New enantiomeric phenomena in toroidal media

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Optical activity is a phenomenon ubiquitous across natural and artificial structures and is generally understood in terms of the coupling between electric and magnetic dipoles [1]. Usually, this dipole approximation is sufficient to explain optical activity in most media. In metamaterials however, engineering of the structure allows for designs where a conventional multipole (electric and magnetic dipole) response is suppressed in favour of more exotic excitations typically excluded from the standard multipole expansion. Here, we report on the first computational study of optical activity in a metamaterial that cannot be attributed to conventional multipoles, and can only be accounted for by the inclusion of the toroidal dipole.

First discussed by Zel'dovich in 1958 [2], the toroidal dipole has been identified by recent research as an essential component in the response of a certain class of metamaterials [3]. Given the angular momentum and parity properties of the toroidal dipole [4], it has been suggested that the toroidal dipole should be able to contribute to optical activity in a manner similar to an electric dipole [5].

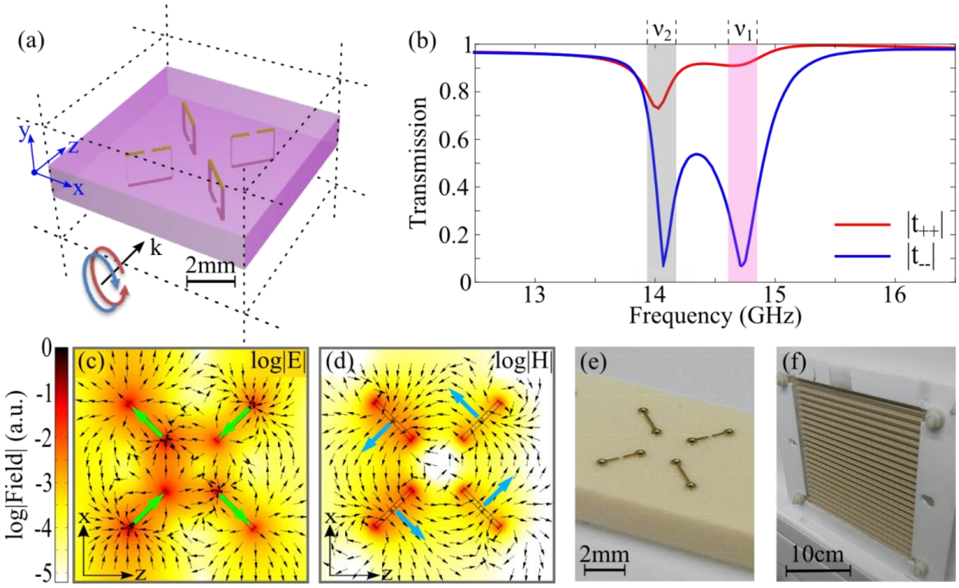

Fig. 1 (a) shows a schematic of a unit cell of the metamaterial. (b) shows the simulated transmission data for right (t_{++}) and left (t_{--}) handed circularly polarised light (R/LHCP). Two bands of resonant circular dichroism are identified at ν_1 and ν_2. (c-d) show the normalised absolute value (log scale) of the electric and magnetic fields respectively and associated field arrows around a unit cell under excitation from LHCP at ν_2. The electric field shows an electric quadrupole distribution, whilst the magnetic field shows a toroidal dipole distribution, as indicated by the electric dipole (green arrows) and magnetic dipole (blue arrows) alignment. (e) and (f) show a photograph of the fabricated metamaterial unit cell and full array respectively.

To verify the prediction we have designed a metamaterial with a unit cell consisting of four rectangular split ring resonators embedded in a low loss dielectric [Fig 1. (a)]. The unit cells were arranged such that the resulting crystal would exhibit a structural chirality. Numerical results indicate two regions of resonant circular dichroism in the metamaterial's transmission spectrum [Fig 1. (b)]. By evaluating the microscopic multipole response of the system, we confirm that the circular dichroism at ν_2 is underpinned by an exotic combination of a conventional electric quadrupole and a non-negligible toroidal dipole excitation [Fig 1. (c-d)]. This is also corroborated with the results of a semi-analytical treatment, which enabled examination of the polarisation eigenstates of the metamaterial and how they vary upon removal of the respective multipole contributions from the metamaterial response. Experiments performed on a fabricated sample in the microwave regime confirm the validity of these numerical results [Fig 1. (e-f)].

References

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