Wonseok Shin, Ph.D.

As of November 2016

Contact Information

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Education

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

M.S. in Electrical Engineering — 2007
Stanford University

B.S. in Physics & Mathematics — 2001
Seoul National University

Academic Experience

Applied Mathematics Instructor — 2015–present
Department of Mathematics, Massachusetts Institute of Technology

Postdoctoral Associate (mentor: Prof. Steven G. Johnson) — 2015–present
Department of Mathematics, Massachusetts Institute of Technology

Postdoctoral Scholar (mentor: Prof. Shanhui Fan) — 2013–2015
Department of Electrical Engineering, Stanford University

Teaching Experience

Instructor of 18.335: Introduction to Numerical Methods — spring 2016
Department of Mathematics, Massachusetts Institute of Technology
- Course on fundamental theory and techniques of numerical linear algebra.
- Large graduate-level class (45 students)

Instructor of EE 256: Numerical Electromagnetics — spring 2014
Department of Electrical Engineering, Stanford University
- Course on time- and frequency-domain Maxwell's eqs. solvers.
- Rated by students as one of the 10 best EE courses (evaluation: 4.82/5.00).

Industry Experience

Software Engineer — 2001–2004
Park Systems, Suwon, South Korea
Developed the following software for scanning probe microscopes (SPMs):
- Data acquisition software on Texas Instruments' digital signal processor in C
- SPM head control software on Microsoft Windows in C++ (VC++)
- Image editing software (similar to Photoshop) in Java (J2SE)

Honors & Awards

Samsung Scholarship (USD 50,000/year), *Samsung Scholarship Foundation*	2006–2011
Summa cum laude graduate, *Seoul National University*	2001
Bronze prize, Collegiate Mathematics Competition, *Korean Mathematical Society*	1999
Silver medal, Korean Mathematical Olympiad (KMO), *Korean Mathematical Society*	1994

Patents

W. Shin, S. Fan. "Simulation of phenomena characterized by partial differential equations." Under review by USPTO (serial number 13/744,999) [link].

RESEARCH OVERVIEW

Design of novel nanophotonic components

I have designed various novel nanophotonic components for integrated optics:

- Focusing lenses made in flat metallic films [*Opt. Lett.* 2010]
- Perfect bends and splitters in plasmonic waveguides [*Nano Lett.* 2013, *Adv. Mater.* 2010]
- Grating couplers launching surface plasmons unidirectionally [*Nano Lett.* 2014]
- Deep-subwavelength spectral separators [*Appl. Phys. Lett.* 2014]
- Plasmonic waveguide stub filters [*Opt. Express* 2015]
- Microfluidic channels that optically trap and release particles [*Lap Chip* 2016]

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 following topics:

- 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]
- The unique properties of modal loss rates at microwave frequencies [*Appl. Phys. Lett.* 2015]

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

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 in domains terminated by 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]

I also developed a numerical method for simulating phenomena involving vastly different frequencies (e.g., GHz modulation of THz signals). Because such phenomena involve multiple frequencies, they cannot be simulated by conventional frequency-domain methods. Conventional time-domain methods cannot be used for practical reason, either, because individual time steps need to be extremely small (due to high frequency signals) compared to the time scale of slow modulation. The new method is a frequency-domain method but can handle multiple frequencies, so it overcomes the shortcomings of both the conventional time- and frequency-domain methods:

- A multi-frequency method, which extends the conventional frequency-domain methods that can handle only a single frequency at a time [*Optica* 2016].

REFEREED JOURNAL PUBLICATIONS

Nanophotonic Component Designs

7. S. A. Khan, C.-M. M. Chang, Z. Zaidi, W. Shin, Y. Shi, A. K. Ellerbee Bowden, O. Solgaard. "Metal-insulator-metal waveguides for particle trapping and separation." *Lab on a Chip* **16** (2016): 2302–8 [link].

6. A. Mahigir, P. Dastmalchi, W. Shin, S. Fan, G. Veronis. "Plasmonic coaxial waveguide-cavity devices." *Opt. Express* **23** (2015): 20549–62 [link].

5. Y. Büyükalp, P. B. Catrysse, W. Shin, S. Fan. "Spectral light separator based on deep-subwavelength 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

4. W. Shin, S. Fan. "Unified picture of modal loss rates from microwave to optical frequencies in deep-subwavelength metallic structures: A case study with slot waveguides." *Applied Physics Letters* **107** (2015): 171102 [link].
3. A. Raman, W. Shin, S. Fan. "Metamaterial band theory: fundamentals & applications." *Science China Information Sciences* **56** (2013): 1–14 [link].
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].

Computational Techniques

3. Y. Shi, W. Shin, S. Fan. "Multi-frequency finite-difference frequency-domain algorithm for active nanophotonic device simulations." *Optica* **3** (2016): 1256–59 [link].
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].

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 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. 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. 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. 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. 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. 2011.

Academic Software Development

MaxwellFDFD *developed in MATLAB* http://www.mit.edu/~wsshin/maxwellfdfd.html

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:

- Adaptive nonuniform grid generation aligned with object boundaries
- Waveguide mode solver and waveguide-mode-generating current source
- 2D and 3D visualization of objects, sources, and solution fields
- Periodic array of objects
- Electric ($\mathbf{J}$) and magnetic ($\mathbf{M}$) current sources
- PEC, PMC, periodic, and Bloch boundary conditions
- Stretched-coordinate perfectly matched layer (SC-PML) and uniaxial PML (UPML)
- Total-field/scattered-field (TF/SF) method
- Power flux calculation

FD3D *developed in C and Python using PETSc* http://www.mit.edu/~wsshin/fd3d.html

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 for spectrum analysis. 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.

jemdoc+MathJax *developed in Python* http://www.mit.edu/~wsshin/jemdoc+mathjax.html

jemdoc is an open-source website generator that is widely used in the academia for generating personal and course websites. *MathJax* is an open-source project founded by AMS and SIAM for displaying LaTeX equations on webpages. Combining these two existing platforms, I have developed *jemdoc+MathJax*, an open-source program for easily creating academic websites containing complex LaTeX equations. See my interview with MathJax.org about jemdoc+MathJax [link].

References

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