Mini-symposium B11
Novel Methods for Computational Photonics and Electromagnetics

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B11-01 Invited
Trefftz Approximations: Finite Difference Schemes and Nonreflecting Boundary Conditions
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In problems of mathematical physics, Trefftz functions, which by definition satisfy (locally) the underlying differential equations of the problem, tend to provide excellent approximations of the solution. This can be taken advantage of in different contexts; here we focus on high-order finite difference schemes and on nonreflecting boundary conditions.

More specifically, Trefftz approximations in wave problems may involve plane waves, cylindrical or spherical harmonics, and combinations thereof. A variety of nonreflecting conditions can be obtained when the Trefftz basis is restricted to outgoing waves only.

We also explore two ideas that, to our knowledge, are completely new: (i) a posteriori adaption of the basis, where new Trefftz functions are chosen as dominant plane-wave components of the solution previously obtained; (ii) Trefftz schemes with auxiliary variables (such as derivatives of the solution) on the exterior boundary. Numerical examples for problems of wave scattering will be given.

B11-02 Invited
Trefftz Approximations: A Nonasymptotic Homogenization Theory of Periodic Electromagnetic Structures
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Our new homogenization methodology involves accurate approximations of fields on fine and coarse scales with Trefftz functions – eigenmodes that satisfy Maxwell’s equations and boundary conditions as accurately as possible. The physical meaning of this approach is in seeking effective material parameters that provide, in a sense, the best approximation of Bloch fields as impedances as well as dispersion relations over an ensemble of physical modes in the structure. The theory is nonasymptotic – i.e., is valid for any composition and size of the lattice cell and does not involve any asymptotic expansions with respect to any small parameter.

In comparison with the existing theories, our methodology has a number of advantages: (i) effective parameters are optimized for a range of illuminating conditions, not just for one incident wave; (ii) the method leads to a linear optimization problem in contrast e.g. with the nonlinear inverse problem of S-parameter retrieval; (iii) not only bulk, but also position-dependent parameters can be defined if needed; (iv) the homogenization methodology comes with a built-in error indicator whose value characterizes the accuracy of homogenization; (v) the proposed theory leads to analytical expressions of bulk material parameters in terms of Bloch fields on the boundary of a lattice cell.

B11-03
Vertical Mode Expansion Method for Transmission of Light Through Bull’s Eye Structures
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In this paper, we develop an efficient numerical method for rigorously computing the fields and transmission of light through bull’s eye structures for the extraordinary optical transmission (EOT) phenomenon. By expanding the electromagnetic field in one dimensional vertical modes and taking a Fourier expansion, a decoupled sparse linear system is obtained when matching the field on the boundaries of the circular hole and grooves. This relatively small linear system can be efficiently solved. Thus, the method eliminates the restriction of numerical simulation of bull’s eye structures with large number of grooves. Also, the transmission of the bull’s eye structures can be calculated accurately by evaluating line integrals on the boundaries of the hole and grooves. Numerical examples show that this method is efficient and accurate. In particular, we found that the EOT enhancement factor can reach 50 for a bull’s eye structure with 22 grooves.

B11-04
Vertical Mode Expansion Method for Transmission of Light Through a Single Elliptical Hole in a Slab
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In the study of scattering of light, the Vertical Mode Expansion Method (Lu et al., J. Opt. Soc. Am. A, 31, 293-300, 2014) is a recently developed method that reduces the original three-dimensional problem to a two-dimensional problem, and it is firstly applied to study the extraordinary optical transmission through a subwavelength circular cylindrical hole in a metallic film. In this paper, we present another application of this method to the case of an elliptical cylindrical hole in a metallic film, including a relatively simple and accurate approach to compute Maxwell functions for complex values of the parameter in the construction of the so-called Dirichlet-to-Neumann maps from general solutions. Numerical examples of normally incident plane wave indicate that the method performs accurately and efficiently.

B11-05 Invited
Fast Calculation of Scattering Problem in Layered Uniaxial Media
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The paper deals with scattering problems where inhomogeneous bodies are embedded within planarly layered uniaxial media and made to interact with given sources. When the layered media are isotropic, the construction of the impedance matrix of the Method of Moment (MoM) can be fast since the dispersion relations of the isotropic media enable to calculate the integral along the azimuth direction in closed form. But, if the uniaxial media are with optical axes parallel to the interfaces, the above fast methods do not apply anymore. However, we might still circumvent it, with the rectilinear mesh as done in traditional practice in volume integral equation methods, achieving efficient construction of the impedance matrix.
In this paper, by the generalized Poisson summation formula and the windowing technique, the relation between the discrete Fourier spectrum and the continuous Fourier spectrum of the spatial response is re-derived, using which the response of the multilayer on a rectilinear mesh can be efficiently and accurately calculated.

When the continuous Fourier spectrum of the response of the laminates to the current basis function is available, which can be stably and efficiently calculated by the new recurrence relations proposed in our pervious contribution, we use such a fast method to construct the impedance matrix of the MoM involving uniaxial layered media whose optical axes lie parallel to their planar interfaces. Numerical tests confirm the efficacy of the proposed method.

B11-06 Invited
Analytical Model for Large-Area Photonic Crystal Lasers
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Photonic-crystal surface-emitting lasers (PCSELs) are recently attracting considerable attention owing to their promising functionality and improved performance compared to conventional semiconductor lasers. The fundamental mechanism accounting for the stable and flexible mode control seen in PCSELs is guided resonance in two-dimensional photonic-crystal slabs. This guided resonance essentially has a delocalized nature and provides an efficient way to channel light from within the photonic-crystal slab to the external environment. This unique property has been exploited in the design of not only PCSELs, but also thermal radiation control, and has also been implicated in newly observed physical phenomena such as optical bound states in the continuum (BIC). One challenge of this research area is how to analytically describe the delocalized resonance in a large-area, finite-size photonic-crystal structure. Brute-force computer simulation methods such as finite-difference time-domain (FDTD) or finite-element method (FEM) are ill-suited to the analysis of devices of such large dimensions due to computational burden. To circumvent this limitation, we have developed an analytical model that allows a new and comprehensive understanding of the guided resonance in finite-size photonic-crystal structures, particularly in PCSELs. Recent progress and achievements made in this theoretical framework will be reviewed and discussed in the presentation.

B11-08
A Massively Parallel Simulation Tool for Analyzing Electromagnetic Characteristics of Electrically Large-Scale Targets
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Numerical simulations on large scale electromagnetic problems suffer from a series of difficulties, such as too large memory consumption, very slowly convergent or not convergent iteration caused by the bad matrix condition number, too long computation time, which makes the serial program of multilevel fast multipole method (MLFMM) not meet the demand of simulations. With the development of cluster and parallel computing technologies, the study on parallelization of MLFMM has been a hot topic in the computational electromagnetics. Based on parallel adaptive application infrastructure called JASMINE (J parallel Adaptive Structured Mesh applications Irastructure), a massive parallel simulation program, JEMS-MLFMM (J ElectroMagnetic Solver - multilevel fast multipole method), is developed for analyzing the electromagnetic characteristics of electrically large-scale targets. By the aid of JASMINE, JEMS-MLFMM is designed and structured oriented to thousands of processors with multi-core on modern MPP. JASMIN is for the application of structured mesh, while MLFMM is a method with unstructured mesh. Therefore, the particle variable provided by JASMIN is adopted to manage edge elements. In addition, the average number of particles in a cell and the maximum number of particles in the region of near interaction are estimated in initialization stage for reducing unnecessary memory consumption. Interpolation and anterpolation are also used for realizing different number of multipole expansion in each level. The validity of JEMS-MLFMM is presented with scattering problems of spherical targets. Several electrically large scale examples, such as scattering of an aerocraft illuminated by plane wave, are also demonstrated.

B11-09
The Weighted Edge Finite Element Method for Maxwell Equations with Strong Singularity
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In the present talk we develop the weighted edge finite element method based on the conception of Rk-generalized solution of the Maxwell equations with strong singularity due to a reentrant corner on the boundary. Numerical experiments of model problems showed that the rate of convergence of the numerical solution to the exact one is more than one and a half times better in comparison with the results established in papers of other mathematicians. Another advantage of this method is simplicity of the solution determination which is an additional benefit for numerical experiments.