Tunable optical addressing of layers in GdFeCo bilayer structure

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Abstract. We show the possibility of tunable optical addressing of layers in GdFeCo bilayer structure supporting surface plasmon polariton excitation. In this case the energy of the TM-polarized incident laser pulse is absorbed mainly in the bottom layer, where surface plasmon is excited. At the same time, TE-polarized pulse experiences total internal reflection and is absorbed mainly in the top layer of the structure. This makes it possible to observe optically-induced magnetization reversal only in one certain layer of GdFeCo bilayer structure determined by the polarization of the pump laser pulse. For the optical probing of the layer magnetization state one can use layer-sensitive polar magnetooptical Kerr technique. It is based on the effect of the zero magnetooptical polar Kerr response of the magnetized layer at certain wavelengths and angles which are different for the two GdFeCo layers of the structure. So probing at two different wavelengths or angles provides us with the information about two different layers individually. Thus the proposed scheme makes it possible to pump and to probe two layers in the GdFeCo bilayer structure independently.

1. Introduction
Nowadays all-optical control of the magnetic state of a medium via femtosecond laser pulses is rapidly developing research area in modern magnetism [1]. It was shown how the magnetization state of ferrimagnetic rare earth transition-metal alloys can be switched by circularly polarized femtosecond laser pulses [2]. Moreover, all-optical helicity-dependent magnetization switching was demonstrated in GdFeCo near its magnetization compensation temperature [3]. The field of magnetization dynamics studies of magnetic multilayers engineered for all-optical switching is also rapidly developing. Recently is was demonstrated how the magnetization dynamics of the individual layer of the multilayered heterostructure can be measured using the layer-sensitive magnetooptical Kerr effect technique [4]. However, the possibility to concentrate the pump-laser energy only in one layer of the multilayered heterostructure and thus to perform switching of the magnetization of individual layer was not discussed before.

We study the bilayered structure with two thin GdFeCo layers separated by the dielectric and show how we can address an individual layer of the structure which means that the energy of the pump laser pulse is absorbed mainly in one layer and how we can switch the layer we address by pump polarization switching.
2. Addressing of a single layer in bilayered structure by pump and by probe

We consider the following structure. Two 10-nm GdFeCo layers separated by a 40-nm layer of Si$_3$N$_4$ are deposited on ZnSe prism. To prevent the structure from the oxidation, the bottom GdFeCo layer is covered with 60-nm thick Si$_3$N$_4$ layer. Using prism with high refractive index allows us to reach total internal reflection conditions at the bottom surface of the structure for both TM and TE polarizations. Due to the presence of the metallic layers light energy in this case is partially absorbed, mainly in the top GdFeCo layer. On the other hand, this structure supports TM-polarized surface plasmon polariton (SPP) excitation at the bottom GdFeCo layer surface. In this case the incident light energy is absorbed mainly in the bottom GdFeCo layer. Therefore the change of the polarization of the incident light allows us to control the layer in which the laser energy is mainly absorbed.

We can smoothly tune the amount of energy absorbed in the top and the bottom layers of the structure by the means of variation of the angle of incidence both in TE and TM polarizations. Thus we can design the configuration described above, where switching between the TE and TM polarizations leads to the symmetrical switching of the absorption in both layers. Numerical simulations show that for incident angle of 45° inside of the ZnSe prism at the operating wavelength of 700 nm for the TE-polarized incident pump pulse the absorption is $A_{TE}^t = 52\%$ for the top layer, $A_{TE}^b = 22\%$ for the bottom layer, and for the TM-polarized pulse $A_{TM}^t = 22\%$ and $A_{TM}^b = 52\%$.

Optically-induced magnetization reversal in GdFeCo is a threshold effect observed for the incident light fluence above $F_0 = 2\,mJ/cm^2$ [3]. Therefore by illuminating the structure with the pump pulses of different polarizations having the fluence, for example, $2.5\cdot F_0$ we will address the particular layer of the structure. The light fluence inside of GdFeCo layers can be estimated for TE-polarized pump as $F_{TE}^t = 1.3F_0$ for the top layer, $F_{TE}^b = 0.55F_0$ for the bottom layer, and for the TM-polarized pump $F_{TM}^t = 0.55F_0$ and $F_{TM}^b = 1.3F_0$. Thus TE-polarized pump addresses and induces magnetization reversal in the top layer of the structure, while the TM-polarized pump addresses the bottom layer.

In order to observe the response from the two layers individually one can use the layer-sensitive magnetooptical Kerr effect technique described in [4]. It is based on the fact that the magnitude of the polar Kerr effect of the finite-width layer depends on its width, and also on the refractive indices and widths of the surrounding layers as well. It can be easily understood since in polar configuration the measured polarization rotation actually is the sum of the ”true” polar Kerr rotation that is observed in reflectance from a semi-infinite magnetized medium and Faraday rotation that occurs while light is transmitted through the layers of the structure and partially is reflected back. At the certain wavelengths and angles the observed polarization rotation (which is the sum of the ”true” polar Kerr effect and Faraday effect) of the reflected light from the magnetized layer becomes zero despite of the non-zero gyration. Under this conditions the polarization rotation of the reflected probe pulse is determined only by the magnetization state of the other GdFeCo layer of the structure. Thus probing at two different wavelengths or angles provides us with the information about two different layers individually.

Therefore the presented approach makes it possible to pump and to probe two layers in the GdFeCo bilayer structure independently.

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