Lab project M2 PPN

Monday & Tuesday from Oct 2025 to March 2026

Title of the project: Inverse Faraday effect in plasmonic devices

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Laboratory / Department / Team : Photonic department; PRISM group

Collaborations: Mathieu Mivelle, Sorbonne Université

Summary:

The inverse Faraday effect (IFE) enables light to generate an effective magnetization without external bias, linking the spin of the optical field to a quasi-static magnetic response. Since the earliest reports in bulk media and metals, the key insight for nanoscale control has been that strongly inhomogeneous optical fields can greatly amplify the spin density and the associated opto-magnetic source currents that underlie the IFE. In plasmonic architectures, near-field localization, field gradients, and nanometric mode volumes provide precisely these conditions, focusing the opto-magnetic response to deep-subwavelength regions and opening routes to ultrafast, nanoscale control of magnetism. Microscopic theory now quantifies IFE-induced orbital magnetism in metals and clarifies how material parameters and disorder shape the response under high-frequency excitation [1]. Complementarily, resonant nanostructures create nonuniform, vectorial fields that map into spatially structured effective magnetic fields via the IFE, as demonstrated at Mie-type resonances and in plasmonic hotspots [2,3]. Beyond general enhancement, plasmonic inverse-design strategies have realized a chiral IFE: the near-field spin density is engineered so that only one helicity produces a strong, localized magnetic field—up to the sub-tesla level—in the vicinity of a nanostructure [4]. These advances establish a consistent physical picture in which nanophotonic control of optical spin and field gradients governs the magnitude, sign, and spatial profile of IFE-induced magnetization.

Harnessing the IFE in practical magneto-optical devices requires bridging near-field plasmonics with magnetization dynamics and thermal pathways. Multiphysics modeling that combines Maxwell electrodynamics, heat flow, and spin-lattice relaxation captures helicity-dependent responses driven by plasmonic hotspots and provides quantitative design rules for material stacks and pulse parameters [5]. Experimentally, plasmon-enabled control of energy deposition has achieved layer-selective, nanometer-resolved all-optical magnetization switching in magnetic heterostructures by tuning polarization and coupling to surface plasmon polaritons, highlighting how near-field engineering can deterministically address specific layers within complex stacks [6]. Taken together, contemporary microscopic theory, resonant near-field enhancement, inverse-designed chiral responses, and device-level modeling converge to position plasmonic IFE as a viable pathway toward energy-efficient, ultrafast, and deeply scaled magneto-optical switching, while also providing testable predictions for disentangling IFE-driven torque from purely thermal mechanisms in future devices.

The proposed lab project lies within this context and aims to further study the IFE experimentally. The lab project is designed to continue into the second semester with a five-month internship to prepare the student for a PhD thesis in September 2026 (funded by PEPR LUMA in the framework of the BERNARDO project). During the lab project, the student will have to implement confocal microscopy experiments to spatially map photocurrents at the nanoscale upon polarization-resolved laser excitation. The student will take in charge the confocal microscope alignments, conduct the electro-optical experiments and proceed to data analysis. Later in the project, during the internship and later the PhD, the student will also receive formal training of the clean room nanofabrication facility (lithography, materials deposition, etching, etc) to design and realize optimized nanostructures. The student will finally conduct sub-wavelength near-field characterization of the light induced photocurrents. All experiments will be conducted on ARCEN-CARNOT and SMARTLIGHT platforms of ICB laboratory.

References

[1] P. Sharma, E. Apostolova, M. Khodas, and A. Levchenko, “Light-induced orbital magnetism in metals via inverse Faraday effect,” Phys. Rev. B 110, 094302 (2024). https://doi.org/10.1103/PhysRevB.110.094302

[2] D. M. Krichevsky, A. V. Uskov, and M. Wubs, “Inverse Faraday effect at Mie resonances,” Phys. Rev. Applied 22, 064087 (2024). https://doi.org/10.1103/PhysRevApplied.22.064087

[3] F. Cheng, S. Bandyopadhyay, and C. Guo, “Multiphysics Modeling of Plasmon-Enhanced All-Optical Helicity-Dependent Switching,” ACS Photonics 10, 1292–1302 (2023). https://doi.org/10.1021/acsphotonics.2c01815

[4] Y. Mou, X. Yang, B. Gallas, and M. Mivelle, “A chiral inverse Faraday effect mediated by an inversely designed plasmonic antenna,” Nanophotonics 12, 2115–2120 (2023). https://doi.org/10.1515/nanoph-2022-0772

[5] F. Cheng, S. Bandyopadhyay, and C. Guo, “Multiphysics Modeling of Plasmon-Enhanced All-Optical Helicity-Dependent Switching,” ACS Photonics 10, 1292–1302 (2023). https://doi.org/10.1021/acsphotonics.2c01815

[6] D. O. Ignatyeva, C. S. Davies, D. A. Sylgacheva, et al., “Plasmonic layer-selective all-optical switching of magnetization with nanometer resolution,” Nat. Commun. 10, 4786 (2019). https://doi.org/10.1038/s41467-019-12699-0

Type of project (theory / experiment): Experimental

Required skills: Microscopy, Laser alignments, Nanofabrication and characterization