Wonseok Shin, Ph.D.

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Contact Information

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Current Appointment

Postdoctoral Scholar 2013–present
Prof. Shanhui Fan's group, Stanford University

Education

Ph.D. in Electrical Engineering (advisor: Prof. Shanhui Fan) 2006–2013
Stanford University
Dissertation:
"3D finite-difference frequency-domain method for plasmonics and nanophotonics"

M.S. in Electrical Engineering 2004–2007
Stanford University

B.S. in Physics 1997–2001
Seoul National University

B.S. in Mathematics 1997–2001
Seoul National University

Industry Experience

Software Engineer 2001–2004
Park Systems, Suwon, South Korea
Developed software for Park Systems' scanning probe microscope (SPM), including
- data acquisition software on Texas Instruments' digital signal processor in C
- control software on Microsoft Windows in C++ (VC++)
- image editing software (similar to Photoshop) in Java (J2SE)

Teaching Experience

Principal Instructor of EE 256: Numerical Electromagnetics spring 2014
Electrical Engineering, Stanford University
- taught how to implement time- and frequency-domain Maxwell's eqs. solvers
- evaluated by students as one of the 10 best EE courses in spring 2014
- course evaluation: 4.82/5.00 (area mean: 4.35)
- instructor evaluation: 4.73/5.00 (area mean: 4.28)

Honors & Awards

Samsung Scholarship (USD 50,000/year, 5 years), *Samsung Scholarship Foundation* 2006–2011
Graduate Study Abroad Scholarship, *Korea Science and Engineering Foundation* 2004–2006
Summa cum laude graduate, *Seoul National University* 2001
Merit-based scholarship, *Seoul National University* 1997–2001
Bronze prize, Collegiate Mathematics Competition, *Korean Mathematical Society* 1999
Bronze medal, Korean Mathematical Olympiad (KMO), *Korean Mathematical Society* 1995
Silver medal, Korean Mathematical Olympiad (KMO), *Korean Mathematical Society* 1994

Research Overview

Efficient solution of large-scale 3D Maxwell's equations in the frequency domain
I develop efficient techniques for solving large-scale 3D Maxwell's equations in the frequency domain, based on deep understanding of the numerical properties of the Maxwell operator. For example, the following two techniques I developed through doctoral research achieved more than *300-fold* enhancement of solver performance in plasmonics:

- an efficient diagonal preconditioner that greatly enhances the conditioning of the Maxwell operator for problems involving the perfectly matched layer (PML) (*J. Comput. Phys.* 2012)
- an added penalty term that deflates the large near-null space of the Maxwell operator while preserving the definiteness and conditioning of the operator (*Opt. Express* 2013)

In postdoctoral research, I am extending the these techniques to other areas than plasmonics, and seeking to apply the techniques to eigenmode analysis and device optimization.

Design of novel nanophotonic components
Using the above efficient techniques for solving Maxwell's equations, I have designed novel nanophotonic components such as

- focusing lenses made in flat metallic films (*Opt. Lett.* 2010)
- perfect bends and splitters in plasmonic waveguides (*Adv. Mater.* 2010, *Nano Lett.* 2013)
- grating couplers launching surface plasmons unidirectionally (*Nano Lett.* 2014)
- deep-subwavelength spectral separators (*Appl. Phys. Lett.* 2014)

Analysis of the nature of the energy loss in plasmonic and metamaterial systems
The performance of plasmonic and metamaterial devices are limited by the energy loss in metallic components. I seek to understand the nature of the loss, thereby improving the performance of these devices. As groundwork I have explored

- the analytic expressions of mode energy and modal loss rates (*J. Opt. Soc. Am. B* 2012)
- the fundamental upper bound of modal loss rates (*Phys. Rev. Lett.* 2013)

Using these results as a basis, I am investigating the possibility of practical plasmonic and metamaterial devices with reduced loss.

Research Projects Participated

Template-Directed Directionally Solidified Eutectic Metamaterials 2012–2015
Multidisciplinary University Research Initiative (MURI)
Sponsor: Air Force Office of Scientific Research (AFOSR)
PI: Prof. Paul Braun at UIUC

Integrated Hybrid Nanophotonic Circuits 2011–2014
Multidisciplinary University Research Initiative (MURI)
Sponsor: Air Force Office of Scientific Research (AFOSR)
PI: Prof. Mark Brongersma at Stanford University

Modeling, Computation, and Analysis of Optical Responses of Nano Structures 2010–2013
Collaborative Research in the *Division of Mathematical Sciences (DMS)*
Sponsor: National Science Foundation (NSF)
PI: Prof. Shanhui Fan at Stanford University

Robust and Complex On-Chip Nanophotonics 2009–2014
Multidisciplinary University Research Initiative (MURI)
Sponsor: Air Force Office of Scientific Research (AFOSR)
PI: Prof. Shanhui Fan at Stanford University

Refereed Journal Publications

Computational Techniques

2. W. Shin, S. Fan. "Accelerated solution of the frequency-domain Maxwell's equations by engineering the eigenvalue distribution of the operator." *Optics Express* **21** (2013): 22578–95 [link].
1. W. Shin, S. Fan. "Choice of the perfectly matched layer boundary condition for frequency-domain Maxwell's equations solvers." *Journal of Computational Physics* **231** (2012): 3406–31 [link].

Nanophotonic Component Designs

5. Y. Büyükalp, P. B. Catrysse, W. Shin, S. Fan. "Spectral light separator based on deep-sub-wavelength resonant apertures in a metallic film." *Applied Physics Letters* **105** (2014): 011114 [link].
4. T. Liu*, Y. Shen*, W. Shin*, Q. Zhu, S. Fan, C. Jin. "Dislocated double-layer metal gratings: an efficient unidirectional coupler." *Nano Letters* **14** (2014): 3848–54 [link] (***co-first authors**).
3. W. Shin, W. Cai, P. B. Catrysse, G. Veronis, M. L. Brongersma, S. Fan. "Broadband sharp 90-degree bends and T-splitters in plasmonic coaxial waveguides." *Nano Letters* **13** (2013): 4753–58 [link].
2. W. Cai, W. Shin, S. Fan, M. L. Brongersma. "Elements for plasmonic nanocircuits with three-dimensional slot waveguides." *Advanced Materials* **22** (2010): 5120–24 [link].
1. L. Verslegers, P. Catrysse, Z. Yu, W. Shin, Z. Ruan, S. Fan. "Phase front design with metallic pillar arrays." *Optics Letters* **35** (2010): 844–46 [link].

Fundamental Physics

2. A. Raman, W. Shin, S. Fan. "Upper bound on the modal material loss rate in plasmonic and metamaterial systems." *Physical Review Letters* **110** (2013): 183901 [link].
1. W. Shin, A. Raman, S. Fan. "Instantaneous electric energy and electric power dissipation in dispersive media." *Journal of Optical Society of America B* **29** (2012): 1048–54 [link].

Conference Oral Presentations

4. W. Shin, W. Cai, P. B. Catrysse, G. Veronis, M. L. Brongersma, S. Fan. "Plasmonic nano-coaxial waveguides for 90-degree bends and T-splitters." *CLEO*, San Jose, California. June 9–14, 2013.
3. W. Shin, S. Fan. "Choice of the perfectly matched layer boundary condition for iterative solvers of the frequency-domain Maxwell's equations." *28th Annual Review of Progress in Applied Computational Electromagnetics*, Columbus, Ohio. Apr. 10–14, 2012.
2. W. Shin, S. Fan. "Accelerated solution of the frequency-domain Maxwell's equations by engineering the spectrum of the operator using the continuity equation." *12th Copper Mountain Conference on Iterative Methods*, Copper Mountain, Colorado. Mar. 25–30, 2012.
1. W. Shin, S. Fan. "Choice of the perfectly matched layer boundary condition for iterative solvers of the frequency-domain Maxwell's equations." *SPIE Photonics West*, San Francisco, California. Jan. 21–26, 2012.

Conference Poster Presentations

2. W. Shin, A. Raman, S. Fan. "Upper bound on the modal material loss rate in plasmonic and metamaterial systems." *First Year Review of AFOSR MURI: Template-Directed Directionally Solidified Eutectic Metamaterials*, Dayton, Ohio. Oct. 8–9, 2013.
1. W. Shin, A. Raman, S. Fan. "Instantaneous electric energy density and power dissipation density in dispersive media." *IONS NA-3*, Stanford, California. Oct. 13–15, 2011.

SEMINAR PRESENTATIONS

4. W. Shin. "Brief introduction to the finite-difference frequency-domain method." Guest lecture in *EE256: Numerical Electromagnetics*, Stanford University, Stanford, California. May 24, 2013.
3. W. Shin. "Modification of Maxwell's equations for iterative methods." *Linear Algebra and Optimization Seminar*, Stanford University, Stanford, California. Feb. 21, 2013.
2. W. Shin. "3D finite-differenece frequency-domain method for plasmonics and nanophotonics." *Optics and Electronics Seminar*, Stanford University, Stanford, California. Jan. 28, 2013.
1. W. Shin. "A large-scale FDFD solver of Maxwell's equations for nanophotonics." *Seminar at KAIST (host: Prof. Yong-Hee Lee)*, Daejun, South Korea. Aug. 19, 2009.

ACADEMIC SOFTWARE DEVELOPMENT

MaxwellFDFD http://web.stanford.edu/~wsshin/maxwellfdfd

Developed in MATLAB

MaxwellFDFD is a MATLAB-based package that solves the frequency-domain Maxwell's equations. It constructs a system of linear equations out of Maxwell's equations by the finite-difference frequency-domain (FDFD) method, and hence the name MaxwellFDFD. The constructed system is solved by MATLAB's built-in direct solvers. MaxwellFDFD has the following major features:

- dynamic nonuniform grid generation aligned with object boundaries
- waveguide mode solver and waveguide-mode-generating current source
- visualization of objects, sources, and solution fields in 2D and 3D
- periodic array of objects
- electric ($\mathbf{J}_e$) and magnetic ($\mathbf{J}_m$) current sources
- PEC, PMC, periodic, and Bloch boundary conditions
- uniaxial perfectly matched layer (UPML) and stretched-coordinate PML (SC-PML)
- total-field/scattered-field (TF/SF) method
- power flux calculation

FD3D http://web.stanford.edu/~wsshin/fd3d

Developed in C and Python using PETSc

FD3D is a parallelized computational kernel for solving the frequency-domain Maxwell's equations. It is a companion program of MaxwellFDFD: users can easily generate the input files for FD3D from MaxwellFDFD, and import the solution calculated by FD3D into MaxwellFDFD for further analysis. FD3D uses PETSc for matrix and vector management, and it runs on any LINUX clusters that support MPI communication. FD3D is also equipped with Python scripts that help run the program on LINUX clusters.

Unlike MaxwellFDFD, FD3D solves the constructed system of linear equations by Krylov iterative solvers rather than direct solvers to avoid large memory consumption. Using the various techniques developed throughout my doctoral research, FD3D achieves more than 300-fold speedup compared with conventional iterative solvers of the frequency-domain Maxwell's equations.