ACHROMATIC ANALOG OF A QUARTER-WAVE PLATE


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Is it possible to achieve wavelength-independent transformation of the polarization of light on the basis of adiabatic tracking of smooth variation in the parameters of the medium by the polarization? This question is considered for conditions where circularly polarized light is converted into linearly polarized light.

In experimental and applied optics, various transformations of the state of polarization of light are required. The quarter-wave plate, which is often used to transform the polarization, operates at a fixed wavelength. Devices that permit operation in a broader wavelength range, thanks either to smoothing of the wavelength dependence or the selection of only a discrete set of wavelengths, were discussed in [1, 2]. In [3], a method of tuning a composite quarter-wave plate to a particular wavelength was proposed. The Fresnel rhombus, which is a well-known device for transforming the polarization [4], permits operation in a broad wavelength range, but the quality of transformation depends on the dispersion of the material from which the rhombus is made.

The aim of the present work is to investigate the possibility of achieving wavelength-independent transformation of the polarization of light on the basis of adiabatic tracking of smooth variation in the parameters of the medium by the polarization.

Consider the most frequently encountered problem: the transformation of circularly polarized radiation into linearly polarized radiation (or vice versa).

A state of polarization that does not change when light passes through a medium is said to be intrinsic. For birefringent crystals, the intrinsic polarization is linear. In optically active media, it is circular. For materials characterized by both optical activity and birefringence, the intrinsic polarization is elliptical.

Consider the situation in which the medium is optically active at the input, there is no birefringence, and the intrinsic polarization is circular. On moving along the z coordinate, birefringence appears in the medium and smoothly increases, and the intrinsic polarization is smoothly transformed to elliptical and then to linear (Fig. 1). This situation arises when one end of the optically active medium is compressed or placed in an electric field, causing birefringence. The resulting birefringence is smoothly inhomogeneous over space; the dielectric-permittivity tensor of the medium takes the form

\[ \mathbf{\varepsilon}(\mathbf{r}) = \begin{pmatrix} \varepsilon_x(z) & -iG \\ iG & \varepsilon_y(z) \end{pmatrix}, \]

where \( \varepsilon_x(z) = n_x^2(z) \) is the square of the refractive index for a wave linearly polarized along the x axis; \( \varepsilon_y(z) = n_y^2(z) \) is the square of the refractive index for a wave linearly polarized along the y axis; \( G \) is the gyration constant, proportional to the optical activity of the medium. The electromagnetic field in this medium conforms to a wave equation of the following form in the given coordinates

\[
\frac{\partial^2 E_x}{\partial z^2} + \left( \frac{\omega}{c} \right)^2 n_x^2 E_x + \left( \frac{\omega}{c} \right)^2 (-iG) E_y = 0, \\
\frac{\partial^2 E_y}{\partial z^2} + \left( \frac{\omega}{c} \right)^2 (iG) E_x + \left( \frac{\omega}{c} \right)^2 n_y^2 E_y = 0.
\]

Fig. 1. State of intrinsic polarization for a medium with optical activity and smoothly increasing birefringence along the z axis.

Fig. 2. Dependence of the intensity of the x component of the field $I_x = |\tilde{E}_x|^2$ (1) and the y component of the field $I_y = |\tilde{E}_y|^2$ (2) on z, for $\lambda_1 = 434$ nm, $G = 41.924$ deg/mm, $n_{av} = 1.553963$; $\lambda_2 = 589.3$ nm, $G = 21.724$ deg/mm, $n_{av} = 1.544246$; $\lambda_3 = 760.8$ nm, $G = 12.704$ deg/mm, $n_{av} = 1.539071$.

With a slow dependence of the coefficients in the equations on z and initial conditions corresponding to the intrinsic wave, the solution of Eq. (2) describes a wave that remains intrinsic as it propagates along the z axis [5].

We write $E_x$ and $E_y$ in the form

$$E_x = \tilde{E}_x(z) e^{i\kappa_0 z},$$
$$E_y = \tilde{E}_y(z) e^{i\kappa_0 z},$$

where $\kappa_0^2 = (\omega/c)^2(\varepsilon_x + \varepsilon_y)/2$; $\omega$ is the frequency of the optical radiation; $c$ is the velocity of light; $\tilde{E}_x(z)$ and $\tilde{E}_y(z)$ are slowly varying complex amplitudes. Substituting Eq. (3) into Eq. (2) and neglecting the second derivatives $\partial^2\tilde{E}_x/\partial z^2$ and $\partial^2\tilde{E}_y/\partial z^2$, we obtain equations for $\tilde{E}_x(z)$ and $\tilde{E}_y(z)$

$$2i\kappa_0 \frac{\partial \tilde{E}_x}{\partial z} + \left(\frac{\omega}{c}\right)^2 \Delta x \tilde{E}_x + \left(\frac{\omega}{c}\right)^2 (-iG) \tilde{E}_y = 0,$$  
$$2i\kappa_0 \frac{\partial \tilde{E}_y}{\partial z} - \left(\frac{\omega}{c}\right)^3 \Delta x \tilde{E}_y + \left(\frac{\omega}{c}\right)^2 (iG) \tilde{E}_x = 0,$$

where $\Delta x(z) = [\varepsilon_x(z) - \varepsilon_y(z)]/2$ is proportional to the birefringence of the medium and depends smoothly on z.