometric and physical property ubiquitous in nature, playing a critical role in food safety, pharmaceutical development, clinical diagnostics, and materials science. Although a pair of chiral enantiomers share identical chemical compositions, subtle differences in their three-dimensional configurations can lead to drastically different biological activities and pharmacological effects. As a result, achieving highly sensitive and non-destructive sorting and detection of chiral molecules has long been a central challenge across chemistry, life sciences, and materials research.

Conventional chiral analysis techniques predominantly rely on non-optical approaches, such as chemical derivatization, biochemical reactions, or chromatographic separation. While these methods are well established, they often suffer from complex procedures, large sample



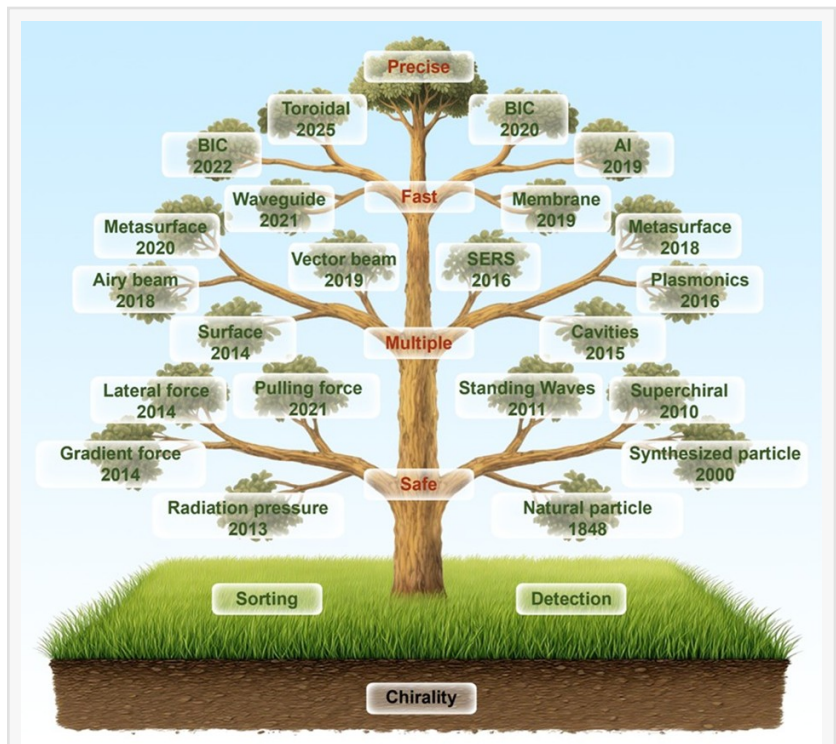
Schematic overview of the review, highlighting the diverse optical systems, physical mechanisms, analytical techniques, and target particles that enable optical sorting and detection of chiral particles. The illustration summarizes advances in nanophotoni

consumption, and limited real-time capability. In contrast, optical approaches based on light-matter interactions offer unique advantages, including non-contact operation, non-destructive probing, and ease of integration, making them increasingly attractive for chiral analysis.

From a physical standpoint, chiral light-matter interactions typically originate from weak coupling at the electric and magnetic dipole levels, resulting in intrinsically small signal strengths and limited chiral selectivity. For optical sorting, generating sufficiently strong and selective chiral optical forces is nontrivial due to their subtle dependence on field helicity, momentum, and near field gradients. For optical detection, reliably distinguishing weak chiral signatures from background remains a central bottleneck, particularly at low concentrations. These theoretical and practical challenges have motivated the rapid development of engineered light fields, nanophotonic platforms, and AI-assisted strategies, which together form the core focus of this review.

Highlights of This Work

Recently, a research team led by Prof. Zhanshan Wang and Prof. Xinbin Cheng from the School of Physical Science and Engineering, as well as Shanghai Eye Diseases Prevention & Treatment Center, Tongji University, published a comprehensive review that systematically summarizes recent progress in optical sorting and detection of chiral particles. The review analyzes the underlying mechanisms governing enhanced chiral light-matter interactions across different physical platforms, explores the feasibility and advantages of artificial intelligence-assisted strategies in chiral research, and provides an outlook on key challenges and future development trends toward practical applications. The study was made available online on March 23, 2026 and was published in volume 9 and issue 6 of the journal [Opto-Electronic Advances](#) (OEA) on June 07, 2026.



A timeline illustrating the major milestones in optical chirality research, tracing the evolution of optical sorting and detection technologies from early studies of natural chiral particles to recent advances in metasurfaces, bound states in the continuum



Researchers from the Institute of Precision Optical Engineering (IPOE), Tongji University, whose interdisciplinary expertise in optics, nanophotonics, and biomedical engineering underpins advances in optical technologies for sorting and detecting chiral p

From a functional perspective, the review categorizes optical chirality research into two core directions: optical sorting and optical detection. For optical sorting, the discussion begins with traditional optical forces, including optical radiation pressure, gradient forces, lateral forces, and pulling forces, and further summarizes how structured light fields and vector beams enhance and selectively control chiral optical forces. The review further extends to near-field optical forces supported by emerging physical concepts such as bound states in the continuum and exceptional points, highlighting the potential of nanophotonics platforms, such as metasurfaces and photonic crystals, for achieving efficient and stable chiral sorting.

For optical detection, the review follows a similar physical evolution from far-field to near-field approaches, systematically summarizing the roles of interference and standing-wave fields, plasmonic structures, optical microcavities, and metasurfaces in enhancing light–chiral matter interactions. Among these platforms, metasurfaces and other micro- and nano-optical elements, supported by different types of optical resonances, enable precise control of light–chiral matter interactions while simultaneously balancing low optical loss and strong optical chirality field enhancement, offering significant potential for improving the sensitivity of chiral detection in practical applications. In addition, the review systematically summarizes emerging applications of artificial intelligence and machine learning in chiral detection, providing new technical pathways for high-throughput identification of multiple chiral components in complex samples.

Overall, this review not only provides a comprehensive overview of recent advances in optical sorting and detection of chiral particles, but also offers a comparative analysis of different optical platforms in terms of applicable molecular scale, detection sensitivity, and experimental complexity, serving as a valuable reference for researchers in this field. Despite existing challenges such as high fabrication cost, limited system stability, and constrained throughput, the continued integration of nanophotonics, microfluidics, and artificial intelligence is expected to further improve the efficiency and accuracy of optical chiral technologies, opening new avenues for future scientific research and practical applications.

Team Introduction:

The Institute of Precision Optical Engineering (IPOE) at Tongji University (Team leaders: Professor Zhanshan Wang, Distinguished Professor of the Changjiang Scholars Program and recipient of the National Science Fund for Distinguished Young Scholars, and Professor Xinbin Cheng, recipient of the National Science Fund for Distinguished Young Scholars.) has established the first-level discipline of Optical Science and Technology, the second-level discipline of Optics, and the undergraduate program in Optoelectronic Information Science and Engineering. At present, relying on one national platform and three provincial/ministerial platforms—including the National Integrated Circuit Micro/Nano Detection Equipment Industry Metrology and Test Center (Shanghai), the MOE Key Laboratory of Advanced Micro-Structured Materials, Shanghai Frontiers Science Center of Digital Optics, and Shanghai Professional Technical Service Platform for Full-Spectrum and High-Performance Optical Thin Film Devices and Applications, the IPOE has been engaged in education, fundamental science, key technologies, and engineering application

research in the field of precision optical engineering. Taking the ownership of the challenge to overcome cutting-edge scientific problems and targeting breakthroughs on core technologies, the IPOE has accomplished several significant national scientific research projects, received two State Technological Invention Award, one China Patent Award Gold Medal, and more than ten provincial/ministerial-level awards. It has now become an important base for high-level talent cultivation and advanced scientific research.

After two decades of endeavors, by maintaining “loyalty, excellence, innovation, and synergy”, the IPOE has evolved to be a significant institution with many core specialties. Meanwhile, the IPOE will grasp the opportunities presented by the country's “14th Five-Year Plan”, which reaffirms our determination to advance with the times, make the security of people our ultimate goal, dedicate ourselves to work, scale new heights, and consider our unique potentials for developing strengths beyond our core specialties.

Shanghai Eye Disease Prevention and Treatment Center (Shanghai Eye Hospital) was established in 1942 and is the only municipal-level public ophthalmic specialty hospital in Shanghai. It fulfills the dual functions of eye disease prevention and treatment in the city and operates as a tertiary-level medical institution directly under the supervision of Shanghai Shenkang Hospital Development Center. The center serves as the National Clinical Research Center for Ocular Diseases, leads the Eye Disease Prevention and Treatment Alliance under the Yangtze River Delta Coordination Council's Smart Healthcare Development Alliance, and spearheads the Shanghai Visual Health Center. The hospital has secured multiple national key research and development projects from the Ministry of Science and Technology, national-level projects, and National Natural Science Foundation of China projects. It is home to a distinguished team recognized through various talent programs, including the National Candidates for the New Century Hundred, Thousand, and Ten Thousand Talents Project; Shanghai Leading Talents; the Shanghai Medical Garden New Star Training Program for Young Basic Talents; the Shanghai Eastern Talent Program's Youth Initiative; and the Rising Star Program under the Science and Technology Innovation Action Plan. In 2023, the center received approval to begin preparations for its establishment as the Affiliated Eye Hospital of Tongji University. According to the 2023 Science and Technology Evaluation Metrics (STEM) and the 2019–2023 Five-Year Aggregate Science and Technology Evaluation Metrics (ASTEM) reports for Chinese hospitals, the center's ophthalmology discipline ranked among the top ten nationwide in both the STEM and ASTEM rankings, securing the ninth position in each list.

Reference

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