

Duality Symmetry in Hybrid Nanoresonators for Chiral Sensing

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Duality Symmetry in Hybrid Nanoresonators for Chiral Sensing

Ershad Mohammadi¹, Andreas Tittl², Kosmas L. Tsakmakidis³, T.V. Raziman¹,
Alberto G. Curto¹

¹*Department of Applied Physics and Institute for Photonic Integration, Eindhoven University of Technology, Eindhoven, The Netherlands.* ²

Chair in Hybrid Nanosystems, Nanoinstitut Munich, Faculty of Physics, Ludwig-Maximilians-Universität München, 80539, Munich, Germany.

³*Section of Condensed Matter Physics, Department of Physics, National and Kapodistrian University of Athens, Panepistimioupolis, GR-157 84 Athens, Greece*

e.mohammadi@tue.nl

Abstract: Metal nanoparticles support intense electric resonances, while high-index dielectric particles offer strong magnetic resonances. Here, we propose metal-dielectric nanophotonic platforms based on duality symmetry for chiral molecular sensing. © 2020 The Author(s)

1. Introduction

Chirality is vital for the functionality of biomolecules and, consequently, for the interactions of chiral drugs with the human body. The detection and differentiation of chiral molecules is thus of great interest in fields ranging from biology and pharmacy to the cosmetics and food industries. Chiral molecules reveal their handedness through interaction with another chiral entity, such as circularly polarized light. Circular dichroism spectroscopy exploits the differential absorption of chiral samples for right- and left-handed circular polarizations. According to Poynting's theorem, this difference in absorbed power for a chiral sample that is illuminated sequentially with right(+) and left(-) circularly polarized light can be expressed as [1]:

$$P_+ - P_- = 4c_0 \text{Im} \{ \kappa \} C V_s \quad (1)$$

where c_0 , κ and V_s are the speed of light, the Pasteur parameter of the chiral sample [2], and the sample volume, respectively. C represents the optical chirality [3]. The differential absorbed power in eq. (1) is normally exceptionally weak because the Pasteur parameter for biomolecules is extremely small [4] ($\kappa \sim 10^{-4} - 10^{-7}$). Furthermore, a general goal is to push the detection limits down to very small volumes of chiral sample for maximum sensitivity. Interestingly, these weak signals can be compensated by an increase in the optical chirality of the field interacting with the sample, which motivates the quest to find nanophotonic platforms with the highest values of C [5, 6].

For superchiral field formation, we need electric and magnetic fields that are parallel, $\pi/2$ out of phase, and with spectral and spatial overlap. Metallic nanostructures can create intense electric dipole fields through the excitation of localized surface plasmon resonances. On the other hand, high-refractive-index dielectric nanoparticles can exhibit strong magnetic dipole resonances [7–9]. This complementarity opens a hybrid route to exploit both types of resonances for enhancing optical chirality.

Here, we propose a combination of metal and dielectric structures capable of providing (i) strong electric and magnetic fields as well as (ii) equal electric and magnetic response, known as duality symmetry [10]. The latter brings the electric and magnetic resonances to the same spectral and spatial range and satisfies $\pi/2$ phase condition. Furthermore, our hybrid nanostructures offer a degree of freedom in design by decoupling and separately controlling the electric and magnetic response. The concept of duality symmetry (Figure 1a) relies on the electric dipolar field (\mathbf{E}_{dip}) of an electric resonator excited by the incident electric field (\mathbf{E}_{inc}) being analogous to the magnetic dipolar field (\mathbf{H}_{dip}) of a magnetic resonator excited by the incident magnetic field (\mathbf{H}_{inc}). To harness the dual fields of such individual resonators in a nanophotonic system, we first focus on nanodimers to analytically elucidate how duality symmetry can be achieved. Then, to realize strong dual fields with realistic materials, we propose a hybrid metal-dielectric dimer system (Figure 1b) composed of a high-refractive-index dielectric particle placed next to a plasmonic particle. Based on the insights gained from simple nanodimers, we introduce a more complex hybrid metasurface for chiral sensing enabling a 350-fold optical chirality enhancement. The spatially averaged optical chirality is high, resulting in an enhancement of circular dichroism by a factor of 20.

Our theoretical approach shows that this route meets the two fundamental requirements for attaining optical superchiral fields. By combining individually tunable resonators, our hybrid structures offer a design strategy

to achieve chiral fields that is more flexible than for single nanostructures.

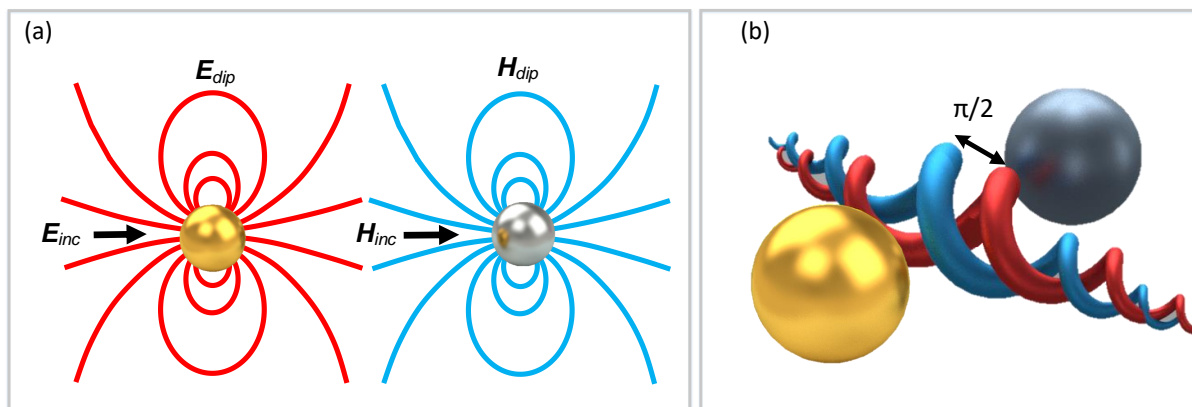


Fig. 1. (a) Concept of duality symmetry to realize superchiral fields. The dual electric (yellow sphere) and magnetic (grey sphere) resonators show analogous electric and magnetic fields that can be used for achieving strong, parallel, spectrally and spatially overlapped and finally $\pi/2$ out of phase electric and magnetic fields. \mathbf{E}_{dip} (red) and \mathbf{H}_{dip} (blue) indicate the dual dipolar fields associated with electric and magnetic resonators. (b) A hybrid metal-dielectric dimer illuminated by circularly polarized light producing strong optical chirality. The strong electric resonance in the plasmonic particle is coupled to the electric resonance of the dielectric particle forming a strong electric hotspot that is fully decoupled from the strong magnetic resonance of the dielectric sphere. The duality symmetry of the structure provides a phase factor of $\pi/2$ between the electric and magnetic hotspots. Red and blue helices indicate the electric and magnetic fields, respectively.

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