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Magnetoplasmonic crystals based on commercial digital discs

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Transversal magneto-optical Kerr effect (TKE) controlled by surface plasmon-polariton resonances is studied in nickel and combined silver/nickel magnetoplasmonic crystals fabricated on the base of commercial digital discs with periods of 320 nm, 740 nm, and 1500 nm. Wood's anomaly is observed in visible and near IR spectral ranges due to fulfilment of phase-matching conditions between surface plasmons and −1, −2, and +1 diffraction orders for the samples with these periods, respectively. Strong asymmetrical Fano-shape resonances are observed in TKE spectra in the vicinity of surface plasmons' resonances. © *2013 AIP Publishing LLC* [http://dx.doi.org/10.1063/1.4801525]

I. INTRODUCTION

Small values of magneto-optical effects strongly restrict their practical applications. Several topics of photonic researches are targeted on the enhancement of magneto-optical response by nanostructuring of magnetic materials. One of them is a magnetophotonic crystal approach, which allows one to enhance magneto-optical Faraday or Kerr effects at the edge of photonic band gap or at the microcavity mode.[1–3] Recently, magneto-optical effects' enhancement was also observed in different types of magnetoplasmonic nanostructures utilizing both local and propagating surface plasmons.[4–10] Magnetoplasmonic nanostructures represent a special class of plasmonic nanostructures fabricated from magnetic metals, for example, from nickel, cobalt, iron or from composites of magnetic materials and noble metals.[4–10] Such structures possess simultaneously magneto-optical activity and surface plasmon-polaritons' (SPPs) resonances. Enhancement of magneto-optical effects appears in the narrow spectral range of SPP resonances and makes these structures attractive for various applications. Development of novel magnetoplasmonic nanostructures for practical applications requires cheap, macroscale, and universal plasmonic platform representing periodic subwavelength metal structures. One of the examples of such commercial structures is digital discs. The surface of digital disc under protective layer represents a set of periodic spiral data tracks, which can be used as templates for fabrication of macroscale magnetoplasmonic nanostructures by deposition of magnetic metals onto uncovered digital discs.

In this work, transversal magneto-optical Kerr effect (TKE) in one-dimensional (1D) magnetoplasmonic crystals based on commercial digital discs is studied. Samples of 1D magnetoplasmonic crystals represent periodic nickel and silver/nickel grooves at the metal surface.

II. SAMPLES

The samples of magnetoplasmonic crystals were fabricated by using polymer templates of commercial digital discs. The polymer spiral gratings inside the Blu-ray disc (BD), DVD, and CD have declared periods of 320, 740, and 1600 nm, respectively. First, protective layer of the digital discs' surface was mechanically removed. Then, metals (silver or nickel) were sputtered on the residual polymer gratings by ionic-plasma deposition. Nickel magnetoplasmonic crystals were fabricated using BD and CD by sputtering the 100-nm-thick nickel films on polymer gratings. The silver/nickel nanostructures were fabricated by sputtering the 100-nm-thick silver and the 5-nm-thick nickel films on BD and DVD. Spatial profiles of the samples obtained by atomic-force microscopy (AFM) are shown in Fig. 1. The obtained periods d of the samples are equal to (320 ± 20), (740 ± 50), and (1500 ± 100) nm and profile heights h are approximately equal to $\simeq 15$, $\simeq 100$, and $\simeq 100$ nm for BD, DVD, and CD, respectively. The profiles have non-sinusoidal shape, which leads to multiple harmonics in spatial Fourier spectra. Magnetic properties of studied samples were measured by vibrating sample magnetometer. Saturated magnetic field strength appears to be below $H = 500$ Oe for in-plane direction for all samples.

III. RESULTS AND DISCUSSION

All measurements of reflection and TKE spectra were carried out in the p-polarization (polarization of the incident light was in the incident plane). Halogen lamp with a monochromator was used as a light source, and a photomultiplier tube with a lock-in amplifier was used as detector. The TKE spectra were measured by using a saturated external AC magnetic field oscillating at the frequency of 75 Hz with the amplitude of $H = 600$ Oe. Magnetic field was oriented in the sample plane and perpendicular to the plane of incidence. The TKE value was defined as $\delta = (R(^{+}H) - R(^{-}H))/(R(0))$. The excitation of surface plasmons at the surface of metallic grating requires fulfilment of phase-matching conditions between the incident electromagnetic wave and the propagating SPP written as follows: $\mathbf{k}_{spp} = \mathbf{k}_x + n\mathbf{g}$, where $\mathbf{k}_{spp}$ and $\mathbf{k}_x$ are SPP wavevectors and projection of the incident radiation wavevector onto metal surface, respectively, $\mathbf{g}$ is reciprocal vector and n is an integer. The excitation of surface plasmons in this case is observed as the

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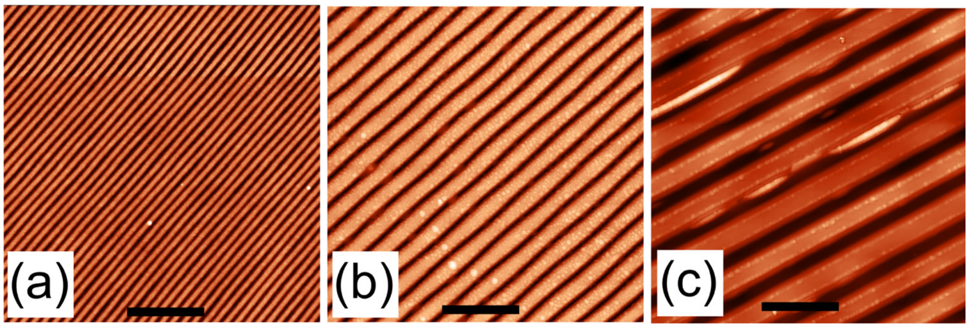

FIG. 1. (a) The AFM image of nickel magnetoplasmonic crystal based on BD with the period of $d = 320$ nm. (b) The AFM image of silver/nickel magnetoplasmonic crystal based on DVD with the period of $d = 740$ nm. (c) The AFM image of nickel magnetoplasmonic crystal based on CD with the period of $d = 1500$ nm. Scale bars are 2 μm.

specular reflection minimum of *p*-polarized light called as Wood's anomaly. Reflection and TKE spectra of BD-based nickel and silver/nickel samples are shown in Fig. 2. The minima in reflection spectra in the vicinity of $\lambda = 620$ nm show spectral ranges of SPP resonances corresponding to the fulfillment of the phase-matching condition involving the -1st diffraction order. Spectral width of the Wood's anomalies for the silver/nickel sample is smaller in comparison with the pure nickel case because the propagation length of plasmons at the silver/nickel surface, being $L_{spp} \simeq 20\,\mu$m at $\lambda = 600$ nm, significantly exceeds $L_{spp} \simeq 2\,\mu$m at the nickel surface. The spectral dependences of TKE have strong asymmetrical Fano-type lineshape showing enhancement of TKE in the narrow spectral range. The TKE modulation at the SPP resonance achieves the value of $\Delta\delta \simeq 0.01$ for both samples. The spectral width of the TKE resonance between maximum and minimum is $\Delta\lambda = 6$ nm, which corresponds to the relative energy interval of $\Delta\omega/\omega_{spp} = \Delta\lambda/\lambda_{spp} \sim 10^{-2}$. For silver/nickel magnetoplasmonic crystals, the derivative of TKE spectrum at the resonance achieves the value of $d\delta/d\lambda = 1.5 \times 10^{-3}\,\mathrm{nm}^{-1}$ where TKE is one order of magnitude larger in comparison with plain silver/nickel film.

Reflection and TKE spectra of DVD-based silver/nickel magnetoplasmonic crystals measured at different angles of incidence are shown in Fig. 3. Contrary to the BD case, the reflection spectra have the Fano shape in the vicinity of SPP resonances excited under phase-matching conditions corresponding to the -2nd diffraction order. The TKE modulation in the vicinity of the SPP resonance is increased under increasing the angle of incidence due to the increase of the efficiency of the light coupling to SPPs. The difference between maximum and minimum of TKE at the SPP resonance achieves the value of $\delta = 8 \times 10^{-3}$ at $\theta = 65°$ that is one order of magnitude larger than that of the plain silver/nickel film but less than for the BD-based silver/nickel

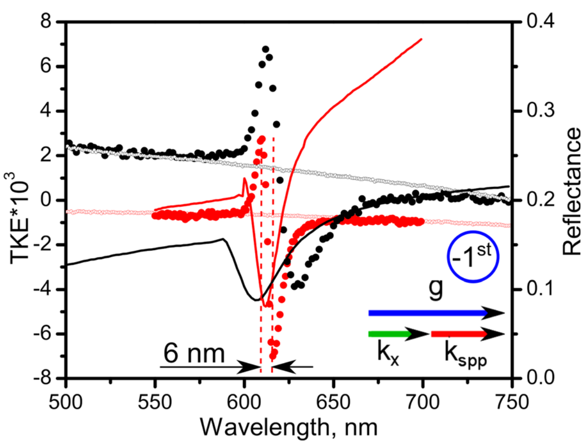

FIG. 2. Reflection (solid curves) and TKE (filled circles) spectra measured at the angle of incidence $\theta = 60°$ for nickel (black color) and silver/nickel (red color) magnetoplasmonic crystals with the period of $d = 320$ nm. Reference TKE spectra of plain nickel and silver/nickel films measured under the same conditions are shown by open circles. The SPP excitation condition for the case of the -1st diffraction order is schematically shown in the sketch.

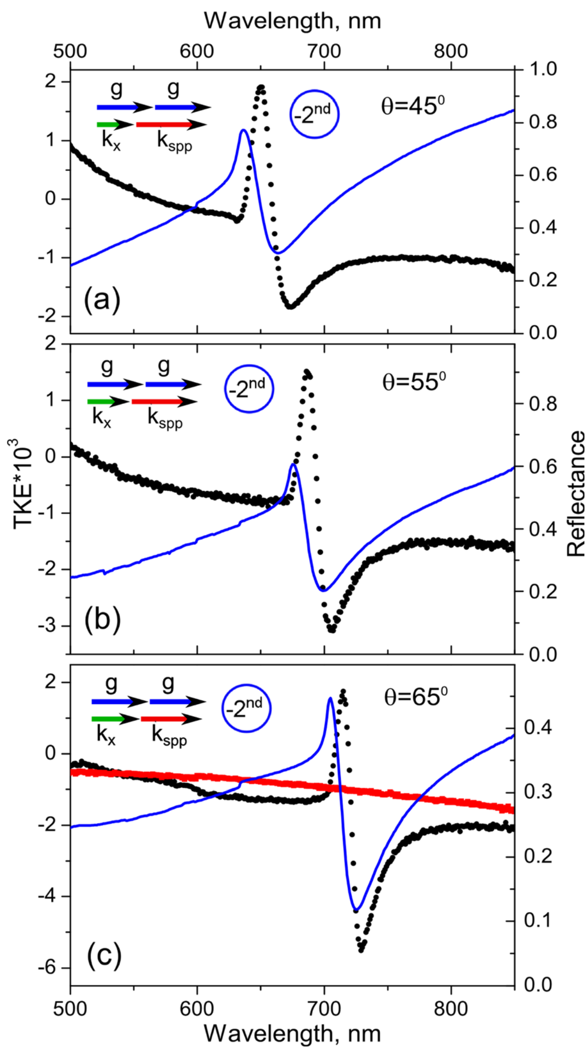

FIG. 3. Reflection (solid curve) and TKE (circles) spectra measured at different angles of incidence θ for the silver/nickel magnetoplasmonic crystal with the period of $d = 740$ nm. (a) $\theta = 45°$, (b) $\theta = 55°$, and (c) $\theta = 65°$. Reference TKE spectrum of the plain nickel/silver film at $\theta = 65°$ is shown by squares. The SPP excitation conditions for the case of the -2nd diffraction order are shown in the sketches.

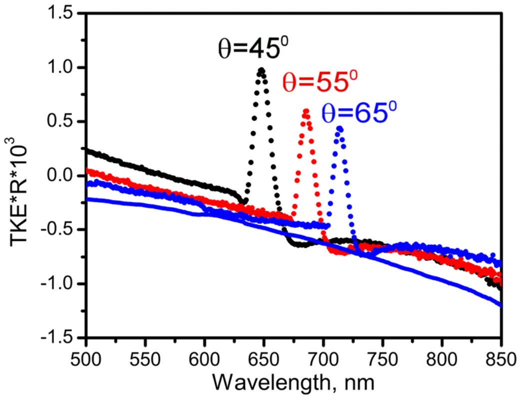

FIG. 4. Spectral dependences of magneto-optical activity $\Delta R = \delta \cdot R$ measured for the nickel/silver magnetoplasmonic crystal with $d = 740$ nm at different angles of incidence. The spectrum of magneto-optical activity for the reference plain nickel/silver film measured at $\theta = 65°$ is shown by solid curve.

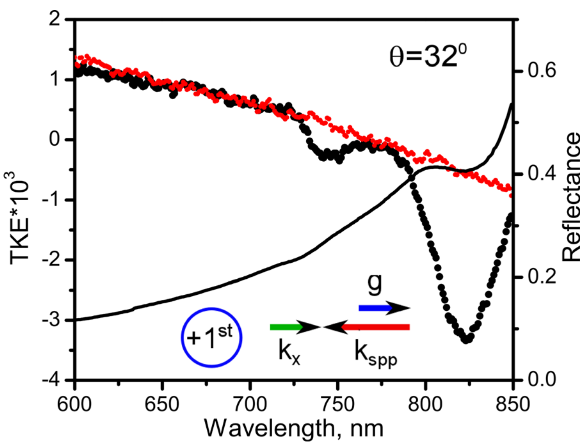

FIG. 5. Reflection (solid curve) and TKE (circles) spectra for nickel magnetoplasmonic crystals with the period of $d = 1500$ nm and for the plain nickel film measured at $\theta = 32°$. The SPP excitation condition for the case of the +1st diffraction order is shown in the sketch.

magnetoplasmonic crystals. The spectral derivative of TKE achieves the value of $d\delta/d\lambda = 0.6 \times 10^{-3}\,\text{nm}^{-1}$.

For applications, the value of magneto-optical activity $\Delta R = \delta \cdot R$ is important. This parameter is similar to the figure of merit for the magneto-optical Faraday effect. The spectral dependences of $\Delta R = \delta \cdot R$ for the same samples and conditions as shown in Fig. 3 are depicted in Fig. 4. The ΔR spectra have sharp lineshape in the narrow spectral range of the SPP resonance. The spectral derivative achieves the value of $d(\Delta R)/d\lambda = 10^{-4}\,\text{nm}^{-1}$.

Reflection and TKE spectra of CD-based nickel magnetoplasmonic crystals measured at the angle of incidence $\theta = 32°$ are shown in Fig. 5. In this case, SPP excitation appears under the phase-matching condition corresponding to the +1st diffraction order. The SPP excitation is manifested itself as wide and weak dip around $\lambda = 825$ nm. The TKE spectrum is also resonantly changed in the vicinity of the SPP resonance but TKE value and its derivative are smaller in comparison with BD and DVD based magnetoplasmonic crystals.

In conclusion, nickel and combined silver/nickel magnetoplasmonic crystals based on commercial digital discs are fabricated. Enhancement of transversal Kerr effect and the magneto-optical activity in the narrow spectral range of the SPP excitation is observed. The strongest changing of the TKE value and its spectral derivative at the SPP the resonances are observed for Blu-ray-based silver/nickel sample.

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[1]M. Inoue, R. Fujikawa, A. Baryshev, A. Khanikaev, P. B. Lim, H. Uchida, O. Aktsipetrov, A. Fedyanin, T. Murzina, and A. Granovsky, J. Phys. D: Appl. Phys. **39**, R151 (2006).
[2]M. Inoue, K. Arai, T. Fujii, and M. Abe, J. Appl. Phys. **85**, 5768 (1999).
[3]A. B. Khanikaev, A. B. Baryshev, P. B. Lim, H. Uchida, M. Inoue, A. G. Zhdanov, A. A. Fedyanin, A. I. Maydykovskiy, and O. A. Aktsipetrov, Phys. Rev. B **78**, 193102 (2008).
[4]G. Armelles, A. Cebollada, A. Garcia-Martin, J. M. Garcia-Martin, M. U. Gonzalez, J. B. Gonzalez-Diaz, E. Ferreiro-Vila, and J. F. Torrado, J. Opt. A, Pure Appl. Opt. **11**, 114023 (2009).
[5]A. A. Grunin, A. G. Zhdanov, A. A. Ezhov, E. A. Ganshina, and A. A. Fedyanin, Appl. Phys. Lett. **97**, 261908 (2010).
[6]C. Clavero, K. Yang, J. R. Skuza, and R. A. Lukaszew, Opt. Express **18**, 7743 (2010).
[7]V. I. Belotelov, I. A. Akimov, M. Pohl, V. A. Kotov, S. Kasture, A. S. Vengurlekar, A. V. Gopal, D. R. Yakovlev, A. K. Zvezdin, and M. Bayer, Nat. Nanotechnol. **6**, 370 (2011).
[8]A. A. Grunin, N. A. Sapoletova, K. S. Napolskii, A. A. Eliseev, and A. A. Fedyanin, J. Appl. Phys. **111**, 07A948 (2012).
[9]A. V. Chetvertukhin, A. A. Grunin, A. V. Baryshev, T. V. Dolgova, H. Uchida, M. Inoue, and A. A. Fedyanin, J. Magn. Magn. Mater. **324**, 3516 (2012).
[10]A. V. Chetvertukhin, A. V. Baryshev, H. Uchida, M. Inoue, and A. A. Fedyanin, J. Appl. Phys. **111**, 07A946 (2012).