Applications of the spatial spectral Maxwell solver

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1. INTRODUCTION

Accurate and efficient Maxwell solvers are needed for electromagnetic scattering problems in layered media, which have wide and important applications in applications like wafer metrology, photonics and metamaterials. The spatial spectral integral equation Maxwell solver was developed to address electromagnetic scattering problems in layered media [1].

2. THE SPATIAL SPECTRAL METHOD

The main integral equation for the spatial spectral method is:

$$\mathbf{E}^i(\mathbf{x}) = \mathcal{C}_\varepsilon(\mathbf{x}) \cdot \mathbf{F}(\mathbf{x}) - \mathcal{F}_T^{-1}\left\{ \int_{\mathbb{R}} \mathcal{G}(\mathbf{k}_T, z, z') \cdot \mathcal{F}_T[\chi \mathcal{C}_\varepsilon(\mathbf{x}_T, z') \cdot \mathbf{F}(\mathbf{x}_T, z')] dz' \right\}, \tag{1}$$

where $\mathcal{F}_T[\cdot]$ is a Fourier transformation and $\mathcal{F}_T^{-1}[\cdot]$ its inverse. $\mathcal{G}$ is the spectral-domain Green operator of the layered medium, and $\mathbf{F}$ is an auxiliary field. A Gabor-frame in the transverse plane is used in the spatial spectral method to represent all involved functions in the domain-integral equation, which establishes a fast and exact transformation between the spatial and spectral domains. A normal vector field (NVF) formulation is used in the field-material interaction operators $\mathcal{C}_\varepsilon, \chi\mathcal{C}_\varepsilon$ to improve the system's accuracy. Advanced iterative methods such as `BiCGstab(ℓ)` or `IDR(s)` are used to solve the system, and a NVF-BD preconditioner was developed in [2] to reduce the number of iterations and computation time for the cases with high contrast or negative permittivity.

3. DEMONSTRATIONS OF THE SPATIAL SPECTRAL SOLVER

The capabilities of the spatial spectral Maxwell solver will be illustrated for the following examples.

- A 2D TM scattering problem with high contrast value and large geometrical dimension. Computation-time analysis shows that the total solution time is reduced by about 50% after applying the NVF-BD preconditioner [2].
- A 3D problem for a scatter with relative permittivity $\varepsilon_r = 17$ in free space. The number of iterations is significantly reduced by applying the NVF-BD preconditioner [2]. Furthermore, an improved field-material interaction operator is introduced to improve the accuracy.
- A computer-generated waveguide hologram (CGWH) device is simulated and studied with the spatial spectral method [3]. The hologram area contains 10126 bar-type scatterers in a 41.6×41.4 μm area, and an average relative error of 10^{-3} is achieved on the far field.
- A metalens case is studied by the spatial spectral method. Numerical results show the height of the scatterers is a crucial parameter for the rate of convergence.

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