Chirality of Light and the Magneto-Electric Effect

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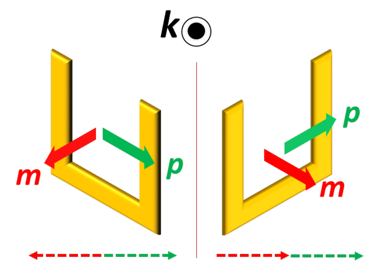
Introduction

Circular dichroism (CD) spectroscopy is used to detect chirality for a compound in solution. In particular, nonzero response is measured only for chiral compounds, which may have nonvanishing rotational strength[1] for molecular states *n*,0, electric dipole ***p***, and magnetic dipole ***m***.

One such structure is the U-shaped Au split ring resonator (SRR). So-called "extrinsic chirality" occurs when the SRR is tilted *out of the plane* perpendicular to wavevector ***k*** and is determined by projection of ***p*** and ***m*** onto this plane: A paradigm in scattering theory is the point dipole scatterer to model scattering by very small but strongly scattering particles. In such a theory, each scatterer is approximated as an electric dipole moment that is proportional to the driving electric field E. When the light hits the first resonator, some light is scattered and absorbed by it. The rest of the transmitted light will be in a certain formation based on its chirality going in.



The goal of the experiment is to theoretically and computationally design a dimer of split ring resonators (SRR) to selectively block out the transmission of one type of circularly polarized light (either left-handed or right-handed) and allow the transmission of the other type.

By analyzing density plots representing the extinction cross section of the light, the chirality of the light can be easily shown. For example, if the resonator is shifted to a certain side when viewed upon perpendicular to the xy plane, then the light must be chiral opposite to that side. In order to make these plots, we represented the matrices in MATLAB programming.

SRR backscattering: methods

Here, we follow the point-dipoles-approximation approach and the unit system of Sersic et al.[7] Take the G matrix that governs the light particle i feels from particle j to be

$$\overline{\overline{G}}(r_i, r_j) = \begin{pmatrix} \overline{\overline{G}}_{EE}(r_i, r_j) & \overline{\overline{G}}_{EH}(r_i, r_j) \\ \overline{\overline{G}}_{HE}(r_i, r_j) & \overline{\overline{G}}_{HH}(r_i, r_j) \end{pmatrix},$$

Where the matrix contains four matrices of electric field feeling electric field, magnetic field feeling electric field, and so on. Then, represent the resulting electric and magnetic dipoles for the dimer such that SRR1 and SRR2 are at two different locations on top of each other:

$$\begin{pmatrix} \mathbf{p}_{1,L/R} \\ \mathbf{m}_{1,L/R} \\ \mathbf{p}_{2,,L/R} \\ \mathbf{m}_{2,,L/R} \end{pmatrix} = \left[\overline{\overline{I}}_{12\times12} - \begin{pmatrix} \overline{\overline{0}}_{6\times6} & \overline{\overline{\alpha}}_{rot}(\beta_1, \psi_1, \theta_1)\overline{\overline{G}}(\mathbf{r}_1, \mathbf{r}_2) \\ \overline{\overline{\alpha}}_{rot}(\beta_2, \psi_2, \theta_2)\overline{\overline{G}}(\mathbf{r}_2, \mathbf{r}_1) & \overline{\overline{0}}_{6\times6} \end{pmatrix} \right]^{-1}$$

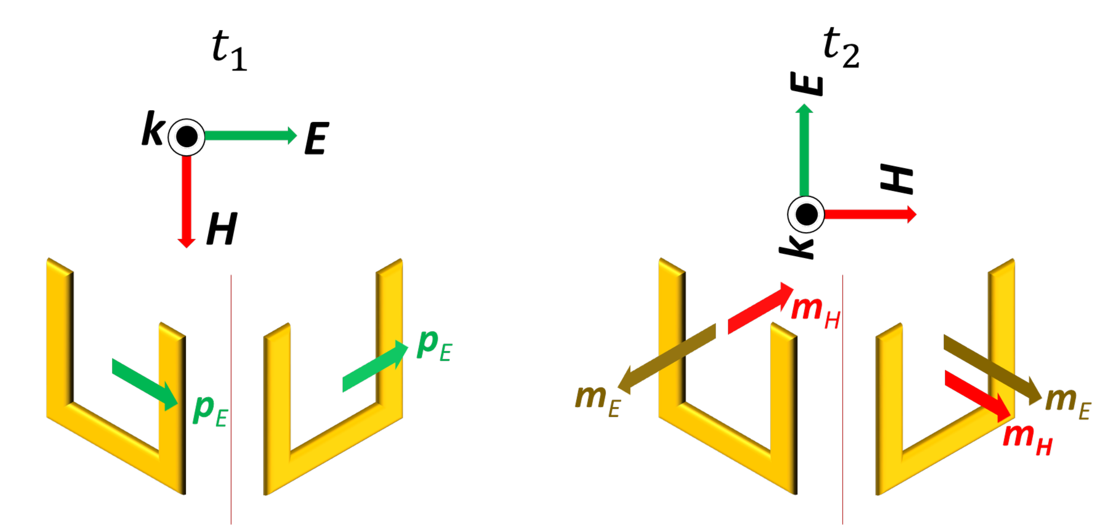
$$\times \begin{pmatrix} \overline{\overline{\alpha}}_{rot}(\beta_1, \psi_1, \theta_1) & \overline{\overline{0}}_{6\times6} \\ \overline{\overline{0}}_{6\times6} & \overline{\overline{\alpha}}_{rot}(\beta_2, \psi_2, \theta_2) \end{pmatrix} \begin{pmatrix} \mathbf{E}_{1,L/R} \\ \mathbf{H}_{1,L/R} \\ \mathbf{E}_{2,L/R} \\ \mathbf{H}_{2,L/R} \end{pmatrix},$$

Finally, calculate the resulting extinction cross section (the scattered light that does not get transmitted through the resonator) by dividing the extinction power by the intensity of the light when it hits the resonator.

$$\sigma_{ext,L/R} = \frac{2\pi\epsilon_0\omega \mathrm{Im}\left[\begin{pmatrix} \mathbf{E}_{1,L/R} \\ \mathbf{H}_{1,L/R} \\ \mathbf{E}_{2,L/R} \\ \mathbf{H}_{2,L/R} \end{pmatrix}^* \cdot \begin{pmatrix} \mathbf{p}_{1,L/R} \\ \mathbf{m}_{1,L/R} \\ \mathbf{p}_{2,,L/R} \\ \mathbf{m}_{2,,L/R} \end{pmatrix} \right]}{\dfrac{|\mathbf{E}_{L/R}|^2}{2Z_0}}$$

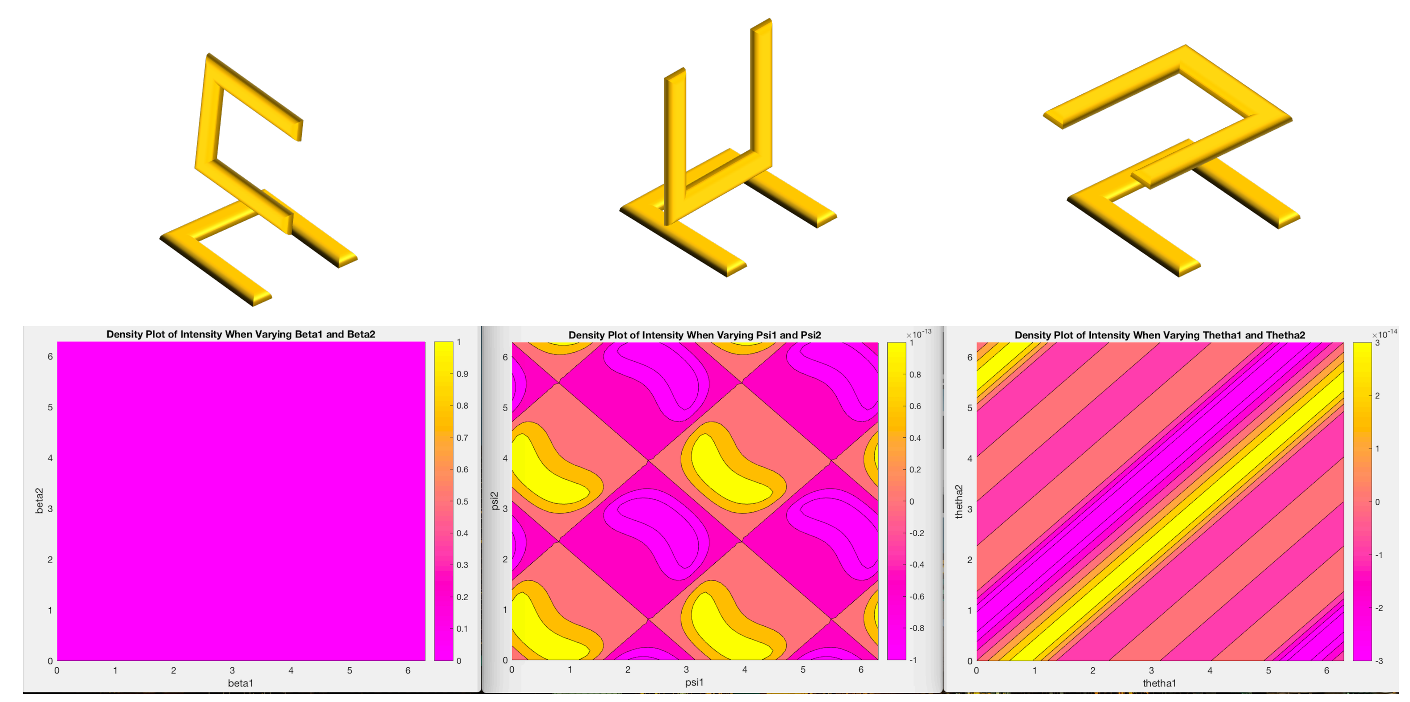
SRR extrinsic chirality: heuristic model

The extrinsic chirality of an SRR is represented by the interference of the ***H***-induced $\boldsymbol{m}_H$ and ***E***-induced $\boldsymbol{m}_E$. The ***E***-induced $\mathbf{p}_E$ is also shown.

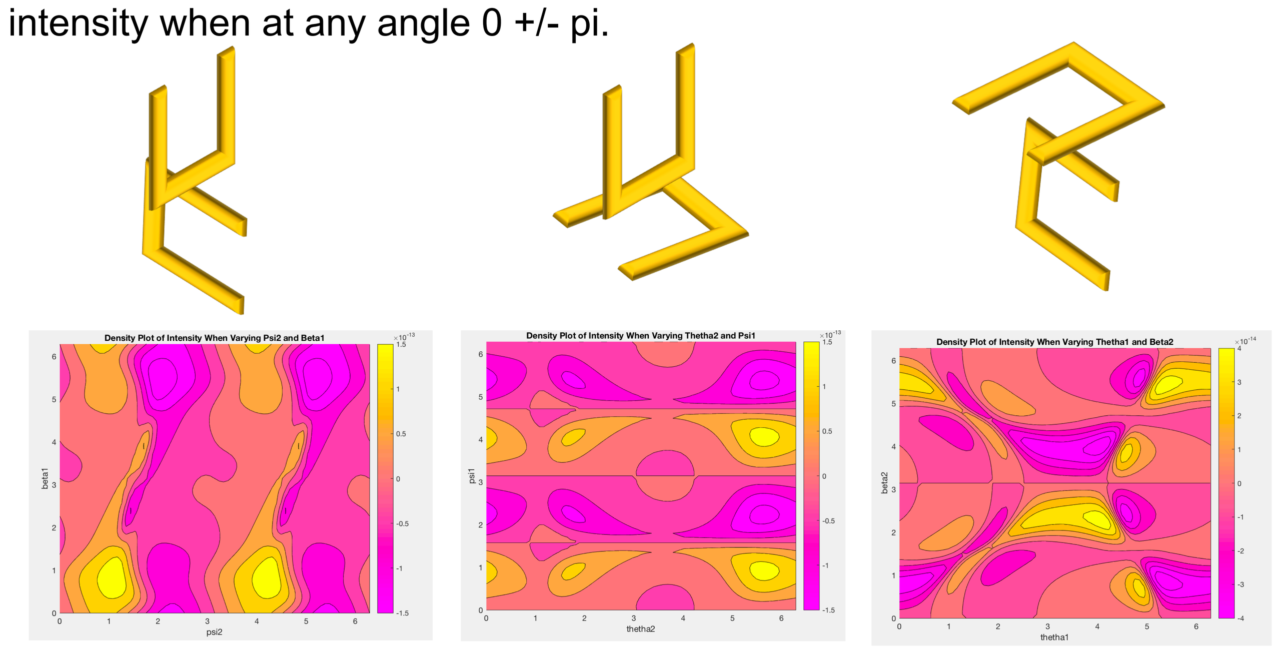


Backscattering: simulations for two SRRs

Based on the chirality of the light, it can either hit the resonator left-handed or right-handed. To account for this, the values in the density plot are represented as the difference of the extinction cross section of left handed and right handed light when the same angle is changed on both resonators.



By varying beta in both resonators, we can see that the intensity is always 0. This is because both resonators are symmetrical no matter the angle they are set at rotated along the x axis. When considering theta or the angle for rotation along the z axis, the intensity is 0 on the diagonal as the two resonators are symmetrical. The angle psi (represented in the middle plot) gives the same intensity when at any angle 0 +/- pi.

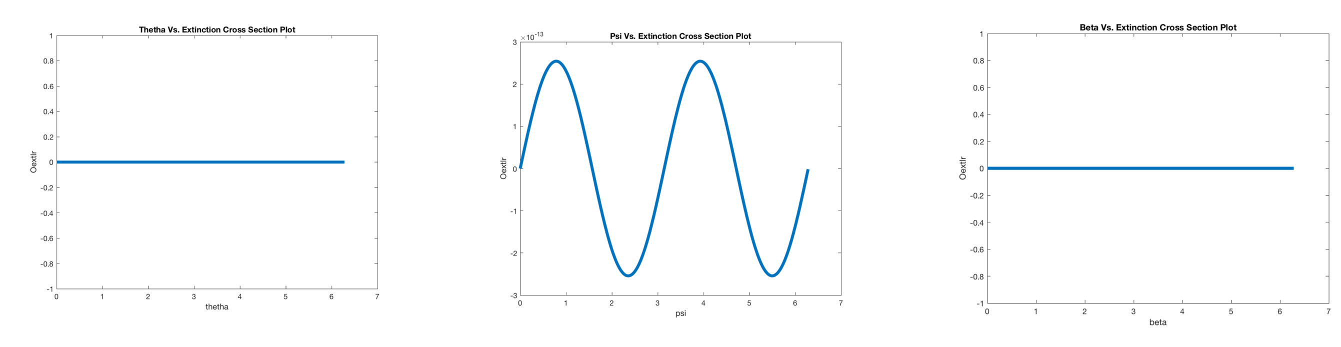


Next, we focused the testing on varying two different angles on the resonators. By comparing the new plots to the previous plots, we could see similarities in the extinction cross section. When examining the original psi1 and psi2 plot, the periodicity among the diagonal is similar to the periodicity among the vertical on the thetha2/psi1 plot and the horizontal of the beta1/psi2 plot. Additionally, the thetha1/beta2 plot shows a negative symmetry about the line beta2 = pi.

Backscattering: simulations for one SRR

Assuming the light travels perpendicular to the xy plane, we can change the angle beta(x), psi(y), or thetha(z) and analyze how much light will be absorbed by the resonator or lost in the process. We can predict that for rotation around the x or z axis the light lost should be the same no matter of the chirality of the light.

Through analysis of the following graphs, we could conclude that the extinction cross section (Oextlr) would not change in psi and thetha since the light will hit the resonator and the same point every time.



Similar to the psi plot for two resonators, the single resonator psi plot is periodic like a sine graph. Regardless of how much light is absorbed by the resonator, we know that for beta and theta the left-handed and right-handed light would give the same reading. However, for the psi plot when one spin is positive, the other is 0, making the graph oscillate between positive and negative values.

Conclusion and Future Directions

By the use of simulations to vary the angles of resonators to analyze the chirality of light, we concluded that changing the resonators in the beta and thetha direction directly causes a higher extinction cross section no matter the chirality of the light. Additionally, if the two resonators are symmetrical in any way chirality does not effect the cross section. Only in the case that the resonators are differed in multiple ways can very little transmitted light pass through the final resonator. In the future, we hope to explore the application of nanostructures as sensors for physical properties that affect the orientation of the nanostructures.

References

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Acknowledgments

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