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Magnetoplasmonic crystals for detection of short wavelength spin waves

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Abstract. Presently the coherent excitation of spin ensembles using plasmonic structures is of prime research importance since it potentially can expand the functionalities of magnonics. Optical visualisation of spin waves of small wavelengths (50 - 300 nm) is not possible by light due to the diffraction limit. However, plasmonic gratings allow it. In this work, gold gratings on magnetic films are investigated, and the optical properties of the plasmonic crystals were studied by simulations and experiments of the transmittance and magneto-optical effects.

1. Introduction

To date, the latest achievements of science and technology have led to the possibility of creating new functional magnetic structures of various design, which have modified optical properties, with characteristic dimensions in the order of several tens of nanometers. Such nanostructures allow control the characteristics of optical radiation at a scale smaller than the wavelength of light. The effectiveness of this control is achieved mainly by nanostructuring materials [1], which enables to create a medium with predetermined optical properties and enhance the optical and magneto-optical effects by only optimizing the geometric structure.

2. Plasmonic grating of the subwave period

Magnetostatic spin waves are waves of magnetization in a continuous magnetic medium having a rather wide range of wavelengths. Of special interest for modern quantum and magnon technologies are spin waves, in which the wavelength is less than 1 micron. Such waves can be detected using a grid of microwires [2], using the effect of electromagnetic induction. However, this method is not always convenient, since it does not allow rearranging the grating properties and changing the sensitivity to spin waves of different types and different spectral ranges. Therefore, a more promising method of excitation and detection is a magneto-optical method based on recording the precession of magnetization due to the magneto-optical Faraday effect and the transverse Kerr effect. However, this method has a spatial resolution constraint associated with the diffraction limit, because of which registration of spin waves with a submicron wavelength is difficult to perform. In this work we present a method for solving such a problem by using a plasmonic grating deposited on a magnetic dielectric in which spin waves propagate. The excitation of plasmonic resonances leads to an increase in the sensitivity of the magneto-optical technique and can make it possible to record spin waves whose wavelength is much less than the diffraction limit.

Electromagnetic simulations of the optical properties of the structure in the presence of a spin wave was carried out by the method of rigorous coupled-wave analysis (RCWA), adapted for the case when the gyration vector proportional to the magnetization vector and specifying the off-diagonal components of the permittivity tensor changes laterally in space according to a harmonic law. In this case, the period of the structure is a multiple of the period of gyration variation in space and the corresponding directions of the periodicity coincide. The direction of the gyration vector can be arbitrary, which makes it possible to calculate the magneto-optical effects in any configuration.

Due to the plasmonic grating, waveguide modes and surface plasmon polaritons are excited in the structure under consideration, which leads to resonances in the transmission spectra, the Faraday angle, and the magneto-optical transverse Kerr effect. Resonances in these spectra are optimized by selecting the parameters of the grating: the height, the width of the air gap and the period.

The dependencies of the angle Faraday and the transverse Kerr effect at a fixed resonance wavelength on the relative position of the slit and the maximum of the gyration demonstrate a harmonic appearance analogous to the dependence of the gyration in the film on the coordinate. Moreover, the extrema of these dependences of the Faraday angle and the transverse Kerr effect arise when the extremum of the gyration coincides with the center of the gap. With increasing k waves number, that is, with an increase in the number of spin wavelengths within the gold grating period, the value of magneto-optical effects decreases, that is, the recording of shorter spin waves is limited by the sensitivity level of the spectrometer or detector.

The investigations carried out show that when spin waves propagate through a magnetic film with a plasmonic coating, precession of the magnetization can be recorded by measuring the dependence of the Faraday angle or the transverse Kerr effect on time. At the same time, when observed at a wavelength corresponding to the resonance of the magneto-optical effect, the amplitude of the detected signal in the plasmonic crystal exceeds by more than 10 times the amplitude of the signal when viewed with a focused laser beam in a magnetic film without plasmonic coating.

Thus, it has been demonstrated that the application of a plasmonic coating to a magnetic film makes it possible to obtain information about the amplitude, wavelength, and frequency of the spin wave propagating in the material much more effectively by a magneto-optical method. It is important to note that there is no need to focus the laser beam into a spot close to the diffraction limit, which greatly simplifies the experimental procedure.

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