Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl19

Charge Transfer between Magnetic Anisotropic Centers in Garnet Lattice under an Influence of Eliptically Polarized Light

I. Davidenko [a]

[a] Kiev National University, Vladimirskaya Str., 64, Kiev, 01033, Ukraine

Version of record first published: 24 Sep 2006

To cite this article: I. Davidenko (2001): Charge Transfer between Magnetic Anisotropic Centers in Garnet Lattice under an Influence of Eliptically Polarized Light, Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals, 361:1, 107-112

To link to this article: http://dx.doi.org/10.1080/10587250108025726

Mol. Cryst. and Liq. Cryst., 2001, Vol. 361, pp. 107-112
Reprints available directly from the publisher
Photocopying permitted by license only

Charge Transfer between Magnetic Anisotropic Centers in Garnet Lattice under an Influence of Eliptically Polarized Light

I. DAVIDENKO

Kiev National University, Vladimirskaya Str., 64, Kiev, 01033, Ukraine

Electron transitions between magnetic anisotropic impurity centers in garnet crystal lattice under the influence of elliptically polarized light are considered. The theoretical model of the occupancies kinetics of such centers was developed. Spatially inhomogeneous distribution of the energy of photoinduced magnetic anisotropy was calculated in the sample being illuminated with light with modulated polarization. A conclusion about a possibility of recording of holographic magnetic gratings in the investigated materials was made depending on results obtained.

Keywords: photoinduced effects; anisotropy; garnets

INTRODUCTION

The physical nature of photoinduced effects (PIE) in ordered mediums is connected with the formation of optical or/and magnetic anisotropy within the illuminated sample region showing itself in particular in the experimentally observed photoinduced linear birefringence or a spin-reorientation transition. In accordance to the modern conceptions [1] the PIE nature is connected with photoinduced charge transfer between anisotropic impurity centers localized in crystal sites with different environment symmetry. PIE are the most widely investigated in different garnets with various dopants, for example in magnetic yttrium-iron garnets doped with silicon (YIG:Si) and cobalt (YIG:Co) and in non-magnetic garnet $Ca_3Mn_2Ge_3O_{12}$ (CaMnGe).

Up to now PIE caused by linearly polarized or unpolarized light in garnets were studied intensively. The subject of the present investigation is the development of microscopic model to describe PIE appearing in

non-magnetic and magnetic garnets under the influence of spatially modulated elliptically polarized light. This situation is realized during holographic recording if the sample is illuminated with two coherent linearly polarized light beams with mutually perpendicular polarization vectors (Fig.1). Electron transitions between anisotropic impurity centers under the influence of elliptically polarized light are considered at the present work for the first time. As a result, a spatial distribution of optical or/and magnetic anisotropy arises in the exposed sample region due to the ellipticity and polarization ellipse orientation of the total incident wave field.

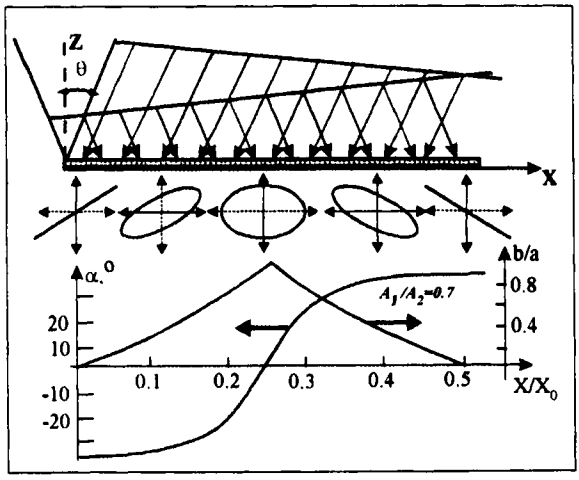

FIGURE 1 Spatial distribution of ellipticity (b/a) and azimuth (α) of the polarization ellipse of the total wave field when illuminating the garnet sample with two mutually perpendicular linearly polarized light beams with amplitudes A_1 and A_2. The coordinate X is normalized by the spatial period X_0.

THEORETICAL MODEL

The microscopic reason for the induced anisotropy is an effective redistribution of occupancies of anisotropic photoactive centers between crystal sites with different environment symmetry occurring through a charge transfer between them. The ions Mn^{3+}, Fe^{2+} and Co^{2+} are considered as such centers in CaMnGe, YIG:Si and YIG:Co respectively[2,3]. Those

ions create a distortion of the oxygen environment in the octahedral sites of the garnet crystal lattice due to the presence of the orbital degeneracy in their ground state. As a result, both photoexcitation probabilities and charge transfer velocities depend on the light polarization. All previous experimental investigations [1-3] testifies that above noted ions localized in octahedral garnet sites make the largest contribution to optical and magnetic anisotropy.

Both magnetic garnets YIG:Si and YIG:Co could be considered as semiconductors with the width of prohibited band 2.9 eV. Impurities existence causes appearance of energetic impurity levels which can be situated within the prohibited band depending on the nature and properties of dopant ions. Lifgr of a definite spectral interval involvs an optical recharge of impurity centers with different environment symmetry. As result, an appearance of macroscopic magnetic anisotropy becomes possible upon the illumination with linearly polarized light. This is a reason of experimentally observed [1,3] photoinduced magnetization switching within illuminated sample regions.

The band energetic structure of non-magnetic CaMnGe garnet is not described in details at the present time. Its description requires additional experimental investigations of electric and photoconductivity. This is a subject of our following work. Now only the possibility of charge transfer between Mn ions is supposed without definition of the mechanisms. Similarly to the previous case of the magnetic garnets an effective redistribution of strongly anisotropic ions Mn^{3+} between the octahedral sites in the garnet crystal lattice is the result of the charge transfer between Mn ions. This one shows itself in experimentally observed formation of photoinduced linear birefringence [2].

Detailed consideration of the photoactive center excitation with elliptically polarized light being a sum of two orthogonal linearly polarized components $\vec{A}_1 = \vec{e}_1 e^{i\phi}$ and $\vec{A}_2 = \vec{e}_2$ where ϕ is a phase difference between the components, was performed. As result, the probability of light absorbtion in active centers was obtained:

$$\omega = AI\,[1 + B\cos^2\varphi + \chi\,(1 + B\sin^2\varphi)] \qquad (1)$$

where $\chi = e_2 / e_1$, I is the light intensity, φ is the angle between the main axis of polarization ellipse and the symmetry axis of considered photoactive center, A and B are the phenomenological constants. At the magnetization presence in magnetic garnets the similar analysis could be made resulting in appearance of the additional factor in the expression (1):

$$\omega = AI\,[1+B\cos^2\varphi + \chi(1+B\sin^2\varphi)](1+C\cos^2\psi) \qquad (2)$$

where C is the phenomenological constant, ψ is the angle between magnetization $\vec{M}$ and the symmetry axis of considered photoactive center.

The knowledge of photoexcitation probability (1)-(2) allows to deduce the probability of charge transfer between the four types of octahedral centers of garnet crystal lattice in the following form:

$$\Omega_i = AI\,K\,[1 + B\cos^2\varphi_i + \chi\,(1 + B\sin^2\varphi_i)](1+C\cos^2\psi_i) + \nu\exp[-\varepsilon_a/kT] \qquad (3)$$

where index *i* denotes one among four non-equivalent octahedral site $<111>_i$, **K** is the probability of charge transfer from one ion excited state into another non-equivalent site, ν is the frequency factor, ε_a is the activation energy, k is the Boltzmann constant, T is the temperature. The first and the second term in equation (3) characterize the probability of the charge transfer under illumination and athermoactivated process, respectively. Evidently, light induced charge transfer forms a non-equilibrium distribution of occupancies, which consequently creates a photoinduced optical or/and magnetic anisotropy. The thermoactivated process equalizes the occupancies of all types of centers. After turning the light off only the second term remains in the expression (3).

The time dependence of the octahedral site occupancies n_i under light influence can be described by the simplest system of kinetic equations. In general, this system for octahedral centers consists of four equations. However, for non-magnetic garnets only two Ω_i are different. For the magnetic garnet YIG:Co in the experimental geometric configuration[3] the system of kinetic equations consists of three equations. It was solved for both garnets, assuming an equal number of photoactive centers in all octahedral sites before the illumination (process of anisotropy induction) and for the process of anisotropy relaxation assuming that saturation was reached before switching the light off.

For the non-magnetic CaMnGe garnet the non-equilibrium difference Δn of occupancies in the octahedral sites was obtained to be $\Delta n = \Delta n_0\,(1 - \exp[-t/\tau_1])$ and $\Delta n = \Delta n_0\exp[-t/\tau_2]$ for the above noted processes, respectively. Here τ_1 and τ_2 are the characteristic times of induction and relaxation, respectively, which are dependent on Ω_i, i.e. on light polarization. Evidently, experimentally observed photoinduced linear birefringence is proportional to Δn. The obtained results of our numerical simulations are plotted in Fig.2.

For the magnetic garnets YIG:Si and YIG:Co the solutions of the kinetic equations have more complicate form as comparedto the previous case. Using the single ion approximation we have calculated the energy of

magnetic anisotropy. The result of numerical simulations of the photoinduced magnetic anisotropy spatial distribution appearing during the sample illumination with light with polarization spatial distribution accordingly to Fig.1 are shown in Fig.3. Calculations were made for the phase with magnetization direction $\vec{M}\|[111]$. Plotted results are normalized by N and phenomenological constant Λ used in the single ion approximation.

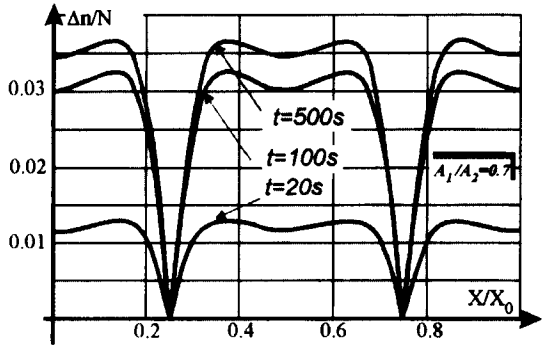

FIGURE 2 Time dependence $\Delta n(t)$ normalized by the photoactive centers concentration N for the non-magnetic CaMnGe garnet accordingly to the numerical calculations.

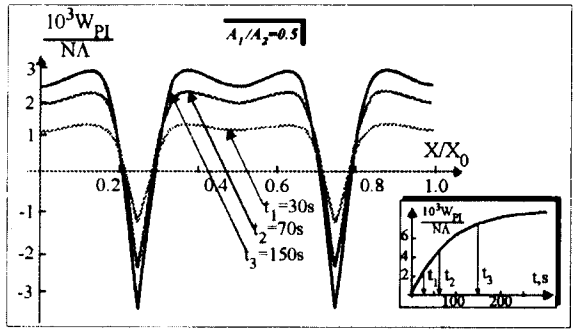

FIGURE 3 The results of numerical simulations of the PMA energy spatial distribution for different times of the sample illumination with elliptically polarized light. Insert: dynamics of PMA energy growth in the fixed point along the X axis (see Fig.1).

As it easily could be seen from the Fig.3, at the certain values of ellipticity and polarization ellipse orientation magnetic phase with magnetization direction $\vec{M}\|[111]$ becomes energetically unfavorable within limited spatial region due to growth of the energy of this phase. That means a formation of conditions for magnetization switching within this region. Preconditions for remagnetization are absent when the polarization of the incident light beam is close to circular. Taking into consideration the available values of PMA energy [3] in YIG:Co from the analysis of the obtained PMA profile follows a possibility of stripe magnetic domain structure formation andstabilization, i.e. the possibility to record holographic magnetic gratings in thin films of YIG:Co.

The fitting of the experimental results [2] for the non-magnetic grating recording in the garnet $Ca_3Mn_2Ge_3O_{12}$ was performed [4] within the scope of the developed model. A good agreement between experimental and theoretical results was reached.

CONCLUSIONS

The simplified microscopic model of optical and magnetic anisotropy formation under the influence of elliptically polarized light was developed. The developed model operates with charge transfer between anisotropic centers and resulting redistribution of their occupancies. It has a generalized character and could be used in different materials, for example in organic materials and molecular crystals. Known [1] experimental results obtained during holographic grating recording in non-magnetic CaMnGe garnet were explained within the scope of the developed model. The possibility of magnetic holographic grating formation in YIG:Co was predicted basing on obtained theoretical results.

The researches were financially supported within the scope of the project INTAS 97-366.

References

[1] V.F. Kovalenko and E.L. Nagaev, *Sov. Phys.Usp*, 29, 297 (1986); E.L. Nagaev, *Phys. Status Solidi*, 145, 11 (1988), and references therein.
[2] V.A. Bedarev, S.L. Gnatchenko, *Low Temp.Phys.* 20 (1994) 100.
[3] A.B. Chizhik, I.I. Davidenko, A. Maziewski, A. Stupakiewicz, *Phys. Rev. B*57 (1998) 14366.
[4] In preparation for publication.