Planar differential interferometry using ferronematics

C. Tyszkiewicz and T. Pustelny

Institute of Physics, Silesian University of Technology, Krzywoustego 2, Gliwice, Poland

Using ferronematic (FN) layer as a cover layer for planar waveguide it is possible to make effective refractive index of a TM mode depended on a magnetic field intensity if the layer will be suitably oriented in respect to a waveguide. It is obvious that a refractive index of a waveguide layer must be greater than the nematic liquid crystal (LC) ordinary and extraordinary refractive indexes. As a results a phase difference between TE and TM modes depends only on TM mode phase changes. The origin of these changes relies on a nematic LC spatial structure, which can be shifted in a presence of mono-domain ferromagnetic particles. If the optical power density of an each mode is the same and axis of a polarizer is tilted for both mode polarization planes, at the angle of 45 degrees, then the light intensity after a polarizer my be written as

$$I = I_0\left[1 + \cos\left(\Delta\varphi(H)\right)\right], \tag{1}$$

where I_0 is the single mode light intensity, $\Delta\varphi$ is the TM mode phase difference at the waveguide end, and H is the magnetic field intensity. The TM mode phase difference $\Delta\varphi$ is a function of the TM-mode effective refractive-index change under influence of magnetic field. It can be expressed as follows

$$\Delta\varphi = \frac{2\pi}{\lambda} z\Delta N_{efTM}\,, \tag{2}$$

where N_{efTM} is the TM-mode effective refractive index, λ is the wavelength, and z is the light propagation length in a given magnetic field region.

Let's take into account structure provided on a Fig. 1.

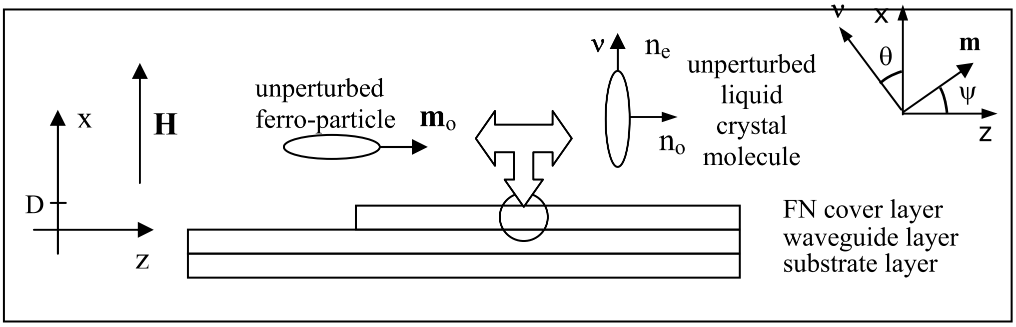

Fig. 1. Cross-section of a planar waveguide covered with a flat ferronematic (FN) layer of thickness D placed in an external magnetic field **H**. Descriptions: **ν** – liquid-crystal (LC) matrix director; **m** – ferro-particle magnetization director; θ – nematic particle tilt angle, ψ – ferro-particle tilt angle; n_f, n_c – refractive indexes of a waveguide and a substrate layers, respectively; n_o, n_e – ordinary and extraordinary NLC refractive indexes, respectively.

In absence of magnetic field, the director ν of liquid crystal molecules is parallel to x axis and the ferro-particles magnetic moment is parallel to z axis. As a consequence, the cover layer refractive index for a TM mode is equal to n_e. When magnetic filed parallel to x axis is applied in the structure, provided on the Fig.1, then the spatial orientation of nematic liquid crystal matrix changes only in the *xz* plain. The existence of boundary conditions at the FN layer limiting-planes causes creation of a cover layer and a resultant refractive index distribution for the TM mode along the *x* axis is equal to

$$n_{cTM}(x) = \sqrt{\frac{n_0^2 n_e^2}{n_0^2 \sin^2[\theta(x)] + n_e^2 \cos^2[\theta(x)]}} \quad , \qquad (3)$$

where θ(x) is the distribution of a liquid crystal molecules tilt angle along the *x* axis.

For a given distribution $n_{cTM}(x)$ it is possible to calculate effective refractive index for a TM mode by solving the following wave equation

$$\frac{d^2 H_y}{dx^2} + n^2(x)\frac{d}{dx}\left(\frac{1}{n^2(x)}\right)\frac{dH_y}{dx} + \frac{2\pi}{\lambda}\left(n^2(x) - N^2_{efTM}\right)H_y = 0 \, , \qquad (4)$$

where $n(x)$ is the distribution of refractive index in all structure layers. In our case refractive index is constant within waveguide and substrate layers.

In order to calculate the tilt angle distribution θ(x), free-energy functional for the FN layer has to be minimized for a given H. For weak magnetic fields, $H < w/M_s d$, where w is the ferro-particle anchoring strength and M_s is the ferro-particle saturation magnetization, the function θ(x) acquires parabolic profile

$$\theta(x) = \frac{M_s f H D^2}{8k_3}\left(1 - \frac{4x^2}{D^2}\right), \qquad (5)$$

where k_3 is the Frank elastic constant of bend deformation, and f is the mean value of ferro-particles volume concentration. Substituting above into equation (3) and then solving equation (4) we can find how the TM-mode effective refractive-index is influenced by a presence of magnetic field. Using in turn equations (2) and (1) the light intensity at the end of a waveguide as function of magnetic field strength can be found.

Name of the corresponding author: Cuma Tyszkiewicz
e-mail address: cuma@optics.polsl.gliwice.pl
url's: http://fizyka.polsl.gliwice.pl/