Femtosecond Intrapulse Evolution of Faraday Rotation in Magnetophotonic Crystals

Alexandr I. Musorin[1], Margarita I. Sharipova[1], Tatyana V. Dolgova[1], Mitsuteru Inoue[2], Andrey A. Fedyanin[1]

1) Faculty of Physics, Lomonosov Moscow State University, 119991 Moscow, Russia

2) Toyohashi University of Technology, Hibarigaoka, Tempaku-cho, 441-8580 Toyohashi, Aichi, Japan

musorin@nanolab.phys.msu.ru

Abstract: Time-resolved Faraday effect is studied experimentally in magnetophotonic crystals on a femtosecond timescale. It is shown that temporal behavior of polarization state strongly depends on the pulse wavelength.

1. Introduction

Slow light is a phenomenon explained by low group velocity of the pulsed light. Faraday effect can be greatly enhanced in multilayered structures due to the artificial dispersion [1, 2]. The Faraday rotation of the wave envelope depends on the difference between the inverse group and phase velocities, v_{gr} and v_{ph} respectively:

$$\theta = \Omega_L \left(\frac{1}{v_{gr}} - \frac{1}{v_{ph}} \right) d, \qquad (1)$$

where Ω_L is the Larmor frequency and d is the thickness of the material. Consequently, slow light and Faraday rotation are the direct counterparts that represent the effective time of light-matter interaction. In the steady-state case Faraday rotation θ scales linearly with thickness of gyrotropic media. If short laser pulses illuminate the medium, non-stationary behavior of Faraday rotation can be found on the timescale of pulse duration [3]. Magnetophotonic crystals, as being layered nanostructures, can modulate electric filed amplitude and phase of a femtosecond pulse in time. For example, Faraday angle at the initial part of the pulse can differ from that at its tail, and from the steady-state value.

In this work femtosecond dynamics of Faraday rotation is demonstrated experimentally in magnetophotonic crystals by polarization-sensitive correlation spectroscopy.

2. Samples and set-up

The studied magnetophotonic crystal was fabricated from half-wavelength-thick Bi-doped yttrium iron garnet placed between two Bragg reflectors of five pairs of alternating quarter-wavelength-thick silicon oxide and tantalum oxide. The cavity mode is located at 895 nm. The sample is grown on a glass substrate by the RF sputtering of corresponding targets in Ar atmosphere.

The set-up consists of polarization-sensitive and correlation parts (Fig. 1). Ti:Sapphire laser pulses pass through a 45°-oriented Glan-Taylor prism, the sample in DC magnetic field (2 kOe), photoelastic modulator (PEM), mounted coaxially to polarizer, and analyzed by 90°-oriented Glan-Taylor prism. The radiation is separated by a 50/50 beamsplitter into two beamlets, one of which contains variable delay line. Both beams are co-focused on the nonlinear beta-Barium-borate (BBO) crystal, generating non-collinear double-frequency optical radiation, that is detected with photomultiplier tube. The signal locked in to the doubled PEM frequency and its DC component are detected by a lock-in amplifier. The Faraday angle is proportional to the ratio of AC to DC signals.

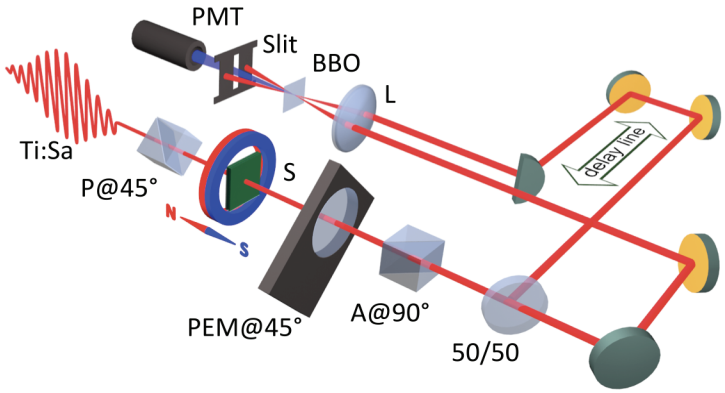

Fig. 1. Experimental setup scheme. P - polarizer, S - sample, PEM - photoelastic modulator, A - analyzer, BBO - nonlinear crystal, PMT – photomultiplier tube.

3. Results

Fig. 2a shows time dependence of Faraday rotation at the microcavity mode (895 nm - blue), where low group velocity of light is expected, and at the detuned wavelengths of 899 (green) and 901 nm (red).

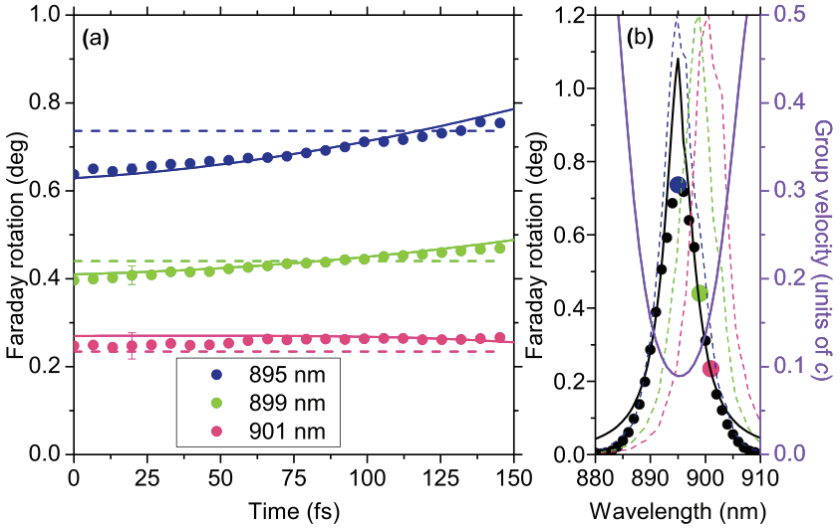

Fig. 2. a) Time dependence of Faraday rotation in magnetophotonic crystal. Color dots are experiment, color lines are calculations. Dash lines are steady-state values. Blue results are for microcavity mode (895 nm). Green (899 nm) and red (901 nm) results for wavelengths detuned from the mode. (b) Faraday rotation spectrum in vicinity of microcavity mode (black dots – experiment, black line - calculations). Color dots are points chosen for time-resolved experiment. Dash color lines indicate spectra of laser with central wavelengths denoted by color dots. Purple line denotes calculated group velocity.

Faraday rotation increases as fast as 0.15 degrees during 150 fs at the center of the mode, which is several times faster than that at the detuned wavelengths. The effect arises because the Faraday rotation is non-reciprocal and therefore, the polarization angle accumulates with time. Faraday rotation spectrum (black) is shown in Fig. 2b in the vicinity of the microcavity mode. The greatest polarization rotation is observed for the lowest value of group velocity (purple). The group velocity is 10-fold smaller than the speed of light in vacuum at the center of the microcavity mode. That is why light spends more time in defect magnetic layer; the time evolution of the pulse is greater compared to the values at detuned wavelengths.

5. References

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