Research proposal: Investigating the use of the S4 software to optimise the design process of ENZ metasurfaces

Scientific background

Epsilon-near-zero materials and metasurfaces are a relatively new and very exciting topic in optical physics which provides many potential pathways for research and applications in the wider world. An ENZ material is one in which the real part of the material's dielectric permittivity is very close to 0. Due to this property, the EM radiation incident on such materials behaves unconventionally: the effective wavelength of the wave in the material is much larger than that in vacuum, meaning that amplitude and phase vary much slower in the material than outside it. In turn, metasurfaces are 2D structures composed of subwavelength elements with spatially varying responses to phase, amplitude and polarisation [1]. We can use this to better control and accurately alter the properties of the incident radiation, leading to many important results and uses (polarisation control, manipulation of refraction laws, focusing, just to name a few).

Arguably the most important feature of ENZ materials is their strong nonlinear response, which makes them dominant over other materials in applications where nonlinear optics is widely used, ranging from fibre optics in telecommunications, to biomedical imaging [2]. However, current methods of simulating and designing ENZ metasurfaces, such as FDTD, can be challenging and slow. This project aims to explore another method (Fourier Modal Method) of simulating such ENZ surfaces, and to investigate its effectiveness as compared to other design methods.

Aim

One of the software that employs FMM is S4 (Stanford Stratified Structure Solver) - a relatively recent software that has been developed to solve Maxwell's equations in layered and periodic structures [3]. This makes it a very powerful tool to quickly solve and find data for a multitude of scenarios involving EM radiation incident of different structures of varying complexity. However, this software has not yet been applied to structures involving ENZ metasurfaces. Thus the main aim of the project is to use this software to code and simulate already existing designs of such surfaces, and to ultimately compare the results from S4 to the reliable and accurate results previously obtained from FDTD simulations.

My focus would then be to investigate the reflection behaviours of such surfaces, and look at how using different geometries of surfaces and altering their parameters affects the efficiency of reflection. Different materials would also be used for antennae on the metasurface, namely gold for investigation with metallic elements, and zirconia (ZrO_2) for the dielectric antennae. To facilitate reflection, a layer of gold "back reflector" will also be used in the structure.

A successful outcome would be to show that the S4 software can simulate already known results to a high degree of accuracy, thus paving the way for its future use in ENZ research. It will also imply more optimal development time for technologies employing ENZ metasurfaces, leading to increased rate of progress in the field.

References:

[1] N. Yu, F. Capasso, *"Flat optics with designer metasurfaces"*, Nature Materials, Vol.13, pg. 139-150 (2014)

[2] T. Yang et al. , *"A Controllable Plasmonic Resonance in a SiC-Loaded Single-Polarisation Single-Mode Photonic Crystal Fiber Enables Its Application as a Compact LWIR Environmental Sensor"*, Materials 2020, 13, 3915

[3] Victor Liu and Shanhui Fan, "S^4: A free electromagnetic solver for layered periodic structures," Computer Physics Communications **183**, 2233-2244 (2012)