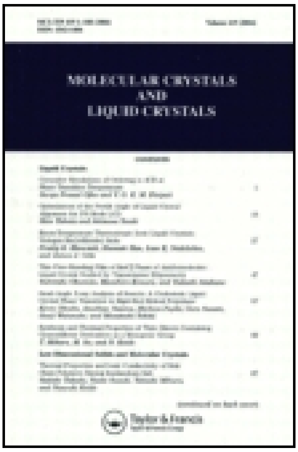

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Tunable Liquid Crystalline Metamaterial Structure in GHz Range

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Tunable Liquid Crystalline Metamaterial Structure in GHz Range

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We analyze the microwave response of Ω-type metamaterial infiltrated with a nematic liquid crystals materials – K15 and BL006. A full-wave analysis technique based on the finite-difference time-domain method (FDTD) was performed using QuickWave 3D electromagnetic solver. Simulation of metamaterial structure with low losses liquid crystals (LC) have been made. LC materials can provide tuning of the metamaterials structure due to reorientation of the liquid crystal director. The main aim of presented work is to determine the influence of LC material on effective refractive index.

Keywords Liquid crystals; metamaterials; negative refractive index; tunability; tunable refractive index

1. Introduction

Metamaterials are artificial materials with negative refractive index. They are very interesting from scientific and application point of view and posses unusual electromagnetic properties not available in nature. Interest of metamaterials has been on for 10 years, when Smith proposed first periodic structure which characterized negative refractive index for GHz waves [4,5]. It was built from an array of metallic wires, between which were Split Ring Resonators (SSR).

Liquid crystals can give possibility to obtain materials with a tunable (−, 0, +) refractive index. Tunability of such structures is done by changing the reorientation of liquid crystal molecules [1–3]. Metamaterials with tunable refractive index are being implemented as an artificial periodic structures containing layer or layers of liquid crystal. Liquid crystals are anisotropic medium and require small electric field to their reorientation. By introducing them to the periodic structure of the

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metamaterial we can tune its parameters, such as refractive index. Tunability of liquid crystalline layer can be done in two ways – by applying an electric field or temperature – in the case of thermotropic liquid crystals.

In this paper we present results of numerical simulations of tunable metamaterial structure operating in microwave frequency range. Based on the results of scattering parameters of metamaterial structure we calculated effective refractive index for two orientations of liquid crystal – homogenous (0^0) and homeotropic (90^0).

2. Properties of Metamaterial Structure

Simulated structure was composed of three different materials – liquid crystal, metallic strips and teflon fiberglass. The presence of teflon fiberglass in the construction of the structure comes from the fact that it is characterized by low losses in GHz wave range. The construction of metal strips can be divided into two parts – the middle part is a split ring resonator – a source of negative permeability, which depart from the metallic strips, which are the source of negative electrical permittivity. Metal parts are opposite oriented to each other on adjacent layers [3,6]. Elementary cell of tunable metamaterial is shown in Figure 1.

In numerical simulations, liquid crystal was characterized by the dielectric tensor, and tangent of loss. LC director lies in the $x-y$ plane. Tunable metamaterial structure was inserted into X-band waveguide to achieve scattering parameters of metamaterial sample. An incident beam with the electric field polarized along the x direction and magnetic field polarized along the y direction was assumed to illuminate the structure along z direction [3,5,6].

A permittivity tensor was used for a rigorous description of LC molecules, where $\varepsilon_e = n_e^2$ and $\varepsilon_o = n_o^2$ are the permittivities parallel and perpendicular to the molecule director, respectively. Parameters of LC's compounds were set as: $n_o = 1.52$, $n_e = 1.60$ for K15, $n_o = 1{,}62$, $n_e = 1{,}74$ for BL006. The loss tangents of K15 were set as *tan*

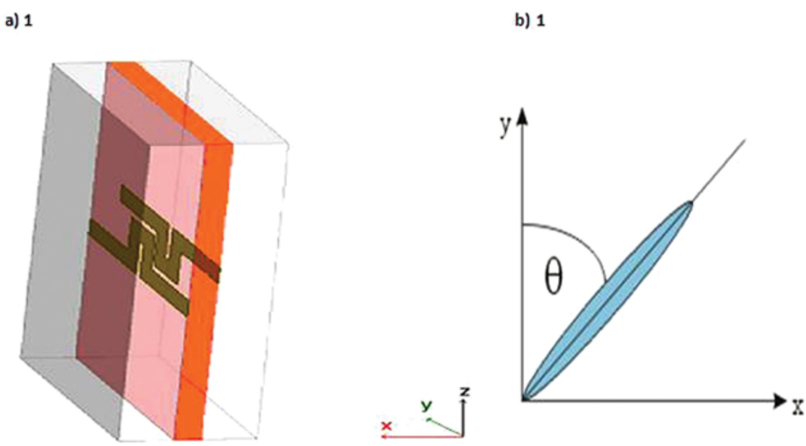

Figure 1. a) Tunable negative index metamaterial employing nematic liquid crystal: teflon fiberglass (grey color), metal patterns (green color) and liquid crystal (orange color). The geometry dimensions are as follows: $t_{teflon} = 1.0$, $t_{LC} = 0.5$ (unit: mm). The unit cells are stacked along the x directions with periodicities of 10.0 mm, b) director orientation of LC molecule. (Figure appears in color online.)

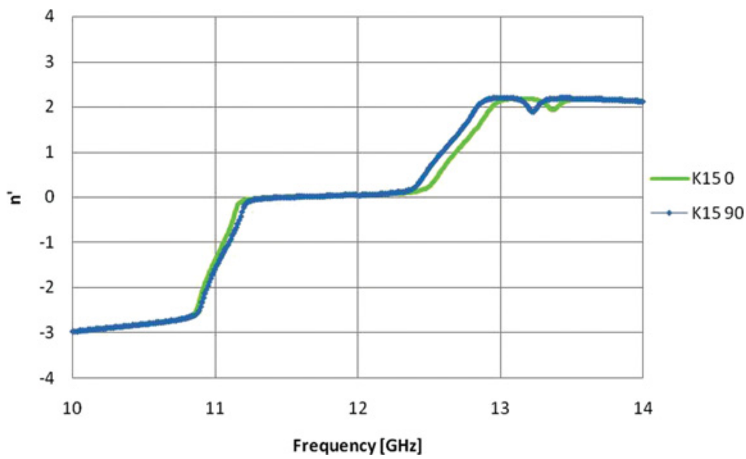

Figure 2. Real part of effective refractive index for homogenous and homeotropic orientation LC for K15 LC compound.

$\delta_o = 0.023$ for *no* and *tan* $\delta_e = 0.05$ for *ne*, and for BL006 *tan* $\delta_o = 0.025$, *tan* $\delta_e = 0.001$. Nematic liquid crystals used in simulations – K15 and BL006 were previously characterized in the GHz frequency [3,7]. Using QuickWave software for electromagnetic design, a full wave analysis was performed to determine the scattering parameters of the structure.

3. Tunable Refractive Index

In simulation scattering parameters of tunable metamaterial were obtained. We compared real and imaginary part of effective refractive index of tunable metamaterial for LC compounds which posses different anisotropy of birefringence. By employing well-known equations [8,9] we calculated tunable refractive index for homogenous and homeotropic ($\theta = 90^0$) LC orientation. Results are presented below.

K15 is probably one of the best known LC material. For this reason we decided to tested them in metamaterial structure operating in microwave frequency range.

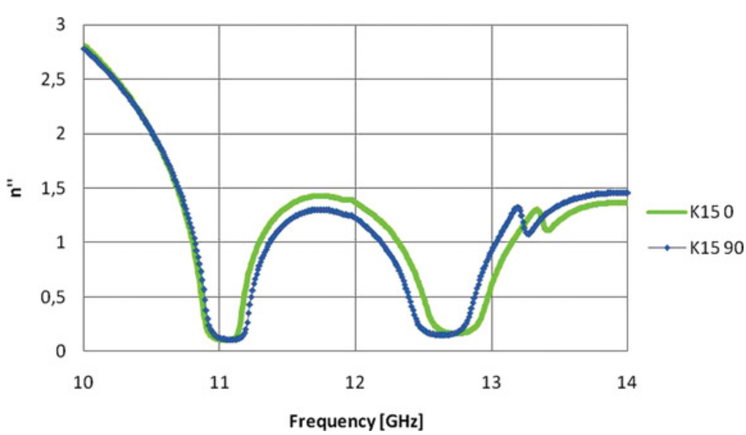

Figure 3. Imaginary part of effective refractive index for homogenous and homeotropic orientation LC for K15 LC compound.

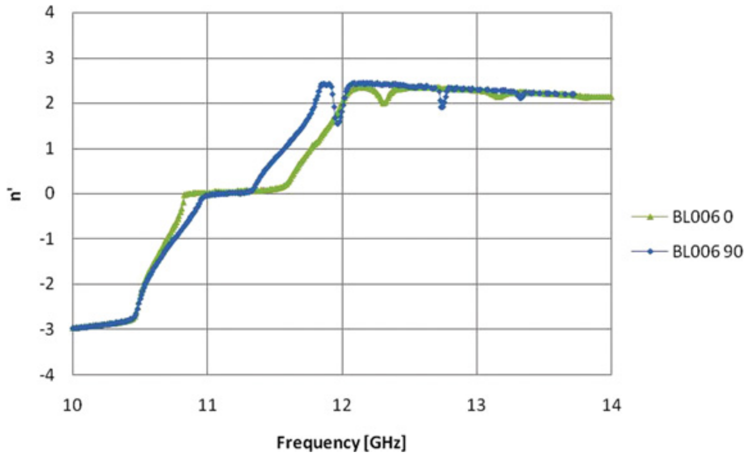

Figure 4. Real part of effective refractive index for homogenous and homeotropic orientation LC, for BL006 LC compound.

From application point of view tunable metamaterials should give us possibility to obtain new material which is characterized by effective parameters. Very interesting problem is tunable refractive index. For metamaterial employing K15 as multilayered substrate we obtained tunability of real part of effective refractive index (Fig. 2) for two frequencies – from 10.8–11.2 GHz and from 12.5 GHz to 13.4 GHz (Fig. 2). Real part of effective refractive index is negative in the range of 10-11.2 GHz. In simulation technique external field is applied to orientate the LC director from parallel x to parallel y (see Fig. 1).

Both real and imaginary parts of effective refractive index are plotted as a function of wavelength. Comparing both real and imaginary parts of effective refractive index for K15 (Fig. 2 and Fig. 3) and BL006 (Fig. 4 and Fig. 5) materials we can notice, that refractive index is negative for wider frequencies for metamaterial infiltrated with K15 LC compound. Tunability is higher for BL006 LC compound, it is

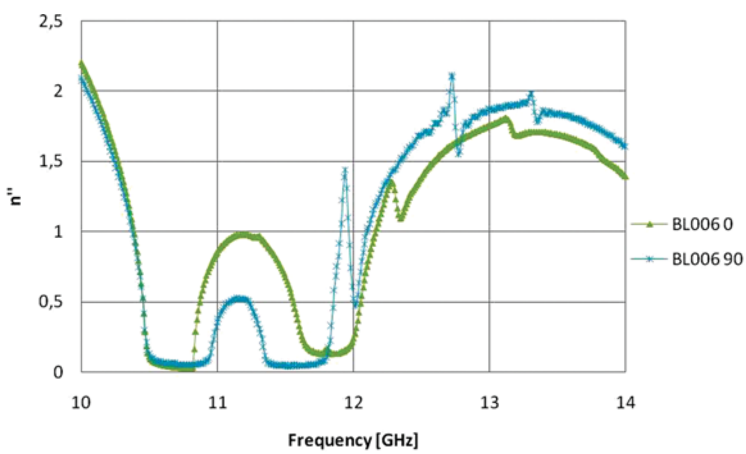

Figure 5. Imaginary part of effective refractive index for homogenous and homeotropic orientation LC for BL006 LC compound.

connected with fact, that BL006 posses bigger Δn than K15. BL006 has lower losses in GHz frequency range what we can see in plots of imaginary part. The peaks in n' and n'' at 12 GHz and above (Figs. 2–5) are the result of the numerical procedure. It is connected with discontinuity and fluctuations of the phase for higher frequencies. Imaginary part takes higher values for metamaterial structure employing K15. The world's work in this area focuses on the search for liquid crystals with the possible highest value of birefringence and low viscosity which facilitates reorientation of LC molecules.

4. Conclusions

Microwave metamaterial having a tunable index of refraction from negative, through zero, to positive values has been proposed. Liquid crystals can give us a possibility to obtain tunable refractive index. Tunability strongly depends on properties of liquid crystal compounds – materials should have high anisotropy of birefringence and low losses in a wide frequency range. Topic is relatively new and needs detailed investigations.

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