Circularly Polarized Light as a Probe for the Dynamics of Chiral Metasurfaces

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In this contribution, we investigate how incident circularly polarized radiation rearranges chiral metasurfaces with averaged optical forces. The Maxwell stress tensor formalism allows extracting the optical forces from numerical simulations for several chiral designs. Because these forces rely upon chiral frequency-dependent resonances, our results also extend to other chiral metasurfaces.

In recent years, the interaction of light with nanostructured metasurfaces has paved the way for the manipulation of electromagnetic force [1], momentum [2] and polarization [3]. Metasurfaces can manipulate the propagation of electromagnetic radiation to high precision, by making use of frequency-dependent dipole moments sustained by subwavelength building blocks without inversion symmetry. However, the incident radiation also influences the properties of metasurfaces, i.e., it exerts an averaged optical force due to momentum transfer between the waves and the sheet. These optical forces provide a new way to position and rearrange chiral metasurfaces with circularly polarized light.

Chiral metamaterials [4] provide an interesting approach to manipulate electromagnetic radiation in a polarization-dependent way. Their building blocks make use of unit cells without inversion symmetry, e.g., gammadions or crossed wires, to impose left-handed or right-handed circularly polarized eigenmodes with distinct behaviours. Macroscopically, chiral materials may turn linearly polarized light (optical activity) and may change the polarization (dichroism). Microscopically, the aforementioned chiral effects arise due to (partially) parallel electric and magnetic dipole moments. As a first part of this work, we investigate how the currents on metamaterial sheets induce these effects [5].

Having obtained a sound understanding of two-dimensional chiral sheets, we perform numerical simulations with a finite-element solver to extract the optical forces acting between sheets due to incident circularly polarized radiation. As for optical forces between wire pairs [1], the frequency dependencies of electric and magnetic dipole resonances on chiral metasurfaces provide a playground for observing these optical forces.

Within classical electrodynamics [6], the incident momentum of light yields two contributions to the overall optical force: the *gradient force* moves objects orthogonally to the direction of the beam propagation, whereas the *scattering force* acts along the direction of propagation [7]. We use the Maxwell stress tensor formalism to calculate the optical force on the metamaterial sheet due to left-handed, right-handed and linearly polarized radiation based upon the momentum transfer between the electromagnetic fields and the metamaterial sheets (Fig. 1). The time-averaged force on a metamaterial sheet is expressed by the flux integral of the Maxwell stress tensor along an arbitrary surface enclosing the object of interest:

$$\langle F_i \rangle = \oint \langle T_{ij} \rangle \, dS_j, \tag{1}$$

where the Maxwell stress tensor is defined as

$$\langle T_{ij} \rangle = \frac{1}{2} Re\left[\epsilon_0 \left(E_i E_j^* - \delta_{ij} \sum E_k E_k^*\right) + \mu_0 \left(H_i H_j^* - \delta_{ij} \sum H_k H_k^*\right)\right]. \tag{2}$$

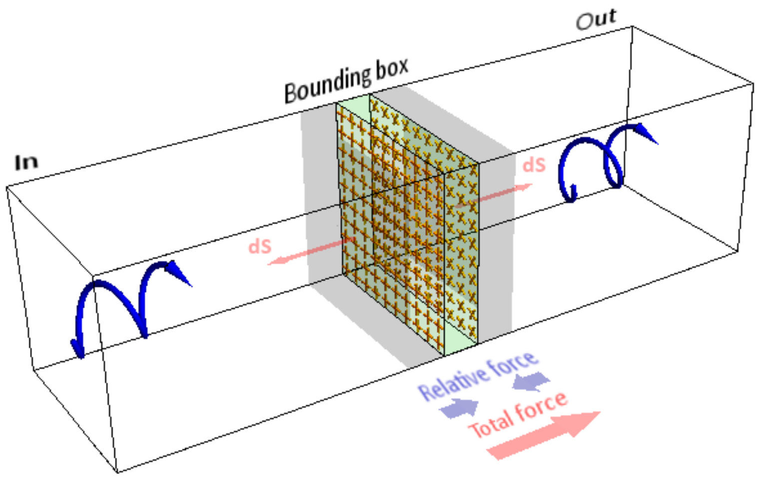

Fig. 1: The optical force due to circularly polarized radiation on a bilayer metasurface decomposes into a difference force between individual sheets and a total force in the direction of propagation of the radiation. The bounding box allows calculating the optical forces with the Maxwell stress tensor formalism.

Eqs. (1)-(2) are a consequence of the conservation of momentum when interacting with metamaterial sheets inside a box (grey). The momentum either changes because of a force F_i or because of flows in energy-momentum T_{ij} through surfaces of the box with normal j.

To analyse the frequency dependence of the optical forces, we consider both the relative and total force on the individual sheets. The relative force changes sign along chiral resonances while the total force is strictly positive, as expected [8]. Other geometric dependencies, such as the separation and the rotation angle between sheets are evaluated quantitatively by observing the resonances, the optical activity and the surface currents.

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