Development of Magnetic Field Sensing Materials and Optical Devices for Power-Grid Applications

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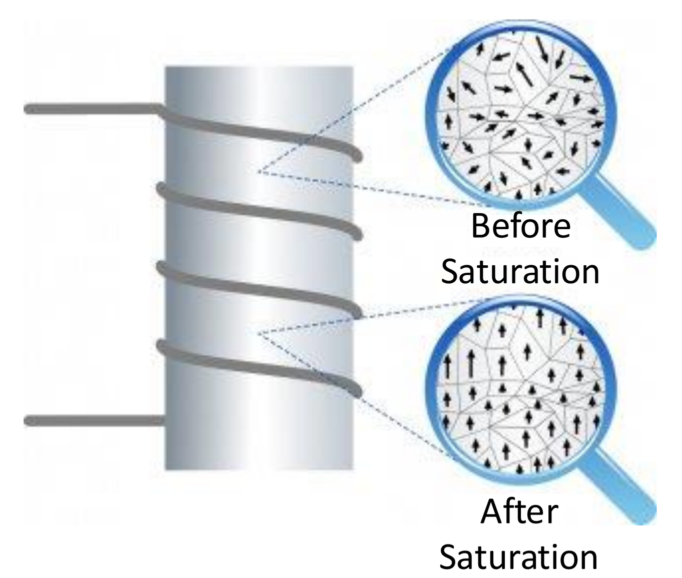
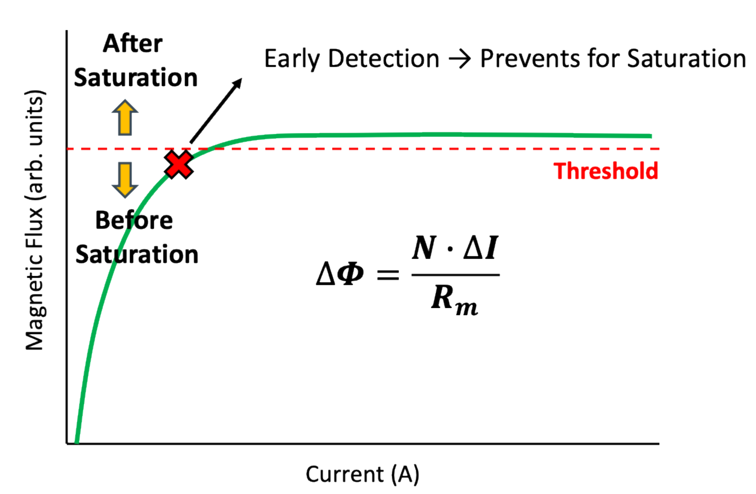
Motivation

The modernization of power grids and integration of renewable energy demand advanced monitoring systems. Magnetic field sensing method has non-invasive, highly sensitive, and real-time capabilities which are ideal for optimizing power grids. Our research leverages YIG single crystal fibers, NV center nanodiamond-polymer composites, and polymer-magnetic nanoparticles on an optical fiber platform, which offers high bandwidth, immunity to electromagnetic interference, and ease of integration into existing infrastructures. These sensors detect faults and imbalances with high accuracy, enhancing grid resilience and contributing to a more stable energy future.





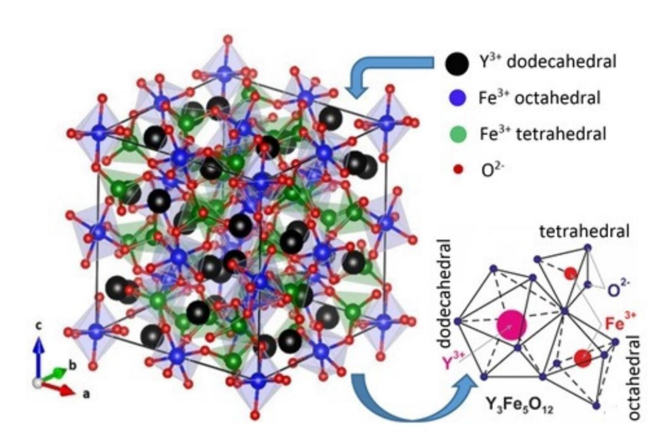
Objective

1. Develop Magneto-Optical and Magnetic Field Sensing Materials
2. Integrate Magnetic Sensing Materials into Optical Platforms
3. Optimize Magnetic Field Sensing for Power-Grid Applications
   - ❑ Test sensor performance for real-time fault detection and current imbalance in simulated grid conditions.
4. Characterize Material-Specific Sensing Mechanisms
   - ❑ Faraday rotation in YIG, ODMR in NV centers, and Néel relaxation with refractive index changes in magnetic nanoparticle composites for tailored sensing responses.
5. Establish Power-Grid Monitoring Solutions
   - ❑ Develop scalable, fiber-integrated sensing solutions for resilient and efficient power-grid monitoring, with a focus on low-maintenance and durable designs

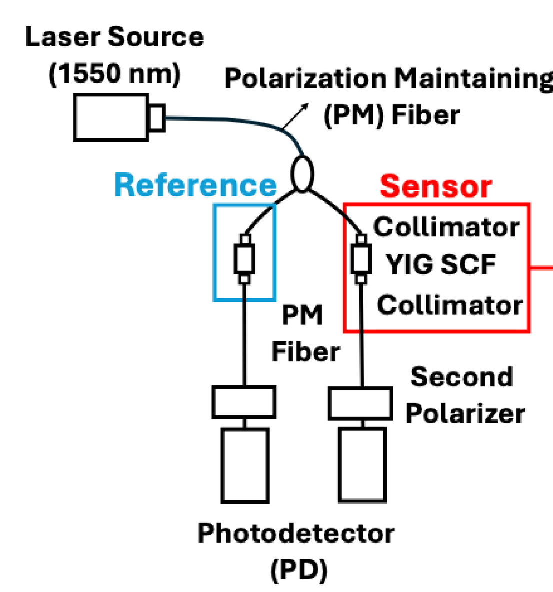
Magnetic Field Sensing Materials and Optical Devices

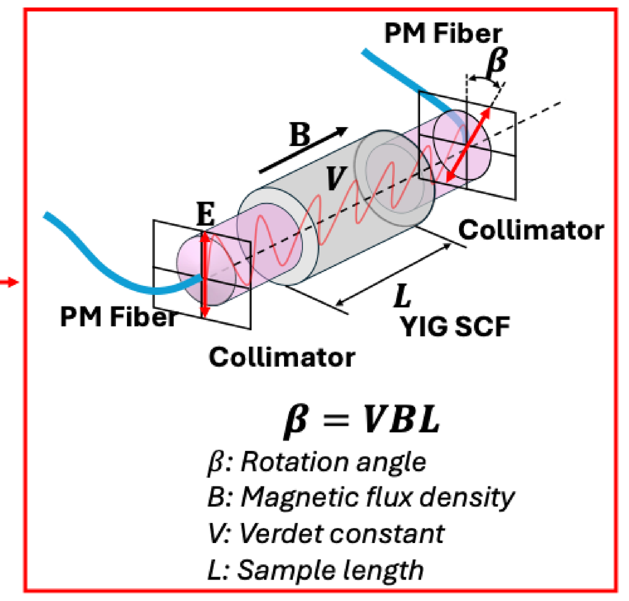
1. Yttrium Iron Garnet (YIG, $Y_3Fe_5O_{12}$) Single Crystal Fiber (SCF)

- ❑ Magneto-Optical Properties (Faraday rotation)
- ❑ Advantages of SCF via LHPG
- ❑ Polarization-based sensing



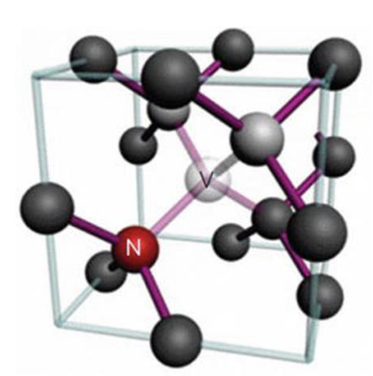
❖ YIG Crystal Structure [1]



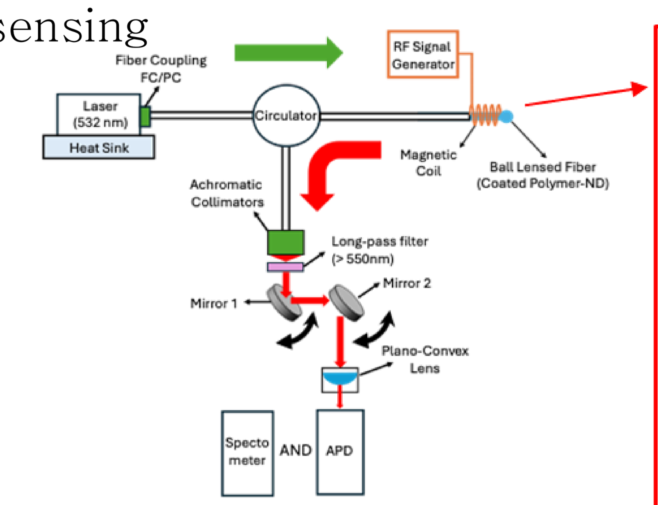


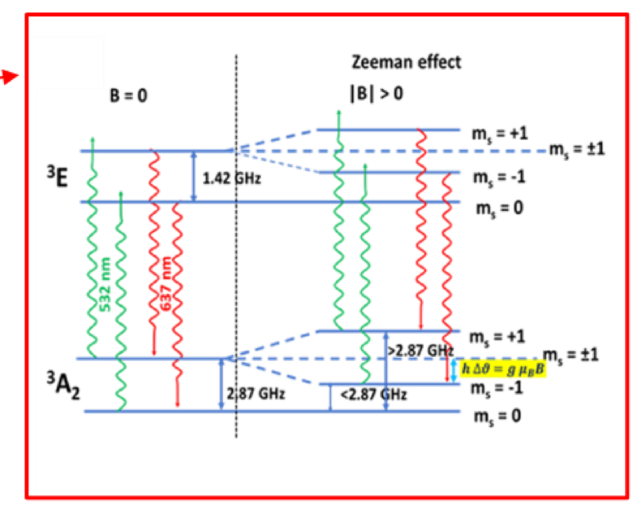
2. Polymer-Nitrogen-Vacancy (NV) Center Nanodiamond Composite

- ❑ Optically Detected Magnetic Resonance (ODMR), Zeeman effect
- ❑ Probe design for fluorescence collection
- ❑ Fluorescence intensity-based sensing



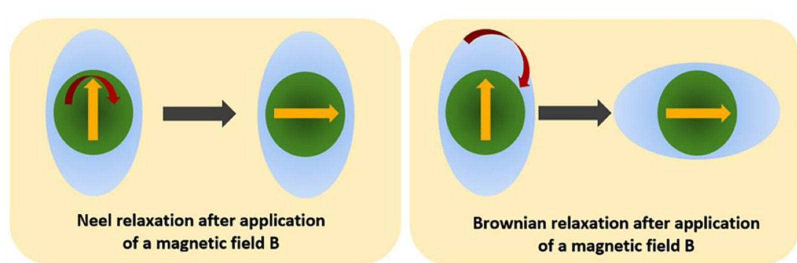
❖ Nitrogen and Vacancy in Diamond Lattice [2]



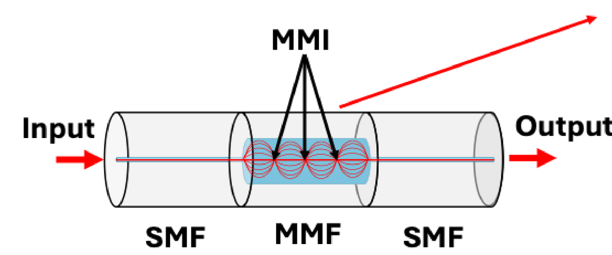


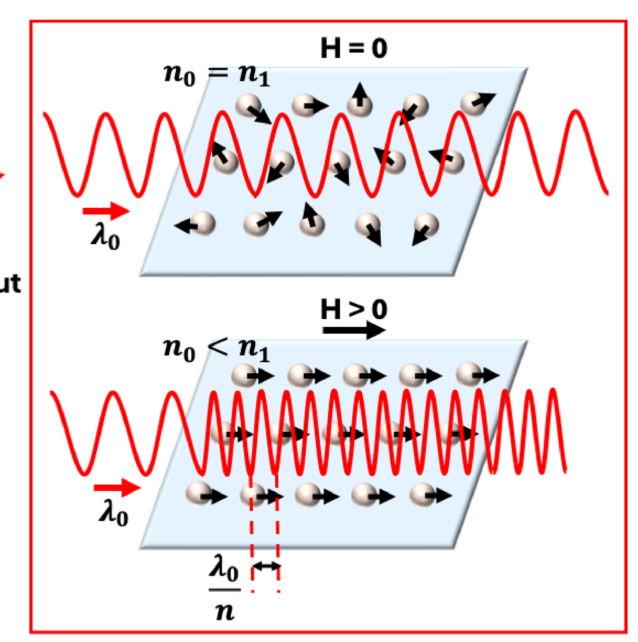
3. Polymer-Magnetic Nanoparticles (NP) Composite

- ❑ Néel relaxation and refractive index change
- ❑ Multimode Interference (MMI)
- ❑ Intensity-based sensing



❖ Néel relaxation and Brownian relaxation [3]





Progress

1. Yttrium Iron Garnet (YIG, $Y_3Fe_5O_{12}$) SCF

- ❑ Fabrication of YIG-SCF with B_2O_3 doping via LHPG
- ❑ Characterization for B_2O_3 doping effect

2. NV Center Nanodiamond Composite

- ❑ Synthesis of PMMA and PVP-NV nanodiamond
- ❑ Confocal imaging of NV center distribution
- ❑ Fabrication of ball-lensed fiber

3. Polymer-Magnetic NP Composite

- ❑ Synthesis of PVA-Iron oxide NP composite
- ❑ Initial feasibility testing

Future Work

1. Yttrium Iron Garnet (YIG, $Y_3Fe_5O_{12}$) SCF

- ❑ Integration of YIG-SCF with an optical fiber platform
- ❑ Direct laser fusion to optical fiber

2. NV Center Nanodiamond Composite

- ❑ Development of a magnetic field delivery design
- ❑ Enhancement of optical setup for improved fluorescence collection

3. Polymer-Magnetic Nanoparticles (NP) Composite

- ❑ Optimization for magnetic NP concentration
- ❑ Establishment of the mechanism correlating Néel relaxation with refractive index change

References

[1] A. J. Princep et al., "The full magnon spectrum of yttrium iron garnet," npj Quant Mater, vol. 2, no. 1, p. 63, Nov. 2017, doi: 10.1038/s41535-017-0067-y.

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[3] Y. Ma, J. Chen, and C. Wang, 'Growth of Diamond Thin Film and Creation of NV Centers', Applications and Use of Diamond. IntechOpen, Jul. 26, 2023. doi: 10.5772/intechopen.108159.