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Electrically controlled reflection and transmission of obliquely incident light by structurally chiral materials

J. Adrian Reyes [a,*], Akhlesh Lakhtakia [b]

[a] *Instituto de Fisica, Universidad Nacional Autonoma de Mexico, Apartado Postal 20-364, CP 01000 Mexico, DF, Mexico*
[b] *Computational and Theoretical Materials Sciences Group (CATMAS), Department of Engineering Science and Mechanics, Pennsylvania State University, University Park, PA 16802-6812, USA*

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Abstract

The solution of a boundary-value problem for the reflection and transmission of obliquely incident plane waves due to a slab of a structurally chiral material (SCM) displaying the Pockels effect with a $\bar{4}2m$ point group symmetry indicates the enhancement of circular Bragg phenomenon by the application of a dc voltage. The enhancement suggests that thinner SCMs can be used as devices such as polarization-rejection filters if the Pockels effect is exploited, for both normally and obliquely incident light.

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1. Introduction

In the predecessor paper [1], we initiated the theory of reflection and transmission of normally incident plane waves by a structurally chiral material (SCM) endowed with electro-optic properties. SCMs are exemplified by chiral nematic and chiral smectic liquid crystals [2] as well as by chiral sculptured thin films [3]. Fabricated as slabs, SCMs are periodically non-homogeneous in the thickness direction. In combination with their structural chirality, their periodic non-homogeneity makes them display the circular Bragg phenomenon, whereby a normally incident, circularly polarized plane wave of a specific handedness is highly reflected in a certain wavelength regime, whereas a similar plane wave but of the reverse handedness is not. This polarization-discriminatory filtering characteristic of SCMs is very attractive in optical technology [3,4].

The propagation of light through an electro-optic SCM under the influence of a low-frequency electric field aligned along its thickness direction was analyzed by us recently [1]. The Pockels effect was assumed to occur [5], and for numerical work the SCM was taken to possess locally a $\bar{4}2m$ point group symmetry. The frequency-domain Maxwell curl equations were cast in a 4×4 matrix representation for propagation along the thickness direction (i.e., parallel to the axis of non-homogeneity), and the Oseen transformation was invoked. The Bragg regime was found to be controlled by the low-frequency electric field. Even more surprisingly at first glance, the Pockels effect was found to create a Bragg regime even when the SCM properties were such that a regime would not exist in the absence of the low-frequency electric field; but this effect can be explained via a generalization of the Oseen transformation [6]. Clearly, the electro-optic nature of a SCM could be exploited for optical switching.

A non-electro-optic SCM can be angle-tuned by rotation about the direction of the incident wave [7]. Then propagation inside the SCM is not parallel to the axis of

* Corresponding author. Tel.: +52 5556225178; fax: +52 5556161535.
E-mail address: adrian@fisica.unam.mx (J. Adrian Reyes).

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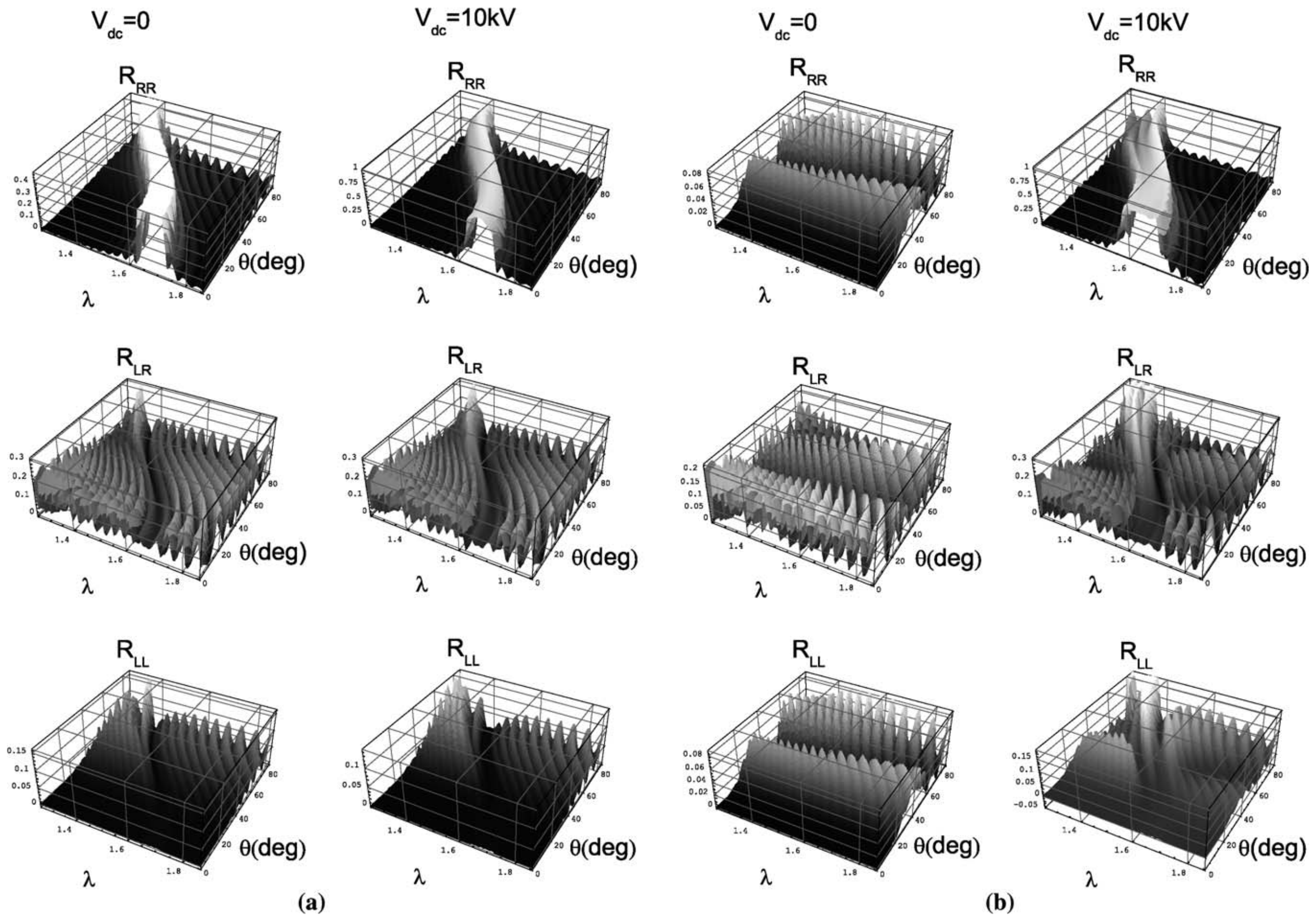

Fig. 1. Reflectances as function of the normalized wavelength λ and the incidence angle θ for $V_{\rm dc} = 0$ and $V_{\rm dc} = 10$ kV. Other parameters are: $\epsilon_1^{(0)} = 2.7$, $\epsilon_3^{(0)} = 3.2$, $r_{41} = 9 \times 10^{-12}$ m V^{-1}, $r_{63} = 3r_{41}$, $h = 1$, $L/\Omega = 40$, $\Omega = 160$ nm, and $\phi = 0°$. (a) $\chi = 45°$, (b) $\chi = 90°$. As $R_{\rm LR}$ and $R_{\rm RL}$ are virtually indistinguishable from each other, plots for $R_{\rm RL}$ are not presented here.

non-homogeneity, and the Bragg regime generally undergoes a blue shift [8]. Knowing these facts, we decided to theoretically investigate the effect of electro-optic nature on the blue shifting of the Bragg regime. Our results are reported here.

The outline of this paper is as follows. Section 2 contains a brief review of the constitutive equations of a SCM exhibiting the Pockels effect and possessing locally a $\bar{4}2m$ point group symmetry [5], followed by a treatment of electromagnetic wave propagation therein which is not necessarily parallel to the axis of non-homogeneity. Section 3 contains representative numerical results and a discussion thereof. An $\exp(-i\omega t)$ time-dependence is implicit here, with ω as the angular frequency and t as time.

2. Theoretical formulation

2.1. Pockels effect and $\bar{4}2m$ symmetry

Let us consider a (non-dissipative) dielectric material susceptible to the Pockels effect when subjected to a low-frequency field $\mathbf{E}^{\rm dc}$. The reciprocal of the optical relative permittivity tensor is usually reported in the literature [5] in the principal coordinate system of the material. Restricting ourselves to the point group symmetry $\bar{4}2m$, we obtained [1]

$$\bar{\epsilon} = \begin{pmatrix} \epsilon_1^{(0)} & -r_{63}\epsilon_1^{(0)2}E_3^{\rm dc} & -r_{41}\epsilon_1^{(0)}\epsilon_3^{(0)}E_2^{\rm dc} \\ -r_{63}\epsilon_1^{(0)2}E_3^{\rm dc} & \epsilon_1^{(0)} & -r_{41}\epsilon_1^{(0)}\epsilon_3^{(0)}E_1^{\rm dc} \\ -r_{41}\epsilon_1^{(0)}\epsilon_3^{(0)}E_2^{\rm dc} & -r_{41}\epsilon_1^{(0)}\epsilon_3^{(0)}E_1^{\rm dc} & \epsilon_3^{(0)} \end{pmatrix} \quad (1)$$

as the relative permittivity tensor correct to the first order with respect to $\mathbf{E}^{\rm dc}$.[1] Here, $E_{1,2,3}^{\rm dc}$ are the Cartesian components of the dc electric field, $\epsilon_{1,3}^{(0)}$ are the principal relative permittivity scalars in the optical regime, whereas r_{41} and r_{63} are the only non-zero electro-optic coefficients in the traditional contracted notation for representing symmetric second-order tensors [5,9]. The 3-axis is designated as the distinguished axis. In the absence of the Pockels effect, we thus have a linear uniaxial dielectric material.

[1] The effect of higher-order terms is likely to be small, because the electro-optic terms in $\bar{\epsilon}^{-1}$ are roughly ten times larger than the non-electro-optic terms even at very high values of $E^{\rm dc}$ [5, p. 404].