Spin-Based Planar Optomagnonic Cavities for Microwave to Optical Photon Conversion

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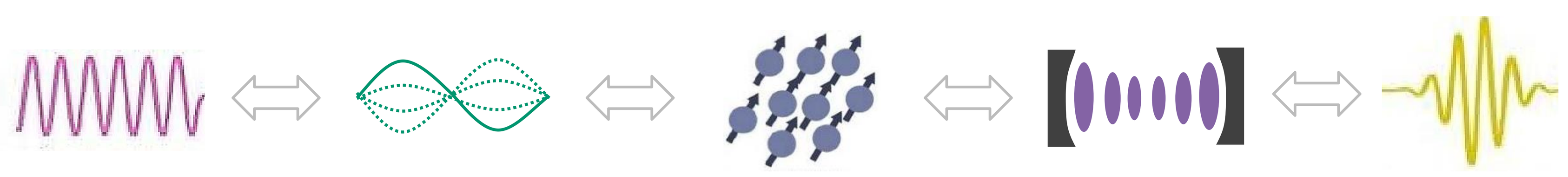
Scope of the Research

Development of magnon-based hybrid quantum systems for coherent conversion between microwave and optical frequency domain. In the proposed hybrid system concept, conversion from MW photons to optical photons takes place by the magneto-optic Faraday effect. YIG was chosen as the best ferrimagnetic material since both magnonic and optical modes.

This technology has crucial importance in many areas:

- Long-distance quantum communications (quantum memories and repeaters)
- Secure quantum networks
- Quantum internet
- Quantum radar

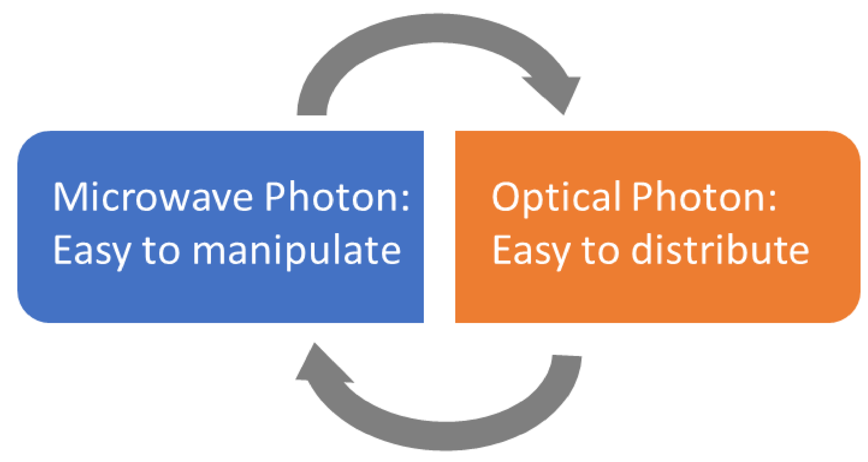
Microwave-Magnon-Photon Conversion



Microwave photon ⇔ Microwave cavity ⇔ Ferromagnetic magnon ⇔ Optical microcavity ⇔ Optical photon

Coupling between 1. Itinerant microwave and microwave cavity mode
2. microwave cavity mode and spin-wave of YIG
3. optical cavity mode and spin-wave oscillations
4. optical itinerant photon and optical cavity mode

Up/Down-Conversion

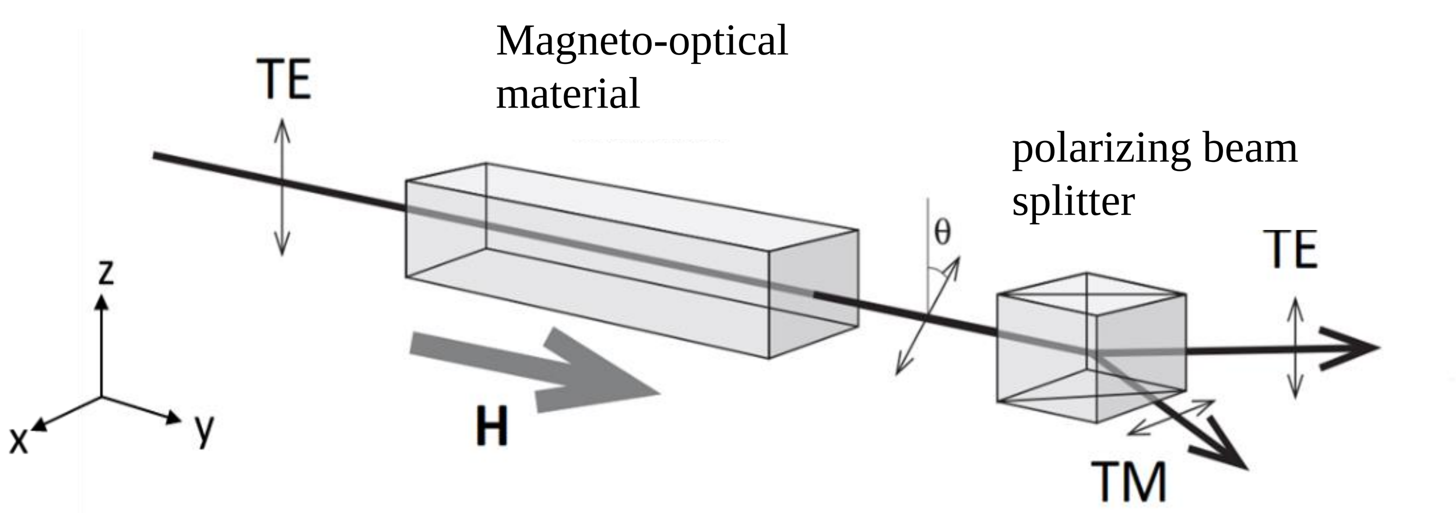


- Typical attenuation at 10 GHz is more than 1 dB m^{-1}
- Long coherence time
- High quantum control
- Scalable

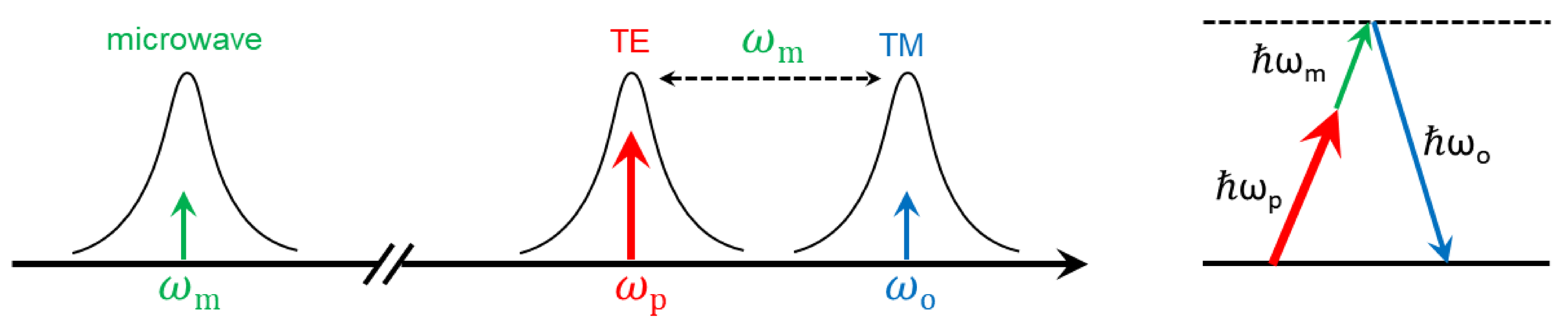
- Loss in optical fibres is below 0.2 dB km^{-1} at telecom wavelengths
- Thermal occupancy of optical frequency channels is close to zero at room temperature

Photon-Magnon Interaction

Faraday Rotation: angle of polarization of the light changes as it propagates through a magnetic material.

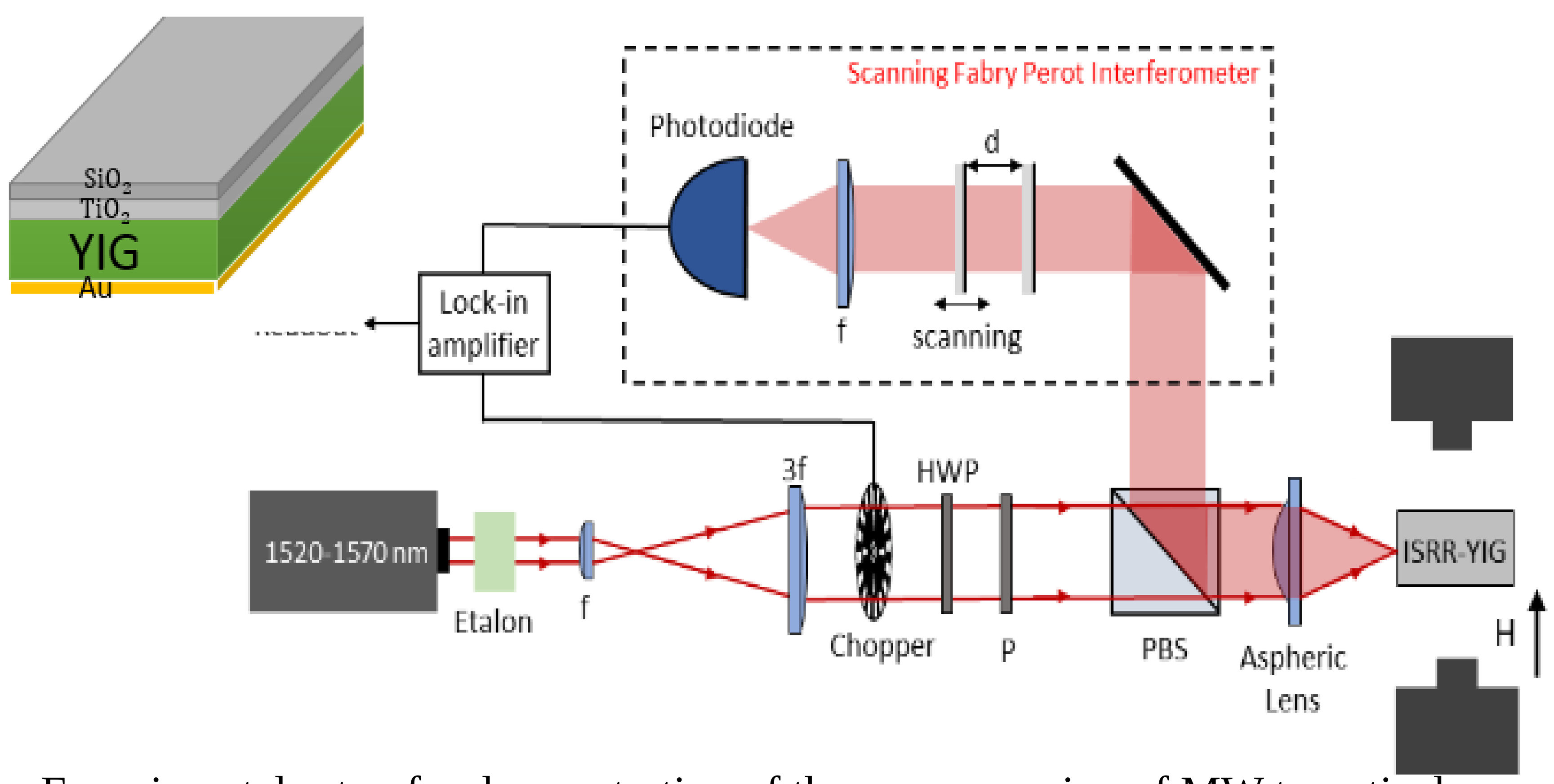


Three-wave-mixing process:



- Stokes and anti-Stokes sidebands at the angular frequency of $\boldsymbol{\omega_0 \pm \omega_{mw}}$
- The pump at $\hbar\omega_p$ and the signal at $\hbar\omega_m$ together excite the medium, leading to the emission of up-converted photons in the at $\boldsymbol{\hbar\omega_0 = \hbar\omega_p + \hbar\omega_m}$.

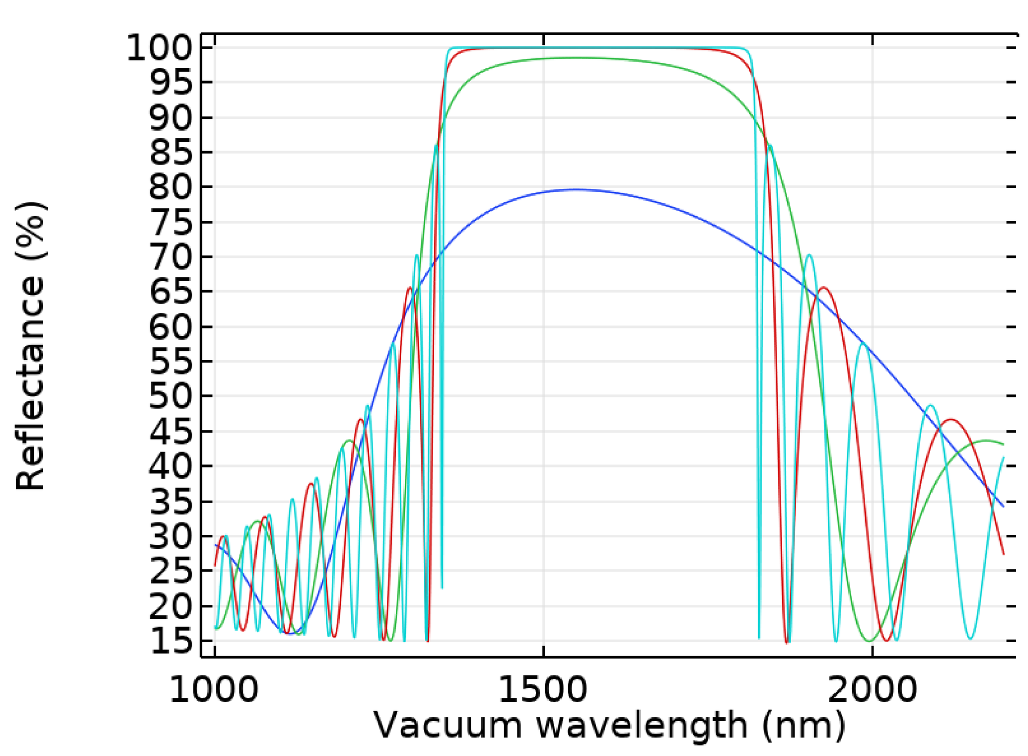
Detection of the converted signal

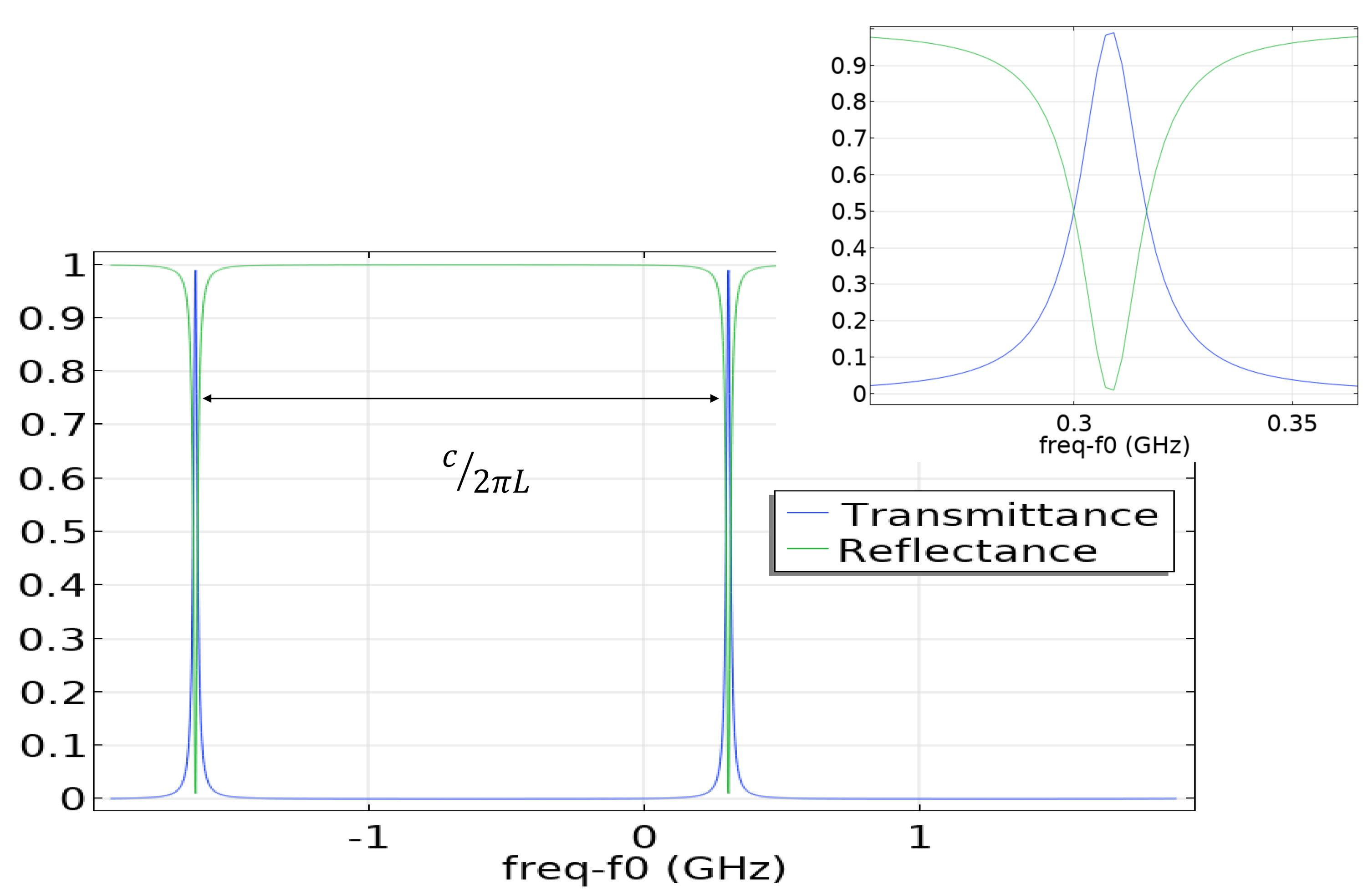


Experimental setup for demonstration of the up-conversion of MW to optical photons based on ISRR-YIG hybrid system is given in the figure above. We plan to use scanning Fabry-Perot interferometer to preform high-resolution analysis of optical spectrum and a detection setup to measure the shifted (Stocks and anti-Stocks lines) in the spectrum of the scattered light due to interaction with YIG film. Intensity of the shifted lines is related to efficiency of conversion from microwave to optical photons or vice versa.

Optical simulation results

- Single-sided TiO_2/SiO_2 multiple structure at 1550 nm





- **In the first graph**, response of the Distributed Bragg Reflector (DBR) grating for different numbers of layers, from minimum of 5 to a maximum of 41 total (TiO_2/SiO_2) layers.
- **In the second graph**, The sweep over two free spectral range shows two resonances of optical cavity. **Inset:** A frequency sweep over the resonance peak.

Conclusions

- We have done preliminary studies to develop the magnon-based system for quantum frequency conversion from microwave band to optic (near IR) band and v.v. In this framework, the structure consisting of Distributed Bragg Reflector (DBR) mirror, YIG material and gold reflector near inverse open-ring resonator (ISRR) as an MW element is planned to be used. The use of MW and optic resonators, as well as the spin-wave (non-uniform) magnetic excitations, is preferred for obtaining higher MW-optical conversion efficiency. We have done simulation studies of the optical part of this system as the first step for realization of this concept. A minimal number of layers in DBR element to realize an optical cavity of desired parameters is estimated. Free spectral range of optical cavity was obtained. We plan further studies: 1) to model an interaction between optical photons and magnons, 2) to test the proposed hybrid structure experimentally.

Reference

H. Sohlstrom, "Fibre Optic Magnetic Field Sensors Utilizing Iron Garnet Materials," 1993.