Generation of spin waves by fs-laser pulses in transparent magnetic films: role of the laser beam diameter

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Abstract. Magnetostatic spin waves (MSWs) in magnetic dielectrics are perspective candidates for various applications including data processing, spin wave logic and quantum information. They can propagate hundreds of microns, some have nonreciprocal character and can be localized near the film interfaces. Excitation of MSWs by fs-laser pulses is beneficial since it provides local excitation and tunability. We demonstrate a method for the optical pumping of MSWs due to the inverse Faraday effect in magnetic dielectrics. Its essence is in the excitation with a nonuniform distribution of the optical power through the film depth and in optimization of the pump beam size. Propagation of the spin waves is demonstrated by detecting the magnetization dynamics tens microns away from the excitation spot. Variation of the pump beam diameter allows tuning between different types of the excited spin waves.

1. Introduction
Magnonics deals with manipulation and control of spin waves that are very promising for information and image processing since spin wave amplitude and phase can be manipulated with relatively low powers. Magnetostatic surface spin waves (MSSWs) demonstrate nonreciprocal propagation [1, 2] and therefore are of prime importance for various applications [1, 3, 4]. Nonreciprocity of the MSSWs appears in relatively thick films so that spin waves have pronounced localization at the interface. A kind of asymmetry between both surfaces of a magnetic film should be present. In the case of magnetic dielectrics the nonreciprocity effect is manifested if one of the film surfaces is metallized. The metallic cover suppresses magnetic field of the MSSW localized at the metal/dielectric interface and thus influences its properties. In some cases, the nonreciprocal behavior is due to the excitation method [2]. Initially optical excitation and control over the magnetostatic spin waves has been reported for backward volume magnetostatic spin wave (BVMSW) patterns [5]. Possibility to optically excite different types of spin waves [6] is crucial for specific applications.

Here we demonstrate a method for the optical generation of the MSWs in magnetic dielectric films and tuning between different MSW types. A method is based on creation of a nonuniform distribution of the circularly polarized optical field through the film depth and on optimization of the pump beam size. In contrast to the spin waves conventionally excited by a microwave field, laser pulses allow local generation of MSWs.

2. Materials and methods
Epitaxial films of various iron garnet compounds have been studied. The average thickness of the films was 4 μm. However magnetostatic spin waves were also registered in the samples with the thickness below 1 μm. The magnetostatic spin waves were excited and detected in the two-color pump-probe experiment using optical pumping by femtosecond laser pulses with duration of 200 fs (Newport Mai Tai HP Ti:Sapphire laser, 80.68 MHz repetition rate combined with Spectra-Physics Inspire Auto 100 optical parametric oscillator) at wavelength of λ = 545 nm (2.28 eV). Variations in the out-of-plane magnetization component caused by the excited magnetization precession in an external magnetic field were detected by the Faraday rotation of the linearly polarized probe beam at λ = 821 nm (1.51eV) that

illuminated the sample at some time delay with respect to the pump beam. Delay line is based on the retroreflector mounted on the linear stage (Newport IMS-500). The time delay between pump and probe pulses was varied from -0.5 to 2.6 ns, where zero time delay corresponds to the simultaneous propagation of the pump and probe pulses through the sample. The bias magnetic field of 100 mT was applied along x-axis (The sample surface is in x-y plane). The probe beam can be spatially separated from the pump beam in order to study the spin wave propagation. The Faraday rotation, θ, was measured with a balanced diode detector using a lock-in technique at a reference frequency of 46 kHz.

3. Results

Figure 1 demonstrates the artistic representation of the experimental technique that was used to study the propagating MSWs. Optical excitation can result in generation of different types of MSWs. Depending on the bias magnetic field direction several types and combinations of

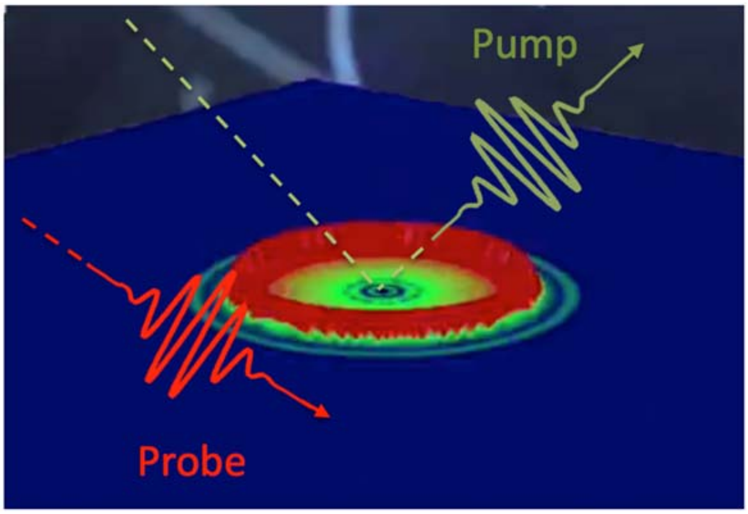

Figure 1. Artistic representation of the spin wave propagation in the iron garnet film induced by the excitation with the pump laser beam (circular polarization). The probing is performed in spatially different location with another laser beam.

MSWs can be excited, i.e. BVMSW, MSSW, and forward volume magnetostatic spin waves (FVMSW). In our experiment the bias magnetic field was applied within the sample surface, which rendered only two possible MSW types: BVMSWs and MSSWs. Time-resolved Faraday rotation signals (Figure 2 a, b) demonstrate the evolution of the magnetization precession depending on the distance between pump and probe spots. The shift of the probe beam results in decrease of the signal intensity, however, the magnetization precession can be detected on the distances larger than 25 μm. One can notice the beating behavior from the curves shape, which is due to the existence of several spectral components. Frequencies of the spectral components depend on the pump beam diameter (Figure 3). Increase of the pump diameter diminishes frequency of the high-frequency mode and increases frequency of the low-frequency mode. Along with that, adjustment of the optical power distribution across the sample volume allows modifying the ratio between the excited BVMSWs and MSSWs. Variation of the pump beam diameter allows gaining additional control and results in tuning possibility between two types of MSWs in our experimental configuration. The propagation pattern of spin waves depends on the direction of the bias field. Moving the bias magnetic field out of the sample surface can result in the excitation of other wave types combination: FVMSWs and BVMSWs.

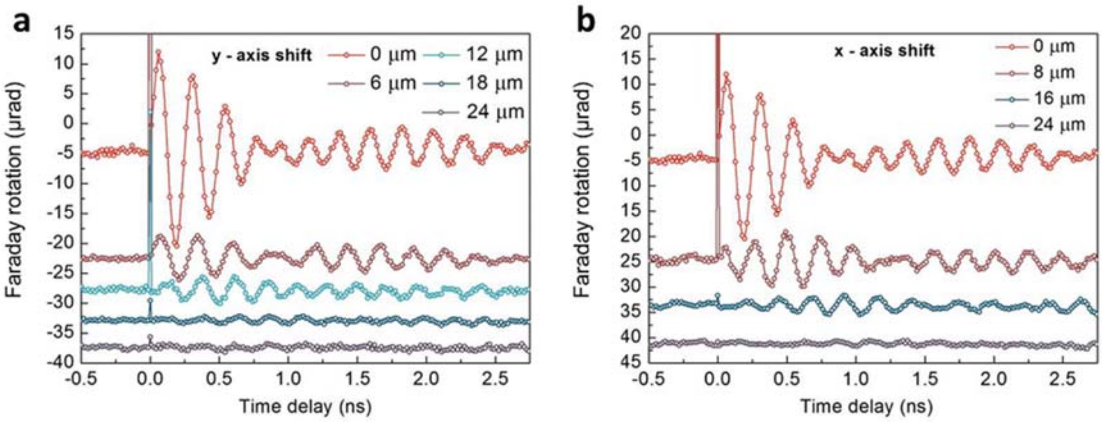

Figure 2. Time-resolved Faraday rotation signals produced by optically excited spin waves in the sample of rare-earth iron garnet with Bi ions and observed at different distances between pump and probe spots: 0, 6, 8, 12, 16, 18 and 24 μm. The pump beam is shifted with respect to the probe along y-axis, i.e. perpendicular to the bias magnetic field **(a)**, or along x-axis, i.e. parallel to the bias magnetic field **(b)**. The composition of the epitaxial film is $Bi_{0.8}Lu_{2.2}Fe_5O_{12}$.

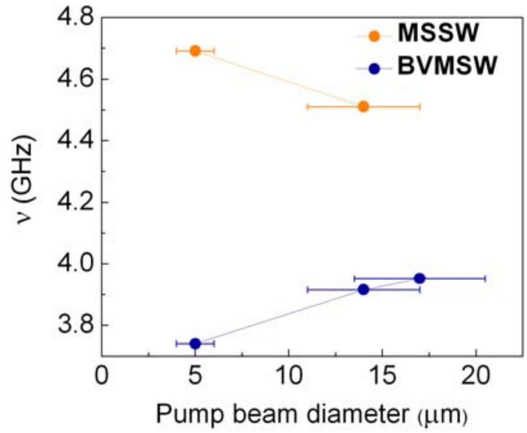

Figure 3. Dependence of the MSSW and BVMSW frequency on the pump beam diameter.

4. Conclusions

In this work we demonstrate local optical generation of the MSWs in magnetic dielectrics, i.e. in thin epitaxial films of rare earth iron garnet, by illuminating the sample with circularly polarized laser pulses at the wavelengths corresponding to moderate optical absorption. Tuning between several types of MSWs can be performed via changing the pump beam diameter. The optical losses provide asymmetric in depth distribution of the optical energy that is a key factor in the MSWs generation. Optical impact on the magnetization state in our experiments is due to the inverse Faraday effect, which may nonlinearly depend on the pump fluence [7]. Optical pumping provides rather broad tunability of the spin waves in frequencies and relative amplitude. Thus, variation of the pump beam diameter by several times allows to excite MSSWs together with BVMSWs or to switch off one of the contributions. As a result, it provides different space distribution of the magnetization dynamics inside the magnetic film.

Selective excitation of the exact MSW type can be performed, including MSSWs. The nonreciprocal character of the MSSWs makes such spin waves valuable in respect to their applications for logic devices, data processing and storage, quantum calculations. Optical excitation of MSWs provides the way to locally probe the magnetic properties of thin and layered materials [8].

Acknowledgements
This work is supported by Russian President Grant (Project No. MD-1615.2017.2).

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