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Waveguiding in all-garnet heteroepitaxial magneto-optical photonic crystals

A. M. Grishin[+*1)], *S. I. Khartsev*[+]

[+]*KTH Royal Institute of Technology, SE-164 40 Stockholm-Kista, Sweden*

[*]*Petrozavodsk State University, 185910 Petrozavodsk, Karelian Republic, Russia*

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Over the past two decades materials with forbidden photonic band have formed a rapidly expanding niche of photonics. They demonstrated great potential for light guiding, filtering, and switching, exceptional dispersion properties and promise integration with Complementary metal–oxide–semiconductor (CMOS) devices on Si platform. Magnetic photonic band gap materials attract special interest since they possess nonreciprocal properties thus can serve as optical isolators (e.g., [1] and references therein).

M. Inoue et al. fabricated and tested the first 1D magneto-optical (MO) photonic crystals (MOPCs) with Ta_2O_5/SiO_2 dielectric mirrors and various MO-materials for the central optical cavity: polycrystalline Bi-substituted dysprosium and yttrium iron garnets as well as granular Co-Sm-O and Fe-Si-O magnetic layers [2].

Significant breakthrough has been achieved using completely substituted bismuth iron garnet $Bi_3Fe_5O_{12}$ (BIG) as a Faraday rotator with a record Faraday rotation (FR) $\Theta_F = -8.4\,\mathrm{deg}/\mu$m at 633 nm [3–5]. The first all-garnet 1D heteroepitaxial pulsed laser deposited $Bi_3Fe_5O_{12}/Y_3Fe_5O_{12}$ MOPC at designed wavelength of 750 nm showed 140 % increased of FR compared with a single layer BIG of equivalent thickness [6]. Finally, the cutting edge results on MO properties were achieved in radio frequency (RF)-sputtered latching-type luminescent $[Bi_{2.97}Er_{0.03}Fe_4Al_{0.5}Ga_{0.5}Fe_5O_{12}/Sm_3Ga_5O_{12}]^m$ MOPCs. To the date, at $\lambda_{res} = 775(640)$ nm, FR $\Theta_F = -14.1(14.8)\,\mathrm{deg}/\mu$m represents the highest achieved MO performance. Compared to a single layer BIG film, specific FR Θ_F was increased by the factor of 12 [7, 8].

In this paper we present results on MO effects in transmission and FR of TM- and TE-polarized incident light that make evident resonant TE-mode waveguiding within a MOPC cavity.

A series of heteroepitaxial $[\mathrm{BIG/SGG}]^m$ MOPCs have been fabricated by RF-magnetron sputtering of composite $3Bi_2O_3 + 5Fe_2O_3$ oxide and stoichiometric $Sm_3Ga_5O_{12}$ (SGG) targets on single crystal Ca, Mg, Zr : $Gd_3Ga_5O_{12}(111)$ substrates [9]. In both mirrors, thickness of layers of Bragg reflectors was chosen to be equal a quarter of wavelength $\lambda_{res}/4n_{BIG(SGG)}$ in the respective material, whereas the BIG in the optical resonance cavity has a thickness $\lambda/2n_{BIG}$. Refractive indices of BIG and SGG at the designed $\lambda_{res} = 750$ nm equal to $n_{BIG} = 2.679$ and $n_{SGG} = 1.960$.

Figure presents optical spectra of transmission T and FR angle Θ_F for TM- and TE-polarized light incident at an angle ϕ on 750-$[\mathrm{BIG/SGG}]^5$ MOPC with five pairs of BIG/SGG reflectors. The oblique geometry removes the degeneracy of TE and TM polarizations that occurred at normal incidence ($\phi = 0$). All the resonant features as edges of the band gap and resonant central peaks experience signi–cant about 60 nm "blueshift" when the incidence angle ϕ increases up to 70°.

TM and TE polarizations behave differently: resonant peak of TM-mode transmission has a constant height whereas an intensity of transmitted TE-polarized light rapidly decreases. Faraday rotation acts in an opposite way: a height of resonant peak of FR falls down with an angle ϕ increase for TM- and exceedingly grows for TE-polarized light.

Comparison of T and Θ_F spectra for transmitted and reflected light concludes that TM-mode exhibits twice stronger reflectivity within the stop band and significantly higher resonant transparency than TE-polarized light.

The angular dependence of the resonance wavelength $\lambda_{res}(\phi)$ has universal character for both the TM and TE polarizations and nicely fits to the formula that expresses the condition of constructive light interference in the crystal with an effective refractive index n_{eff}: $\lambda(\phi) = \lambda(0)[1 - (\sin\phi/n_{eff})^2]^{1/2}$.

The following observations testify the resonant TE-mode waveguiding within a MOPC cavity:

1)e-mail: grishin@kth.se

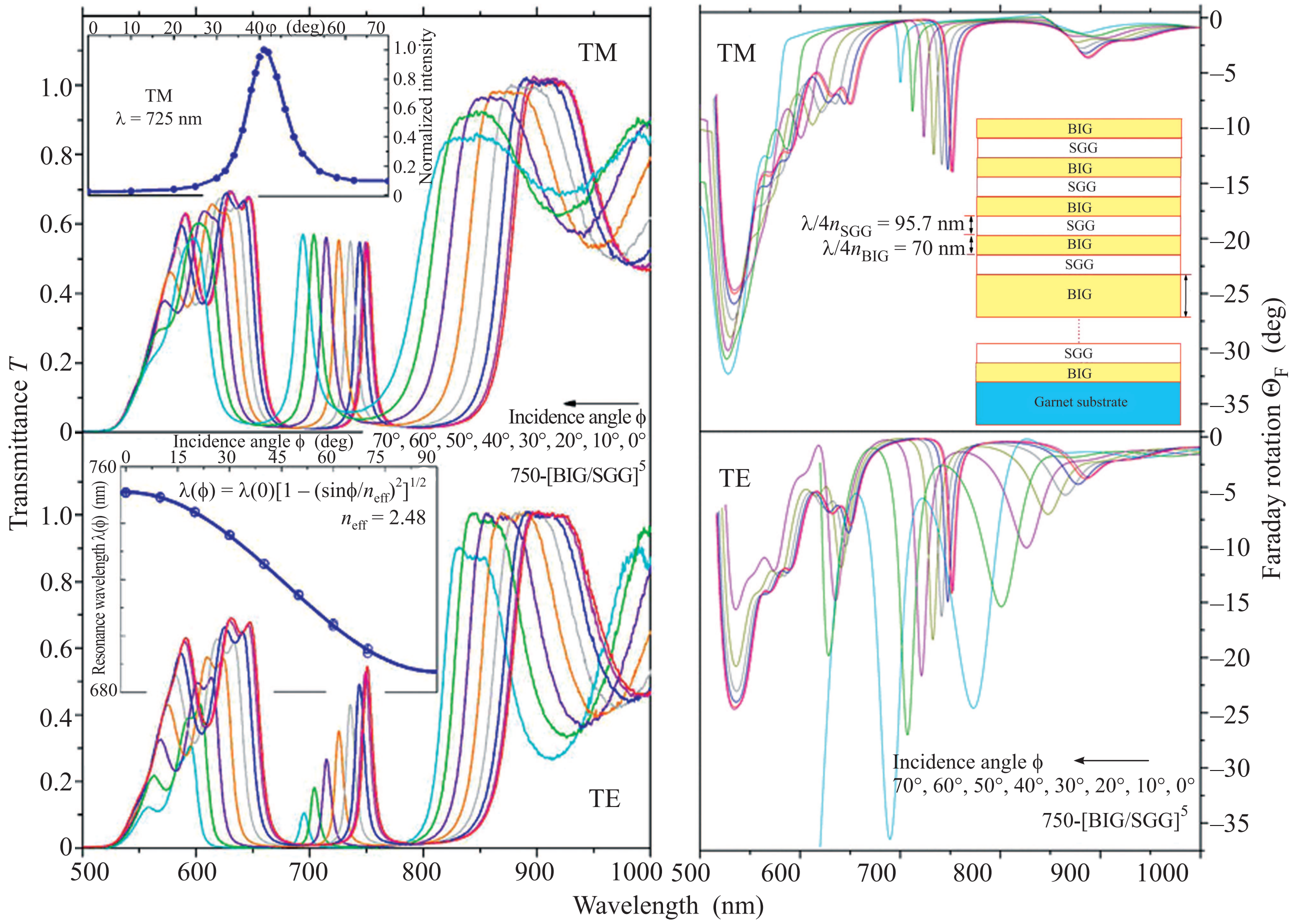

Fig. 1. (Color online) Transmission T and Faraday rotation Θ_F spectra for TM and TE polarizations in the 750-[BIG/SGG]^5 MOPC at various incidence angles ϕ. 750-[BIG/SGG]^4 MOPC is shown schematically in inset in the right frame. In lower inset, experimental angular dependence of the position $\lambda_{res}(\phi)$ of transmission resonance peak for TE and TM polarizations is fitted to the Fabry–Pérot formula with the effective refraction index $n_{eff} = 2.48$. At $\phi = 60°$ and $70°$, too low intensity of transmitted TE-polarized light makes difficult to obtain reliable Faraday rotation data for the wavelengths shorter than 620 nm

• significant reduction of transmissivity T of the resonant TE-mode compared to the TM-polarized light;

• very strong enhancement of FR Θ_F of transmitted TE-mode and, respectively, reduction of FR of TM-polarized light at the resonant wavelength λ_{res};

• much lower reflectance of TE-polarized light compared to the TM-mode.

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