Giant Faraday Effect and Enhanced Transmission in Cobalt-Dielectric Photonic Strustures

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Introduction

Magnetic materials are an essential part of conventional nonreciprocal devices, such as isolators, circulators and nonreciprocal phase shifters [1,2]. However, due to their energy losses, many magnetic materials with otherwise strong nonreciprocal response and superior physical properties, e.g., ferromagnetic metals such as iron and cobalt have been rejected for use in nonreciprocal devices. Recently we have showed by using numerical simulations that a properly designed nonreciprocal metal-dielectric multilayer system can not only become highly transmissive, but it can also produce a strong Faraday rotation [3]. In May 2013, we have come to NHMFL to test such a structure in the MW spectral range.

Experimental

Our structure was a symmetric stack of high-dielectric ceramic (ref index ε_1=38, thickness d_1=1mm) and glass (ε_2=3.8, d_2=3mm) layers with a central half-wave defect and a cobalt nanolayer (d_c=200nm) introduced at the middle of the defect. The structure's lateral dimension was 3 inch in diameter. A high, highly homogeneous magnetic field was required to align cobalt magnetic moments perpendicular to the film plane, to achieve the Faraday Effect geometry. We used a 195mm bore magnet in Cell 4 for our measurements.

Results and Discussion

The cobalt-dielectric structure was placed at the center of the magnet and linearly-polarized microwave radiation was launched and received by conical horns placed above and below the magnet. Microwave field transmission spectra were measured for 2 cross polarizations (parallel and perpendicular to the incident polarization) with in magnetic field applied in the direction of the incident wave. As the magnetic field was increased, the ferromagnetic resonance in cobalt was climbing up in frequency to approach the transmission resonance of the photonic structure. When the two resonances were close to each other in frequency, we were able to achieve the strongest enhancement of the Faraday Effect, keeping the conductivity and magnetic losses at a minimum. Fig. 1, left panel, shows the transmittance for the parallel (blue) and perpendicular (red) polarizations as well as the total transmittance (black), which is just -2 dB compared to -45 dB for the standalone cobalt film. Fig. 2, right panel, shows corresponding Faraday rotation (green) and Faraday ellipticity (magenta) angles at magnetic field 2.05 T. It is seen that at the resonance we are able to achieve 45 degree Faraday rotation with no ellipticity, which are commonly used in MW isolators.

Conclusions

We have achieved, for the first time, 45 degree Faraday rotation from a ferromagnetic metal nanometer film. This result may lead to a host of applications not only in MW range, but in THz and far infrared.

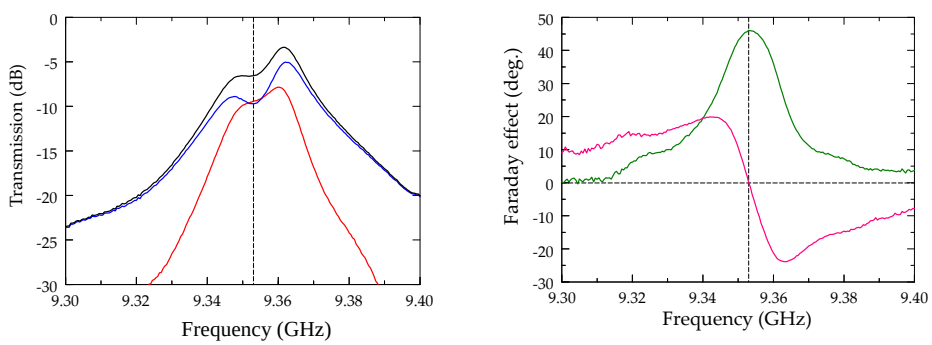

Figure 1: Microwave transmission (upper panel) and Faraday Effect (lower panel) in 200nm cobalt film inserted in a layered photonic structure at 2.05 T.

References

[1] Pozar D. A. *Microwave Engineering*, (Wiley New York, 1998).
[2] Zvezdin A. K. et al. *Modern Magnetooptics and Magnetooptical Materials*, (Taylor & Francis, New York, 1997).
[3] Smith K. et al. J. Phys. D: Appl. Phys. 46, 165002 (2013).