Supporting Information: Magneto-optical response enhanced by Mie resonances in nanoantennas

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Measurements of the magneto-optical response

In order to check the best experimental conditions, we measured the magneto-optical response as a function of the applied external magnetic field. For experimental studies we used a sample comprises an array of silicon nanodisks with a disk diameter of $d = 340$ nm, a height of $h = 220$ nm, and a period $a = 830$ nm, covered with a 5-nm-thick Ni film.

For magneto-optical measurements, we used the same experimental setup as described in the main text. The wavelength was fixed and equal to 685 nm, due to the excitation of the magnetic dipole Mie resonance in a single silicon nanodisk.

The magnitude of the external alternating magnetic field ($f = 117$ Hz) was varied from 100-Oe to 550-Oe. The external magnetic field was produced by a Helmholtz coil and the value of the magnetic field increased with the coil current. The magnitude of the external

magnetic field was measured at the midpoint between the coils by AlphaLab Laboratory gauss-meter Model GM2. The frequency 117 Hz of the magnetic field was chosen in order to eliminate the impact of system's own mechanical resonance. The orientation of the external magnetic field was perpendicular to the wave vector of the incident light.

The relationship between the applied field and the magneto-optical response should not be considered as a hysteresis loop. Because we used alternating magnetic field in the experiment, at each time $(T(+H) + T(-H))/2$ were measured. The dependence of the magneto-optical response on the applied magnetic field trace out a curve, shown in Fig. S1.

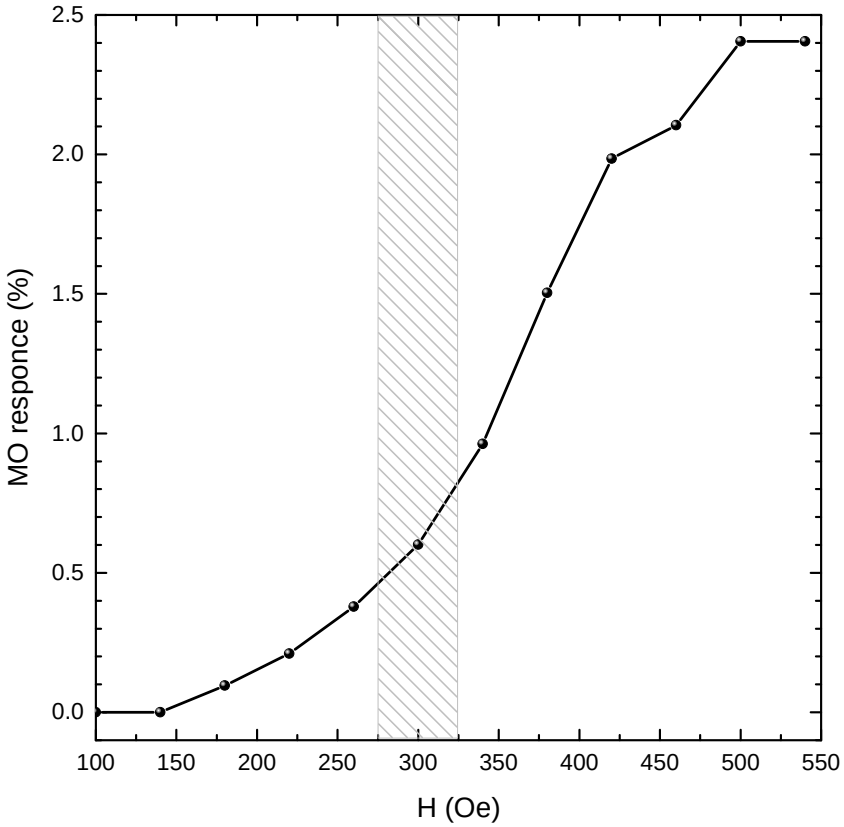

Figure S1: Dependence of the experimental magneto-optical response on the applied external magnetic field.

Numerical simulations

First of all, the transmittance spectrum is calculated in the case of an absent external magnetic field. Next, the calculation of the magneto-optical phenomena in Lumerical FDTD Solutions requires three pre-steps to be done.[1]

- The first one is a creation of anisotropic material. According to the experiment, we simulate a geometry when the magnetization vector is in the plane of the sample and perpendicular to the polarization of the incoming light. In our simulation, the incident plane wave propagates at normal incidence, Z axis. The radiation is polarized in Y direction. So, the magnetization vector is in X direction. The external magnetic field makes the permittivity tensor of nickel non-diagonal:

$$\hat{\varepsilon} = \begin{pmatrix} \varepsilon & 0 & 0 \\ 0 & \varepsilon & ig \\ 0 & -ig & \varepsilon \end{pmatrix}. \tag{S1}$$

  Here, ε is a permittivity and g is a gyration vector. The dispersrion of nickel was taken into account during the simulations for both ε and g.[2]

  However, the anisotropy material in the software must be added as a diagonal matrix. Diagonalization requires eigenvalues and the unitary transformation that makes the permittivity tensor diagonal:

$$\varepsilon_{\text{diag}} = U\varepsilon U^{\dagger}, \tag{S2}$$

  where U is a unitary matrix, $U^{\dagger} = U^{-1}$ is the complex conjugate transpose of U and $\varepsilon_{\text{diag}}$ is diagonal. $\varepsilon_{\text{diag}}$ should be added to the material base of the software.

- The second step is a transformation of field components. This step is realized by inserting a grid attribute object, called matrix transformation. The user has to define a matrix U that converts the field components from Cartesian coordinates into circularly

polarized fields. In the case of magnetization in X direction, the matrix U is as following:

$$U = \frac{1}{\sqrt{2}} \begin{pmatrix} \sqrt{2} & 0 & 0 \\ 0 & 1 & i \\ 0 & 1 & -i \end{pmatrix} \tag{S3}$$

- The final step is a connection between a geometry object in a model and the created anisotropic material. The user has to fill in the parameter "grid attribute name" in properties of a geometric object.

Next, the transmittance spectrum is calculated in case of applying the external magnetic field. The numerical MO response, shown in the main text of the manuscript, is defined by the formula $2 \cdot [T(H) - T(0)]/T(0)$, where $T(H)$ and $T(0)$ is the spectral dependencies of transmittance in case of applied and absent external magnetic field, respectively.

Comparison of magneto-optical responses stimulated by magnetic and electric dipole resonances

It has been shown in a plenty of recent publications that optical Mie-type resonances of high-index dielectric nanostructures can strongly concentrate light energy at the subwavelength scale. It is also known that magneto-optical effects can be enhanced due to the light field localization in the magnetic medium. So one can assume that any kind of Mie-type resonance in high-index dielectric nanoparticles can lead to the significant enhancement of the magneto-optical effects simply due to the strong field localization. In order to check this idea we perform numerical calculations with Lumercial FDTD solutions software for the array of silicon nanodisks, covered with 5-nm Ni film. We design our structure in the way that electric and magnetic dipole resonances of the nanodisks were in the same spectral region. We will further show that the magneto-optical effect enhancement caused by the magnetic dipole resonance excitation several times stronger than in the vicinity of the electric dipole

resonance. To achieve spectrally discernible dipole magnetic and electric resonances of approximately similar Q-factor we considered structure resembling to investigated in the main work. Subdiffractional array is organized by 220-nm-thick silicon nanodisks with diameter of 275 nm and inter-particle distance of 200 nm. Disks are covered with 5-nm-thick nickel film. The metasufrace is embedded into a dielectric environment with n =1.5. The transmission, the spectral derivative of the transmittance $dT/d\lambda$ and MO response spectra shown in Fig. S2(a), (b).

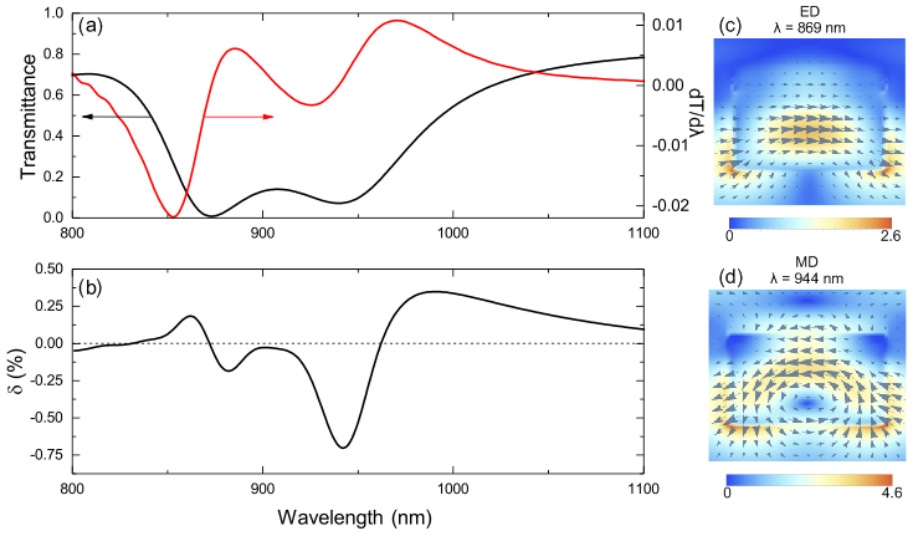

Figure S2: (a) Optical transmittance (black curve) and its derivative (red curve) spectra. (b) Magneto-optical spectrum of the model. (c)-(d) Local electric field distributions in YZ plane for x equals to half of disk diameter (c) for the electric dipole resonance ($\lambda = 870$ nm) (d) and for the magnetic dipole resonance ($\lambda = 944$ nm) of the nanoparticles.

Despite the fact that amplification of the local electric and magnetic fields in the region of magnetic and electric dipole resonances is comparable in magnitude, and also the slope of the resonance curve (see Fig. S2) in the vicinity of the electric dipole resonance exceeds the slope for the magnetic dipole resonance, the enhancement of the magneto-optical response is several times larger in the region of magnetic dipole resonance in comparison with the electric one. These results demonstrate, that magneto-optical effects are not only driven by the simple local field concentration in the nano-resonators, but also depend on the mode character. These statement also has been previously reported in one of the recent works.[3]

Nickel film contribution to the absorption of the structure.

With the aim of confirming the high efficiency and low losses of the considering structure we performed numerical calculation of the absorption coefficient for both structure under study and all-dielectric structure without Ni film. The optical response of the sample is calculated by using the finite-difference time-domain method in the Lumerical FDTD Solutions software. In order to achieve the absorption spectrum of the all-dielectric structure, we model an array of silicon disks placed on a semi-infinite glass substrate. For sample under study we model an array of the same (as for all-dielectric structure) silicon disks covered with a 5-nm-thick Ni film and placed on a semi-infinite glass substrate. The calculated transmittance and reflectance spectra is normalized to the power of the plane wave source. The absorption spectrum is defined as following: $A(\lambda) = 1 - (T(\lambda) + R(\lambda))$, where A is the absorption, T is the transmitance and R is the reflection. The calculated absorption spectra are shown in Fig. S3. It can be noted that for the case of silicon nanodisks with the 5nm-thin Ni

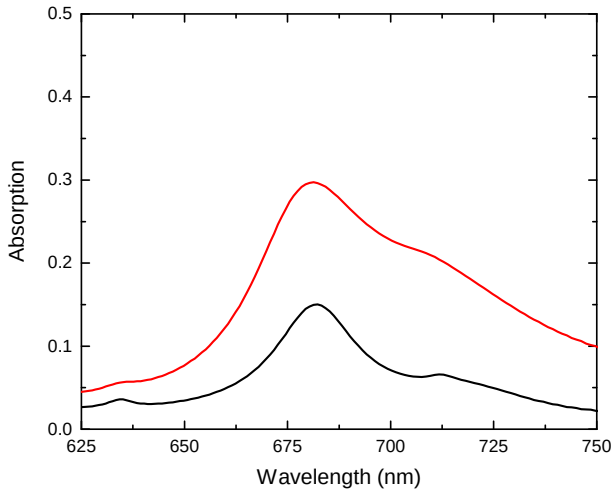

Figure S3: Absorption spectra for all-dielectric structure without Ni film (black curve) and for the sample under study (red curve).

film the absorption increases only by 10-15 % in comparison with the structure without Ni

film, which is not essential for most cases. It is still much less than in the case of metallic nanostructures.

Comparison of magneto-optical responses of the structure in case of garnet and nickel films.

Being a ferromagnetic metal, nickel possesses stronger magnetic response (and magneto-optical as well) comparing to ferrimagnetic garnet materials. We carried out the numerical simulations for the structure under study (an array of silicon disks placed on a semi-infinite glass substrate), where the 5-nm-thick nickel film replaced with the 5-nm-thick yttrium iron garnet film. The MO response for Si-YIG structure is only 0.00075% (see Fig. S4), which is 65 times smaller than for Si-Ni structure. Moreover YIG films must be annealed under high

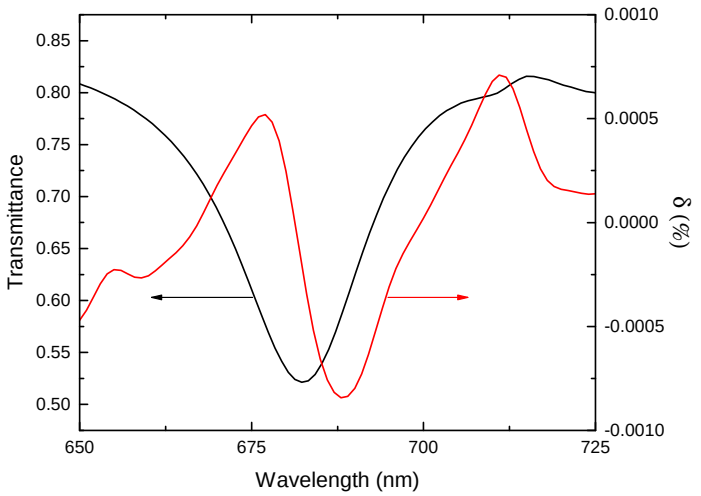

Figure S4: Transmittance (black curve) and magneto-optical response (red curve) of the sample, where 5-nm-thick Ni film replaced with 5-nm-thick YIG film. Other parameters are the same as in the main text.

temperatures (> 750°C) to become magneto-optically active. Although the melting point of silicon is 1440°C one cannot be sure, that nanostructured a-Si disks will be not affected by such influence. It can be predicted that complex refractive index of a-Si will be changed

under thermal impact leading to the shift of the position of the magnetic dipole resonance. The reason for that is the shift of the optical band-gap after annealing process of a-Si. [4] As we mentioned in the "Methods" section, the nickel film was deposited by magnetron sputtering. According to the literature, there is no phase transition of Ni to nickel monosilicide (NiSi) up to temperatures of 250°C .[5]

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