Mohammad Mojtaba Sadafi

Ph.D. Candidate in Electrical and Computer Engineering

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Research Overview & Interests

My research focuses on the fundamental theory and applications of **active and time-varying metasurfaces** and **photonic time crystals**, as well as their interaction with classical and quantum light. This work lies at the intersection of **quantum photonics** and **singular optics**. I combine different approaches, including Floquet–Bloch theory, time-Floquet multipole analysis, the discrete dipole approximation, and full-wave numerical methods, with open quantum-system dynamics to model and control light–matter interactions in dynamic photonic systems. These approaches are applied to a range of material platforms, including two-dimensional materials such as graphene and transition metal dichalcogenides, carbon nanotubes, barium titanate, and plasmonic nanostructures. Earlier work addressed optical manipulation of nanoparticles using orbital angular momentum beams and electrostatically oriented Janus particles. My recent work spans dynamic shaping of quantum-light radiation, electrically tunable excitonic hyperbolicity in carbon nanotubes, a causal theory for dispersive time-varying metasurfaces, and photonic time crystals in moiré superlattices.

Time-Varying Media ▪ Photonic Time Crystals ▪ Metasurfaces ▪ Quantum Photonics ▪ Singular Optics

Research Experience

2021–Present **Graduate Research Assistant**, *Department of Electrical and Computer Engineering, Northeastern University*
Advisor: Hossein Mosallaei.

Photonic Time Crystals in Moiré Superlattices
Developed a tight-binding framework showing that moiré flat bands open a momentum bandgap across the entire Brillouin zone at modulation depths far below the bulk requirement, by decoupling band flatness from radiative lifetime through structural design.
Publications: Newton'26 (under review)

Causal Floquet–Bloch Theory for Dispersive Time-Varying Metasurfaces
Developed and validated a causal Floquet–Bloch theory for dispersive time-varying metasurfaces, enabling harmonic-resolved modeling of dynamic light–matter interactions in excitonic metasurfaces and metasurface-enabled photonic time crystals.
Publications: Nanophotonics'26 (under review) ▪ Metamaterials'26

Programmable Quantum-Emitter Control with Time-Modulated Nanoantenna Arrays
Building on an integrated Lindblad–Maxwell–Bloch framework for time-modulated quantum systems, formulated a quantum-electromagnetic model for time-modulated barium titanate (BTO) nanoantenna arrays, enabling programmable control of diamond NV-center emission.
Publications: npj Nanophoton.'26 ▪ APL Quantum'25 ▪ Metamaterials'26 ▪ MRS'25

Time-Modulated Discrete Dipole Approximation for Dynamic TMD Metasurfaces
Introduced a time-modulated discrete dipole approximation framework for dynamic metasurfaces based on bulk transition metal dichalcogenides (TMDs), integrating the time-Floquet formalism and the extended boundary condition method to model real-time light–matter interactions.

Strongly Coupled Graphene-Based Spatiotemporal Metasurfaces
Investigated electrically tunable mid-infrared metasurfaces in which strong coupling between guided-mode resonances (GMRs) and graphene plasmons enables continuous $\sim 2\pi$ phase modulation, with inverse design raising beam-steering efficiency to 85% and spatiotemporal modulation enabling single-sideband beam steering with $\sim$87% conversion efficiency.
Publications: JOSA B'26 ▪ Metamaterials'26

Time-Floquet Mie Theory for Quantum Emitters near Time-Modulated Nanoparticles
Developed an analytical time-Floquet Mie theory platform, first for dynamic light scattering by a single time-modulated particle and then for its interactions with quantum emitters, demonstrating tunable control of quantum-emitter radiation through temporal modulation.
Publications: PRB'25 ▪ APL'23 ▪ MRS'24

Electrostatic Orientation Control of Optically Asymmetric Janus Particles
Proposed a multiphysics modeling platform combining the boundary element method and rigid-body dynamics to study electrostatic orientation control of optically asymmetric Janus particle clusters for battlefield obscured-vision applications.
Publications: ACS Omega'24 ▪ Sci. Rep.'24 ▪ MRS'24 ▪ MRS'24

Time-Floquet Multipole Expansion for Coupled Time-Varying Meta-Atoms
Formulated and validated a time-Floquet multipole expansion framework for coupled meta-atoms with time-varying optical properties, using finite-difference frequency-domain (FDFD) simulations to study light–particle energy exchange and the emergence of exceptional points.

Selective Optical Manipulation with Highly Focused Orbital Angular Momentum Beams
Developed and validated an analytical framework for highly focused Laguerre–Gaussian beam interactions with particles on plasmonic substrates, using orbital angular momentum states to selectively excite particle modes for controlled optical manipulation.
Publications: Adv. Photonics Res.'23 ▪ MRS'22

Summer 2025 **Visiting Researcher**, *Electrical and Systems Engineering, University of Pennsylvania*

Tunable Excitonic Metasurfaces for Spatial Light Modulation
Conducted research on the design and fabrication of tunable excitonic metasurfaces for spatial light modulator applications using 2D transition metal dichalcogenides. Designed a tunable metasurface by coupling nonlocal modes in a TiO_2 grating to the excitonic resonance of monolayer WS_2, demonstrating wide-angle beam steering.

Chirality-Pure Carbon Nanotube Metasurfaces
Developed chirality-pure carbon nanotube metasurfaces through modeling, simulation, and fabrication, revealing electrically tunable in-plane anisotropy driven by strong excitonic effects and enabling dynamic control over elliptical and hyperbolic dispersion.
Publications: ACS Nano'26

2020–2021 **M.S. Student Researcher**, *Electrical Engineering Department, Sharif University of Technology*

Modeling of Photonic Waveguides, Couplers, and Optical Fibers
Modeled photonic waveguides, directional couplers, and optical fibers using spectral-representation, minimum-reflection, and WKB methods, validated by FDTD simulations.

High-Q Metallic Gratings for Chemical Sensing
Engineered critically coupled, high-quality-factor metallic gratings for chemical sensing and developed an effective circuit model of their response.

2019–2020 **B.S. Student Researcher**, *Electrical Engineering Department, Bu-Ali Sina University*

Frequency-Diverse Metamaterial Arrays for Compressive EMI Source Localization
Designed a frequency-diverse metamaterial-array platform for compressive electromagnetic interference (EMI) source localization, validated through full-wave simulations and experimental measurements, with a circuit model for system integration.
Publications: IEEE Trans. Electromagn. Compat.'26 (in preparation)

Tunable Graphene–Metal Metamaterial Absorber for THz Sensing
Designed a high-Q THz absorber based on graphene–split-ring resonator (SRR) interaction, developed a transmission-line circuit model validated by full-wave simulations, and achieved a label-free chemical and biomedical sensing sensitivity of 597 GHz/RIU.
Publications: Curr. Appl. Phys.'21

Optical Permittivity Models for 2D Materials
Developed experimentally informed optical permittivity models for MoS_2 and WS_2 to simulate photonic devices based on transition metal dichalcogenides.

Publications

Journal Articles

Newton'26 **M. M. Sadafi** and H. Mosallaei. "Photonic Time Crystals in Moiré Superlattices". Under review in *Newton*. Preprint: SSRN 7567239.

Nanophotonics '26 **M. M. Sadafi**, S. Inampudi, and H. Mosallaei. "Floquet-Bloch Theory for Dispersive Time-Varying Metasurfaces". Under review in *Nanophotonics*. Preprint: arXiv:2609.27109.

JOSA B'26 O. Poordashtban, **M. M. Sadafi**, and H. Mosallaei. "Efficient Sideband Generation and Beam Shaping in Strongly Coupled Graphene-Based Spatiotemporal Metasurfaces". In: *Journal of the Optical Society of America B* 43, 8 (2026), pp. 1538–1546. DOI: 10.1364/josab.601458.

ACS Nano'26 J. Lynch, P. Shapturenka, **M. M. Sadafi**, Z. Liu, T. Ruth, K. Jha, Z. Fakhraai, H. Mosallaei, N. Engheta, J. A. Fagan, and D. Jariwala. "Electrically Tunable Excitonic-Hyperbolicity in Chirality-Pure Carbon Nanotubes". In: *ACS Nano* 20, 27 (2026), pp. 19807–19819. DOI: 10.1021/acsnano.6c08474.

npj Nanophoton.'26 A. F. da Mota*, **M. M. Sadafi***, and H. Mosallaei. "Dynamic Quantum-Light Radiation Shaping with Time-Modulated BTO-Driven Nanoantennas Array". In: *npj Nanophotonics* 3, 50 (2026). DOI: 10.1038/s44310-026-00141-5. **Invited paper**.

APL Quantum'25 A. F. da Mota, **M. M. Sadafi**, W.-C. Chiu, B. Barbiellini, M. N. Leuenberger, A. Bansil, and H. Mosallaei. "Dynamics of Time-Modulated Quantum Systems via Integrated Lindblad and Maxwell–Bloch Equations". In: *APL Quantum* 2, 3, 036107 (2025). DOI: 10.1063/5.0271171.

PRB'25 **M. M. Sadafi**, A. F. da Mota, and H. Mosallaei. "Time-Varying Mie Resonators for Real-Time Manipulation of Quantum Emitter Radiation". In: *Physical Review B* 111, 12, 125419 (2025). DOI: 10.1103/physrevb.111.125419.

ACS Omega'24 **M. M. Sadafi**, A. F. da Mota, and H. Mosallaei. "Electrostatic Orientation of Optically Asymmetric Janus Particles". In: *ACS Omega* 9, 50 (2024), pp. 49172–49187. DOI: 10.1021/acsomega.4c05669.

Sci. Rep.'24 A. F. da Mota, **M. M. Sadafi**, and H. Mosallaei. "Asymmetric Imaging through Engineered Janus Particle Obscurants Using a Monte Carlo Approach for Highly Asymmetric Scattering Media". In: *Scientific Reports* 14, 3850 (2024). DOI: 10.1038/s41598-024-54035-7.

APL'23 **M. M. Sadafi**, A. F. da Mota, and H. Mosallaei. "Dynamic Control of Light Scattering in a Single Particle Enabled by Time Modulation". In: *Applied Physics Letters* 123, 10, 101702 (2023). DOI: 10.1063/5.0145291.

Adv. Photonics Res.'23 **M. M. Sadafi**, M. Taghavi, A. F. da Mota, and H. Mosallaei. "Optical Manipulation of Nanoparticles: A Selective Excitation Approach Using Highly Focused Orbital Angular Momentum Beams". In: *Advanced Photonics Research* 4, 7, 2200224 (2023). DOI: 10.1002/adpr.202200224.

Curr. Appl. Phys.'21 **M. M. Sadafi**, H. Karami, and M. Hosseini. "A Tunable Hybrid Graphene-Metal Metamaterial Absorber for Sensing in the THz Regime". In: *Current Applied Physics* 31 (2021), pp. 132–140. DOI: 10.1016/j.cap.2021.07.020.

IEEE Trans. Electromagn. Compat.'26 **M. M. Sadafi**, H. Karami, M. Rubinstein, and F. Rachidi. "A Compressive Sensing Platform for Electromagnetic Interference Source Localization Using Frequency-Diverse Metamaterial Arrays". In preparation for *IEEE Transactions on Electromagnetic Compatibility*.

Conference Proceedings

Metamaterials '26 **M. M. Sadafi**, O. Poordashtban, and H. Mosallaei. "Dynamic Light Scattering from Dispersive Time-Varying Metasurfaces: A Causal Floquet-Bloch Approach". In: *Proc. of the 20th Int'l Congress on Artificial Materials for Novel Wave Phenomena (Metamaterials)*. 2026, pp. 240–242. DOI: 10.1109/metamaterials70235.2026.11718622.

Metamaterials '26 O. Poordashtban, **M. M. Sadafi**, and H. Mosallaei. "Graphene-Integrated Metasurface for Full 2π Mid-Infrared Phase Modulation via GMR-Plasmon Strong Coupling". In: *Proc. of the 20th Int'l Congress on Artificial Materials for Novel Wave Phenomena (Metamaterials)*. 2026, pp. 216–218. DOI: 10.1109/metamaterials70235.2026.11718620.

Conference Presentations

Metamaterials '26 **M. M. Sadafi**, A. F. da Mota, and H. Mosallaei. "Dynamic Quantum Radiation Shaping with Time-Modulated Nanoantenna Arrays". Poster presented at the 20th Int'l Congress on Artificial Materials for Novel Wave Phenomena (Metamaterials 2026).

MRS'25 **M. M. Sadafi**, A. F. da Mota, and H. Mosallaei. "Controlling the Density of States of Quantum Emitters by Space–Time and Floquet Metasurfaces". **Invited talk** presented at the 2025 MRS Fall Meeting & Exhibit.

MRS'24 **M. M. Sadafi**, A. F. da Mota, and H. Mosallaei. "Mie Resonators Made of Time-Varying Materials for Dynamic Control of Electromagnetic Radiation". Presented at the 2024 MRS Fall Meeting & Exhibit.

MRS'24 **M. M. Sadafi**, A. F. da Mota, and H. Mosallaei. "Rotating Dielectric–Plasmonic Janus Particles via Electrostatic Voltages to Enable Optical Functionalities". Presented at the 2024 MRS Fall Meeting & Exhibit.

MRS'24 A. F. da Mota, **M. M. Sadafi**, and H. Mosallaei. "One-Way Smoke—Janus Particle-Engineered Material for Unidirectional Imaging". **Invited talk** presented at the 2024 MRS Fall Meeting & Exhibit.

MRS'22 M. Taghavi, **M. M. Sadafi**, and H. Mosallaei. "Vortex Beams for Photonic Metasails and Optomechanical Rotation". Presented at the 2022 MRS Fall Meeting & Exhibit.

*Equal contribution.

Education

10/21–Present **Ph.D. in Electrical and Computer Engineering**, *Northeastern University*, Boston, MA, GPA: 4.0/4.0
Advisor: Hossein Mosallaei.

10/21–12/23 **M.S. in Electrical and Computer Engineering**, *Northeastern University*, Boston, MA, GPA: 3.96/4.0
Earned en route to the Ph.D.

10/20–07/21 **M.S. in Electrical Engineering**, *Sharif University of Technology*, Tehran, Iran, GPA: 18.97/20
Degree not conferred.

10/16–08/20 **B.S. in Electrical Engineering**, *Bu-Ali Sina University*, Hamedan, Iran, GPA: 19.22/20
Graduated with honors; ranked first in class.

Honors & Awards

2021 **Graduate Fellowship**, *Northeastern University*.

2020 **Admission through the Office of Talented Students**, *Sharif University of Technology*.

2020 **Top Graduating Student with Highest Honors**, Class of 2020, *Bu-Ali Sina University*.

2019 **Top Educational Student Award**, among all students, *Bu-Ali Sina University*.

Teaching Experience

Northeastern University

Summer 2026 Teaching Assistant, Electromagnetic Devices for RF and Wireless Communications

2024–2026 Teaching Assistant, Fundamentals of Electromagnetics (Fall 2024–Fall 2026)

Bu-Ali Sina University

2017–2019 Teaching Assistant, Undergraduate Electrical Engineering Courses
Electromagnetic Theory, Signals and Systems, Electronic Circuits, Circuit Theory II, and Engineering Mathematics (eight course offerings).

Peer Review

Journals *Physical Review Letters* (3), *Physical Review Applied* (1), *Physical Review Research* (1), *Physical Review A* (1), *Physical Review B* (1), *Optics Letters* (1), *Progress in Electromagnetics Research* (1), *IEEE Journal on Selected Areas in Communications* (1)

Technical Skills

Methods Floquet–Bloch and time-Floquet analysis, Mie and multipole theory, discrete dipole approximation, boundary element and extended boundary condition methods, RCWA, FDTD, FDFD, finite-integration technique, open quantum systems

Simulation Lumerical FDTD, Lumerical CHARGE, COMSOL Multiphysics, CST Studio Suite, Ansys HFSS

Circuits & EDA Advanced Design System (ADS), HSPICE, PSpice, Altium Designer

Prog. & tools MATLAB, Python, C/C++, OpenCV, Arduino, Linux, LaTeX, Inkscape, Microsoft Office

Languages English (advanced; TOEFL iBT 112/120), French (elementary), Farsi (native)