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HYBRID NUMERICAL-ASYMPTOTIC BOUNDARY ELEMENT METHODS FOR HIGH FREQUENCY TRANSMISSION PROBLEMS

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High frequency scattering is notoriously challenging for conventional boundary element methods based on piecewise polynomial approximation spaces, because of the large number of degrees of freedom required to capture the oscillatory solution. Hybrid numerical-asymptotic (HNA) methods aim to significantly reduce the dimension of the numerical approximation space by enriching it with oscillatory functions, carefully chosen to capture the high frequency asymptotic behaviour of the wave solution [1].

In this talk I will report some recent advances in HNA boundary element methods for transmission problems (involving penetrable, or dielectric scatterers), relevant, for example, to light scattering by atmospheric ice crystals. For scattering by penetrable convex polygons in two dimensions our algorithm presented in [2] achieves fixed accuracy with a frequency-independent number of BEM degrees of freedom, associated with oscillatory basis functions capturing corner-diffracted waves. Our current investigations suggest that to obtain good performance uniformly across all incident angles it is necessary to include basis functions capturing so-called “lateral” or “head” waves, which in the high frequency asymptotic theory correct for the phase mismatch between the internal and external diffracted waves.

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OPTIMIZING THE DESIGN OF THIN FILM SOLAR CELLS

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We describe an ongoing project to develop a flexible and rigorously justified software tool for optimizing the design of thin film solar cells [1]. We use the differential evolution algorithm (DEA) [3] to optimize the efficiency of a solar cell design. To evaluate the efficiency there are two steps:

Photonic model Maxwell's equations need to be solved in the solar cell to find the generation rate of electrons and holes. We restrict ourselves to the case when Maxwell's equations decouples into s-polarized and p-polarized waves that satisfy different Helmholtz equations.

To solve these Helmholtz equations rapidly we use the Rigorous Coupled Wave Analysis (RCWA) method [4], that is based on using Fourier series in the horizontal (quasi-periodic) direction. Since the technique is meshless, it is easy to change both the geometry of the device and the material parameters for each simulation. We prove convergence of RCWA [2].

Electron transport We use the drift-diffusion model to simulate electron transport in the semiconductor layers of the device. This model involves the density of electrons and holes in the device as well as the static electric field generated by these entities. Using the Hybridizable Discontinuous Galerkin (HDG) scheme [5], we can discretize the system using appropriate piecewise polynomials for each unknown in the system. The resulting system of nonlinear equations is solved by Newton's method, and by using different biasing voltages the optimal efficiency for a given design can be computed. Convergence is proved for a related time domain problem.

We have used the above algorithm to optimize a representative solar cell. Future work will include investigating more novel designs, and implementing a full three dimensional model.

References

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HIGH–ORDER SPECTRAL SIMULATION OF GRAPHENE RIBBONS

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The plasmonics of graphene and other two-dimensional materials has attracted enormous attention in the past decade. Both the possibility of exciting plasmons in the terahertz to midinfrared regime, and the active tunability of graphene has generated a great deal of excitement. Consequently there is significant demand for robust and highly accurate computational schemes which incorporate such materials. We describe an algorithm which models the graphene layer with a surface current that is applicable to a wide class of two-dimensional materials. We reformulate the governing volumetric equations in terms of surface quantities using Dirichlet-Neumann operators, which can be numerical simulated in an efficient, stable, and accurate fashion using a novel High-Order Perturbation of Envelopes methodology. We demonstrate an implementation of this algorithm to study absorbance spectra of TM polarized plane-waves scattered by a periodic grid of graphene ribbons.

ON THE SPECTRAL GEOMETRY OF STEKLOV EIGENVALUE PROBLEMS

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Spectral geometry concerns the study of the interplay between geometric properties of a domain and the spectrum of pseudodifferential operators defined on these domains. Of particular interest in the design of optical and photonic devices is the question of spectral optimization. In this talk, we consider some theoretical and computational questions which arise in the spectral geometry of the Steklov eigenvalue problem for the Laplacian and the Lamé operators. We present discretization methodologies based on both a finite element method, and a boundary integral strategy.

SIMULATION OF LOCALIZED SURFACE PLASMON RESONANCES VIA DIRICHLET-NEUMANN OPERATORS AND IMPEDANCE-IMPEDANCE OPERATORS

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It is important to engineers and scientists alike to simulate scattering returns of electromagnetic radiation from bounded obstacles. In this talk we present High-Order Perturbation of Surfaces algorithms for the simulation of such configurations, implemented with Dirichlet-Neumann Operators and Impedance-Impedance Operators. With an implementation of these approaches we demonstrate the stable, robust, and highly accurate properties of our algorithms. We also demonstrate the validity and utility of our approaches with a sequence of numerical experiments. Moreover, we show how our formulation delivers a straightforward proof of existence, uniqueness, and analyticity of solutions to this problem.