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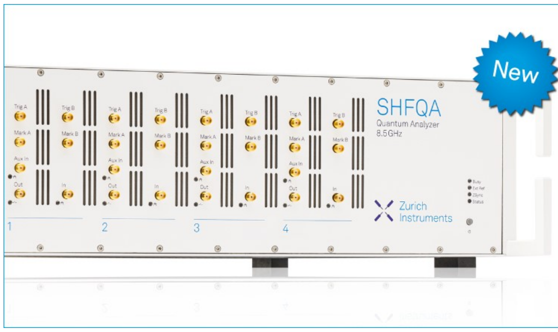

Magneto-Optical Effects in 2D Plasmonic Gratings with Various Types of Ordering

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Abstract. To control light by magnetic field magneto-optical nanostructures can be used. Response of well-known periodical structures is narrowband and depending on light's incident angle. In present work we investigated magneto-optical properties of 2D periodic and quasicrystalline structures. These structures consist of gold grating-patterned layer on top of magnetic dielectric film. We showed that in 2D quasicrystalline structures magnetoplasmonic effects, such as the transverse magneto-optical Kerr effect (TMOKE) and Faraday effect, are broadband. Moreover, their independence of light's polarization and incident angle was demonstrated.

INTRODUCTION

Nanostructured magneto-optical materials that support optical resonances help to efficiently control light using the magnetic field, which can be applied in telecommunication and sensing applications. 1D periodic structures demonstrate a strong dependence of their optical response on light polarization [1-4]. Besides, their resonant character usually leads to a narrowband response. These limitations can be overcome by using 2D plasmonic structures.

Quasicrystals are long-range ordered structures with lack of translational symmetry [5]. In plasmonic quasicrystals – metal-dielectric nanostructures with quasicrystalline pattern – surface plasmon polaritons (SPPs) can be excited [6,7]. Due to dense reciprocal space and the rotational symmetry of quasicrystals, a large number of associated with SPPs modes resonances appear in the structure. As a result, quasicrystalline structures demonstrate a broadband optical response. In addition, optical response of 2D structures doesn't depend on light's polarization [8]. The advantageous feature of quasicrystals is that, compared to periodic and non-periodic structures, it offer a designable broadband optical response [9] due to rich and designable reciprocal lattice.

The multiband resonant transverse magneto-optical Kerr effect (TMOKE) in 1D magnetoplasmonic quasicrystals was demonstrated [10].

Magneto-optical properties of 2D quasicrystalline structures have not been investigated yet. In the present work we research TMOKE and Faraday effect in 2D plasmonic quasicrystals as well as in 2D plasmonic crystals of several types.

EXPERIMENTAL SETUP AND CONSIDERED STRUCTURES

The investigated 2D magnetoplasmonic quasicrystalline structure is formed by a 100 nm /in thick/ golden surface, on top of a 1.6 μm thick bismuth-substituted iron-garnet magnetic dielectric layer on a nonmagnetic substrate.

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To design quasicrystalline pattern of golden film, several 2D periodical arrays of 60 nm dots, with period 600 nm, were superimposed by rotating them with respect to the previous lattices [8]. Gold film was patterned using electron beam lithography and dry etching. Obtained plasmonic quasicrystalline structure has π/5 rotation symmetry.

Magneto-optical spectra of the plasmonic quasicrystal samples were measured by the following experimental setup. A tungsten halogen lamp is used as a light source. After the lamp light passes through the fiber. The light emerging from the fiber was then collimated by an achromatic doublet with a focal length of 300 mm and focused on the sample using a second achromatic doublet with the same focal length. A polarizer (Glan-Taylor prism) is placed between two achromats, which allows to control the polarization of the light incident on the sample. A π/2 phase-shifting plate was located after the polarizer, which made it possible to change the polarization of light without rotating the polarizer in order to prevent the optical path of the beam from shifting while the polarizer was rotating. The light was focused on a sample in a spot with a diameter of about 200 μm. To carry out measurements at different angles of light's incidence, the sample was mounted on a special holder that provides rotation in the plane of the sample.

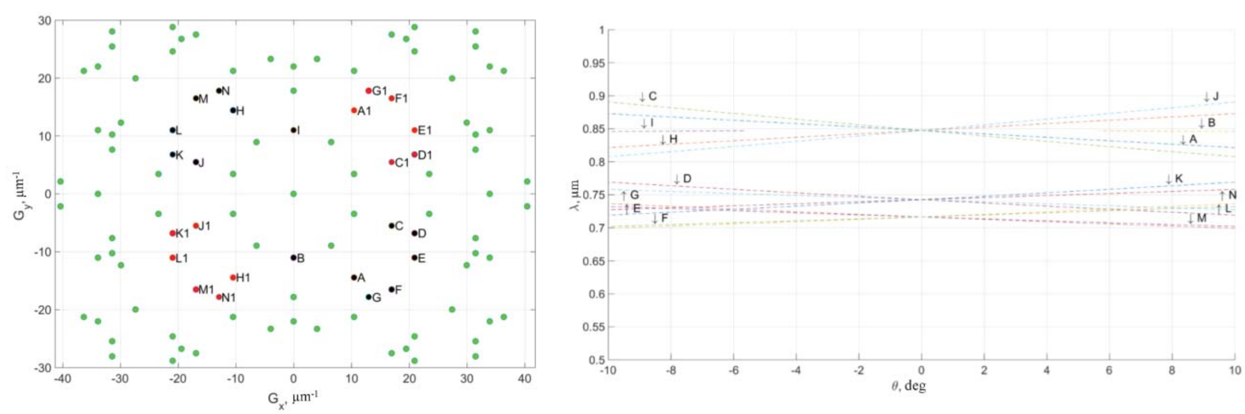
The light passing directly through the sample was then collimated and focused again using an achromatic doublet. To measure at a time in a wide range of angles of incidence of light, the existing installation was changed. The aperture was removed, and lenses with a smaller focal length were used - for focusing from 30 mm, after the sample, a micro lens was used to collimate the light. Thus, this modification ensured measurements in the range of incidence angles from -15º to 15º. The sample was placed in a up to 300 mT field, directed in the plane of the sample. An electromagnet is used to create a magnetic field. The measurements were carried out at room temperature.

RESULTS

Magneto-optical effects can be enhanced due to the excitation of eigenmodes of structure, in particular, upon excitation of surface plasmon polaritons. SPPs can be excited in metal-dielectric structures, in which metal surface is patterned with a grating of grooves or holes. Phase-matching takes place whenever the condition

$$\vec{\beta}_{SPP} = \vec{k}_{\parallel} + \vec{G} \qquad 1)$$

is fulfilled [11], where $\vec{\beta}_{SPP}$ is the SPP propagation vector, $\vec{k}_{\parallel}$ is the in-plane component of the incident light wave vector, Ḡ is the reciprocal lattice vector of the grating found from the Fourier transform of the metal pattern. Fig.1a depicts the reciprocal lattice vectors of investigated quasicrystal.



(a) (b)

FIGURE 1. The reciprocal lattice vectors (a) and dispersion diagram (b) of 2D quasicrystal

Dispersion curves can be calculated using equation

$$\theta = \arcsin\left(\frac{2\pi}{\lambda}\left[\pm\sqrt{\frac{4\pi^2}{\lambda^2}\frac{\varepsilon_1\varepsilon_2}{\varepsilon_1+\varepsilon_2} - G_y^2} - G_x\right]\right) \qquad 2)$$

where ε_1 and ε_2 are permittivity of dielectric and metal respectively.

In the obtained set of dispersion curves (Fig.1b) there are several closely spaced dispersion curves in the range of 700-770 and 800-900 nm, which leads to multiple excitation of SPP in the ranges of 700-770 nm and 800-900 nm. Therefore, a significant increase in the resonance effects associated with the SPP is expected in these ranges. In addition, plasmonic quasicrystal possesses dense designable spectrum, which is one of the most important structure's feature.

The TMOKE specta of several periodical 2D samples (plasmonic crystals with basic angles π/2, π/3, π/4, π/5, 2π/5) and quasiperiodic one were measured (Fig. 2). The TMOKE amplification corresponds to the excitation of the SPP, that is confirmed by experimentally obtained results. The effect of broadband excitation of SPP on the increase in the spectral width of the magneto-optical effect in a two-dimensional magnetoplasmonic quasicrystal was also shown. Moreover, due to rotational symmetry, response of 2D plasmonic quasicrystals has weaker dependence on azimuthal angle of incident light compared to one of 1D quasicrystalline structures.

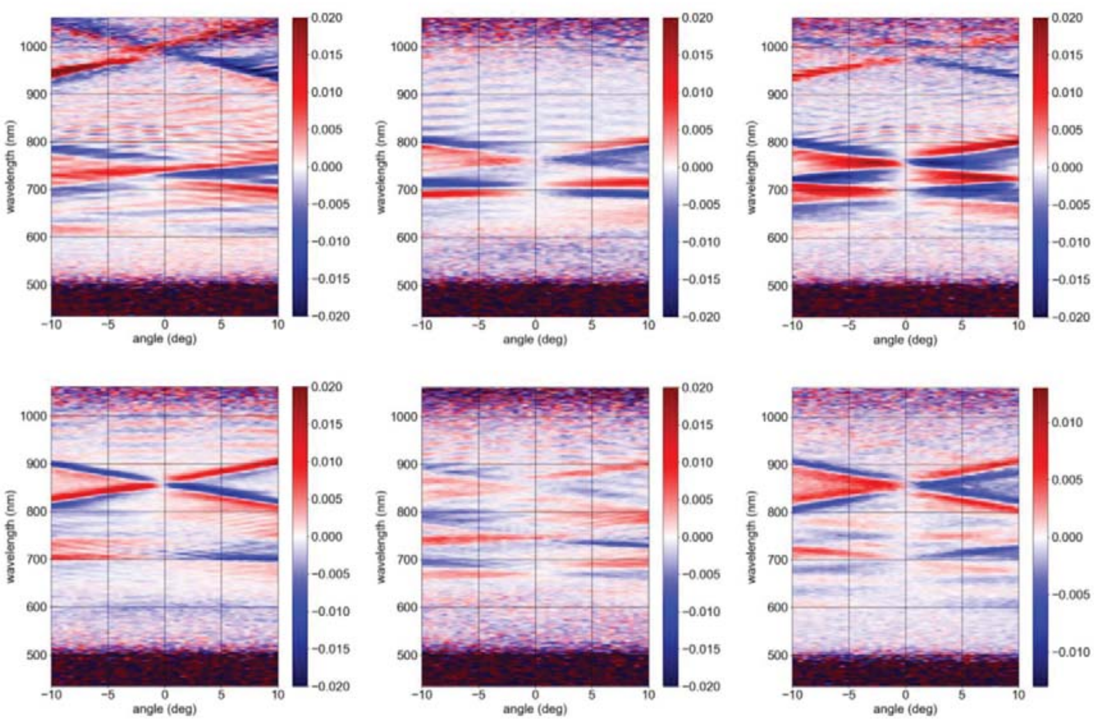


FIGURE 2. The TM-polarized light's TMOKE spectra (upper row: two-dimensional plasmon crystals with angles π/2, π/3, π/4; lower row: crystals with angles π/5, 2π/5 and a two-dimensional quasicrystal)

The measured TMOKE spectra (Fig.3) in a 2D magnetoplasmonic quasicrystal with different polarizations clearly demonstrate the almost complete independence of the shape of the magneto-optical effect from polarization changes, that was predicted theoretically.

Due to quasicrystal's rotational symmetry and dense spectrum of plasmonic resonance, a SPPs propagate in different directions and reciprocal vector has a number of dense spaced G_x and G_y components. As a result, we find, that Faraday effect is broadband and independent of azimuthal angle.

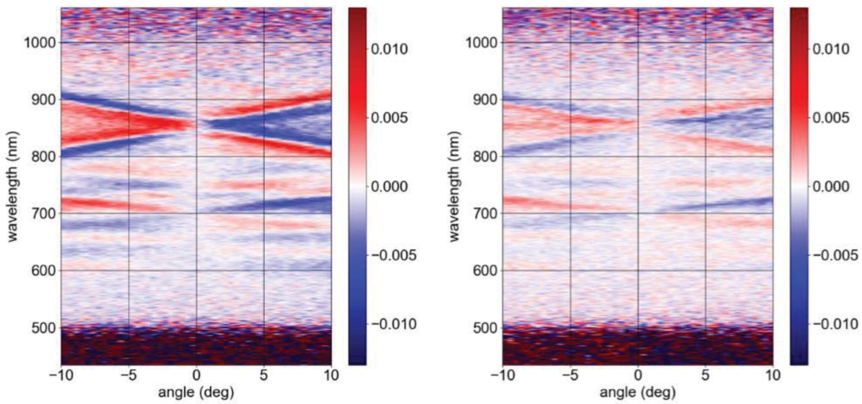


FIGURE 3. TMOKE spectrum in a 2D magnetoplasmonic quasicrystal with TM and TE polarization of incident light

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REFERENCES

1. V. I. Belotelov, L. E. Kreilkamp, I. A. Akimov, A. N. Kalish, D. A. Bykov, S.Kasture,V.J. Yallapragada, A.V. Gopal, A.M. Grishin,S.I. Khartsev, M. Nur-E-Alam, M. Vasiliev, L. L. Doskolovich, D. R. Yakovlev, K. Alameh, A. K. Zvezdin, and M. Bayer, "Plasmon-mediated magnetooptical transparency," Nat. Commun. 4, 2128 (2013).
2. D.O. Ignatyeva, C.S. Davies, D.A. Sylgacheva, A. Tsukamoto, H. Yoshikawa, P.O. Kapralov, V.I. Belotelov and A.V. Kimel, Nature communications, **10** (1), 1-7 (2019).
3. D.O. Ignatyeva and A.P. Sukhorukov "Femtosecond-pulse control in nonlinear plasmonic systems". Physical Review A, **89**(1), 013850 (2014).
4. A.N. Kalish, D.O. Ignatyeva, V.I. Belotelov, L.E. Kreilkamp, I.A. Akimov, Achanta Venu Gopal, M. Bayer, A.P. Sukhorukov, "Transformation of mode polarization in gyrotropic plasmonic waveguides", Laser Physics **24**, 094006 (2014).
5. Y. K. Vekilov and M. A. Chernikov, "Quasicrystals" Phys. Usp. 53, 537–560 (2010).
6. C. Bauer, G. Kobiela, and H. Giessen, "2D quasiperiodic plasmonic crystals," Sci. Rep. 2, 681 (2012).
7. I. Dolev, M. Volodarsky, G. Porat, and A. Arie, "Multiple coupling of surface plasmons in quasiperiodic gratings," Opt. Lett. 36, 1584–1586 (2011).
8. S. Kasture, A. P. Ravishankar, V. J. Yallapragada, R. Patil, N. V. Valappil, G. Mulay, and V. G. Achanta, "Plasmonic quasicrystals with broadband transmission enhancement," Sci. Rep. 4, 5257 (2014).
9. V. G. Achanta, "Plasmonic quasicrystals," Prog. Quantum Electron. 39, 1–23 (2015).
10. Andrey N. Kalish, Roman S. Komarov, Mikhail A. Kozhaev, Venu Gopal Achanta, Sarkis A. Dagesyan, Alexander N. Shaposhnikov, Anatoly R. Prokopov, Vladimir N. Berzhansky, Anatoly K. Zvezdin, and Vladimir I. Belotelov, "Magnetoplasmonic quasicrystals: an approach for multiband magneto-optical response," Optica 5, 617-623 (2018)
11. S. A. Maier, *Plasmonics: fundamentals and applications* (Berlin Heideberg: Springer, 2007). p. 45