INNOVATION PARTNERSHIPS
UNIVERSITY OF MICHIGAN

Fast Hybrid Method for Full-Wave Simulations of Metasurfaces with and without Substrate

TECHNOLOGY NUMBER: 2025-226

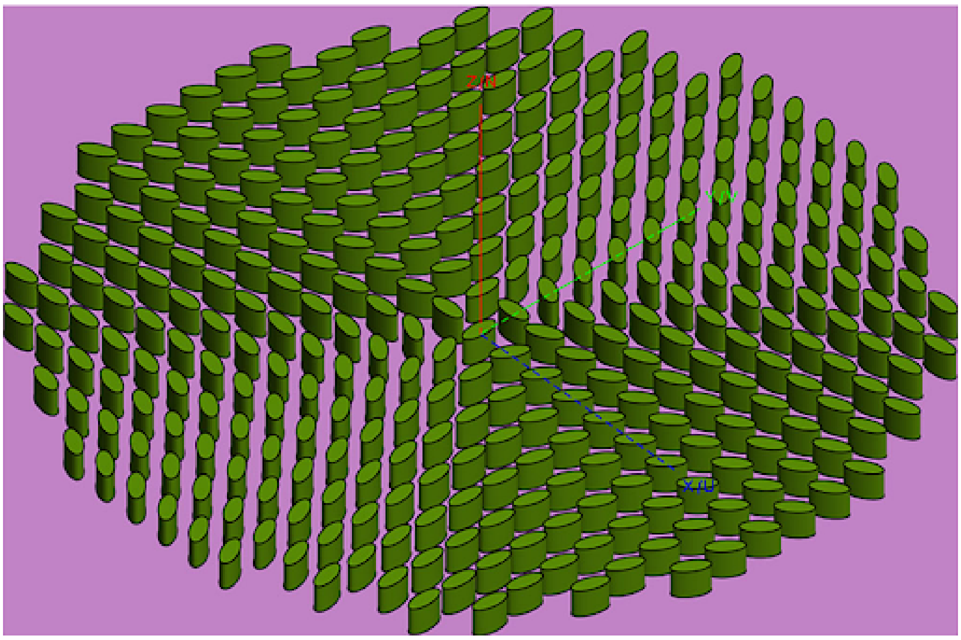

Figure 1. Orbital Angular Momentum (OAM) metasurface

OVERVIEW

Ultra-fast, memory-efficient electromagnetic full wave simulations for realistic, large-scale metasurfaces

- Simulates metasurfaces several hundred to a thousand times faster and with less memory than commercial solvers
- Metasurface design, optimization, characterization, and microwave, antennas quantum/optical device engineering, wireless communications

BACKGROUND

Metasurfaces—engineered surfaces composed of arrays of subwavelength different unit cell scatterers—have revolutionized control over electromagnetic waves in optics, microwaves, terahertz, and quantum domains. Analyzing and designing metasurfaces have relied on computational electromagnetics using commercial solvers like COMSOL, CST, FEKO, and HFSS. The commercial softwares are based on traditional methods such as Finite Element Method (FEM), Finite-difference-time-domain (FDTD) , Method of Moment (MoM) accelerated by MLFMM(Multilevel Fast Multipole) . These methods demand extensive CPU time and memory,

Technology ID
2025-226

Category
Semiconductors, MEMS, and Electronics
Software & Content

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especially as designs scale to thousands of scatterers or involve substrates, limiting their practicality for large or complex metasurfaces. Analytical and quasi-analytical models exist but often oversimplify, neglecting critical inter-element wave interactions or substrate effects. As the demand for rapid prototyping, iterative design, and device optimization grows, there is a critical need for a simulation approach that combines the rigor and accuracy of full-wave methods with dramatically reduced computational requirements. An efficient, scalable solver is essential to keep pace with advances in metasurface-enabled technologies and their applications in optics, communications, antennas, microwaves, imaging, and quantum science.

INNOVATION

Researchers at the University of Michigan have developed the Fast Hybrid Method (FHM) for full-wave electromagnetic simulation of metasurfaces, accommodating both free-space and substrate-supported arrangements. FHM leverages the Foldy-Lax multiple scattering formalism, extracting T-matrix representations of individual scatterers—computed once using any commercial or custom electromagnetic solver—and storing these for rapid reuse. These T-matrices can be systematically rotated to account for orientations of the unit cells (Figure 1) . Interactions among thousands of unit cells are then calculated via fast iterative algorithms and accelerated using Fast Fourier Transform (FFT) operations, efficiently summing scattered fields. Key advances include rigorous support for infinite substrate effects (unavailable in most commercial solvers), library-based handling of arbitrarily rotated or shaped scatterers, and hybrid Vector Cylindrical waves (VCW), Vector spherical waves (VSW), and Vector Plane waves (VPW) basis expansions for both planar and volumetric metasurfaces.

The accuracy of the proposed method is validated through direct comparisons with commercial full-wave electromagnetic solvers. Additionally, comparative studies show FHM achieves up to a 469x speedup (reference 2) and reduces memory demand by over two orders of magnitude—in some cases enabling simulations that would otherwise be impossible on standard computing hardware. Notably, the proposed method uniquely enables the simulation of metasurfaces comprising up to five thousand (reference 2) rotated orbital angular momentum (OAM) unit cells occupying 25 wavelength in radius above a substrate (Figure 1) , a regime that is inaccessible to commercial full-wave solvers due to prohibitive memory requirements. Real-world applications span the design and optimization of lenses, antennas, OAM beam generators, optical and microwave devices, novel quantum devices, and more.

ADDITIONAL INFORMATION

REFERENCES:

1. Jongwoo Jeong and Leung Tsang, "Wave scattering by metasurfaces using the fast hybrid method," Opt. Express 33, 37868-37881 (2025)
2. Tsang, L., Huang, Z. & Jeong, J. Fast hybrid multiple scattering theory for full-wave simulation of metasurface with substrate. npj Metamaterials 1, 6 (2025)

INTELLECTUAL PROPERTY:

Pending

KEYWORDS:

Metasurface, Full-wave simulation, Optics, Photonics, Antennas, Wireless Communications, Microwaves