Voltage controllable metamaterials infiltrated by liquid crystal

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Abstract

In this paper, we report on the experimental demonstration of voltage tunable metamaterial operating under normal incidence at microwave frequencies via nematic liquid crystal. Two types of metamaterial structures, the short wire pair and fishnet prototype, were used for the realization of the variation of effective permeability and effective index, respectively. The results shows, under low external bias voltage, a reversible frequency shift around 400 MHz, for the frequency band presenting the metamaterial properties.

1. Introduction

As a kind of resonant restructure, metamaterial inevitably suffers from narrow bandwidth. The creation of tunable metamaterials, whose operational frequency could be adjusted to other desired frequency, is of great interest to overcome this limitation [1-4]. Recently, liquid crystal (LC) has attracted more attention due to its large birefringence and ease for incorporation [5]. In this paper, we performed experimental and numerical demonstration of voltage tunable single and double negative metamaterials via nematic LC at microwave frequencies.

2. Tunable Negative Permeability Metamaterial.

Figures 1 (a) and (b) depict schematic views of tunable negative permeabliy metamaterial elementary cell incorporated with LC. As shown in Fig. 1(a), the unit cell of tunable metamaterial is composed of a pair of short wires placed on the surface of Teflon fiberglass slabs with voids in between which were infiltrated with a nematic LC. An extra pair of narrower in-plane bars was added to connect adjacent unit cells. From the side view (Figure 1(b)), a thin layer of polyimide (PI) was spanned on the surface of Teflon substrate and copper element to force nematic LC in an alignment state parallel to short wire surface. Using standard printed circuit board technology, the metallic cells were patterned on the surface of Teflon fiberglass. A commercial nematic LC, TEB 30A, with a moderate birefringence, $\Delta n = 0.08$ ($n_0 = 1.65$ and $n_e = 1.73$ (@10GHz) [6]), was infiltrated into the void forming by two layers of short wire array.

Figure 2(a) displays the measured transmission spectra of short wire-pair array under various bias voltages. For zero-bias voltage, a pronounced dip occurs at 9.91 GHz, around which the effective permeability is expected to be negative. As bias voltage gradually increases from 0 to 100 Volt, the resonant frequency shifts down to 9.55 GHz, followed by tuning saturation even the bias voltage is further enhanced. Thus, a frequency shift of 360 MHz in total is achieved experimentally. The simulation performed by using HFSS, shows a good quantitative agreement with the experimental data (See Fig. 2 (b)). For the experiment, since an increasing bias voltage will reorientate LC director from parallel to perpendicular to the surface of short wire, the local electric field mainly polarized along the *z* direction, experiences the dielectric property of LC from the ordinary index, n_o, to the extraordinary index, n_e, hence, leading to the increase of the capacitance of short wire pair and the decrease of the resonance frequency.

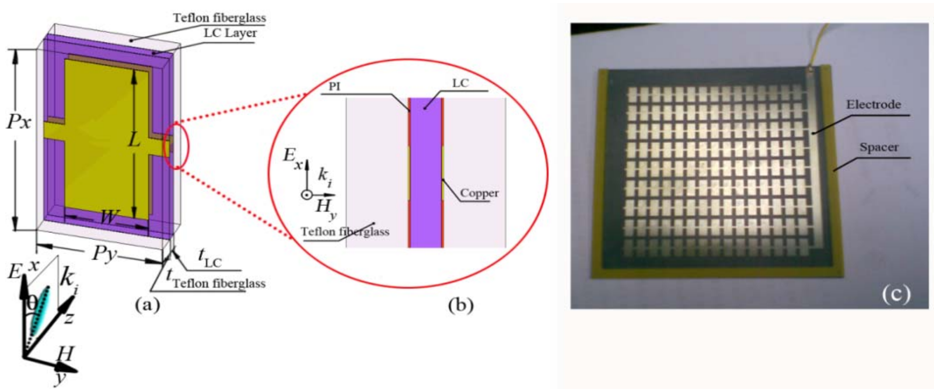

Fig.1: Tunable short wire-pair type negative permeability metamaterial based on anisotropic LC. (a) 3-D and (b) side view of elementary cell. (c) Photograph of metamaterial sample (The top layer of short wire-pair array was removed for clarity). The geometrical parameters of unit cell are as follows: W = 4.00, L = 9.00, Px = 11.00 Py = 6.00, t_{LC} = 0.50, $t_{\text{Teflon fibreglass}}$ =1.00 (unit: mm). The copper bar has a width of 1.00 mm.

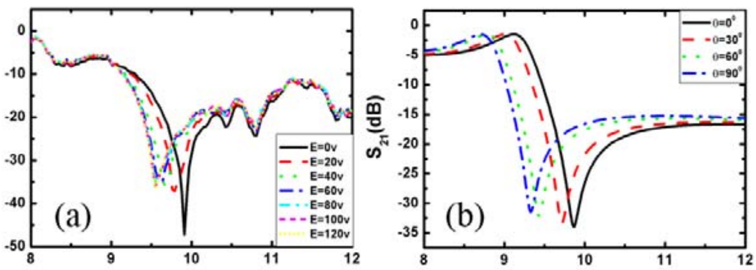

Fig. 2: Experimental transmission (a) and simulated spectra (b) for short wire type negative permeability metamaterial as a function of external DC voltage.

3. Tunable Negative Index Metamaterial

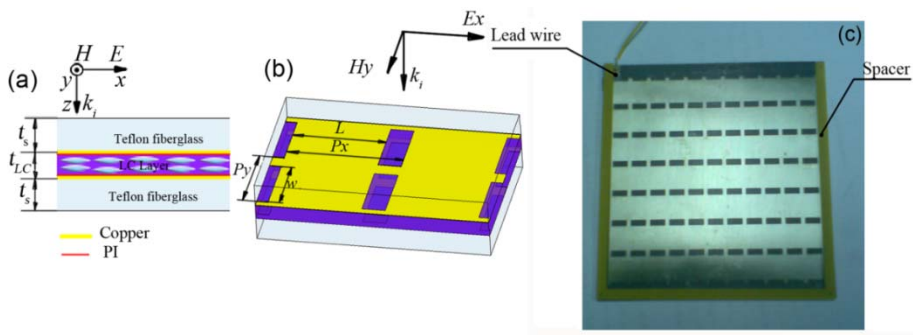

Fig. 3: Tunable fishnet type of NIM based on nematic LC. (a) Side view (b) 3-D view of four elementary cells. (c) Photograph of metamaterial sample. The geometrical parameters of unit cell are as follows: W = 8.00, L = 12.00, Px = 15.00 Py = 10.00, t_{LC} = 0.50, t_s =1.00 (unit: mm).

On the basis of successful demonstration of tunability of negative permeability metamaterial, we designed and fabricated electrically controllable fishnet type of negative index metamaterial in a similar manner as stated in Sec. 2 (Fig. 3). The experimental and simulated transmission spectra were given in Fig. 4. From the simulated result (Fig. 4(a)), it can be seen that for the initial alignment of LC director parallel to the surface of fishnet surface, there is a well-resolved and high intensity transmission peak around 9.01 GHz, which is separated from a quasi unity transmission shoulder starting from 11.0 GHz, by a shallow dip. When the LC director is reorientated from 0º to 90º, it is shown that the ground transmission peak is shifted downward 8.60 GHz. From the experimental data, the fishnet structure exhibits a transmission passband around 9.14 GHz, which is shifted downward to 8.80 GHz for the increasing bias field. The narrower frequency shift range is presumably due to the slightly change of the actual void thickness.

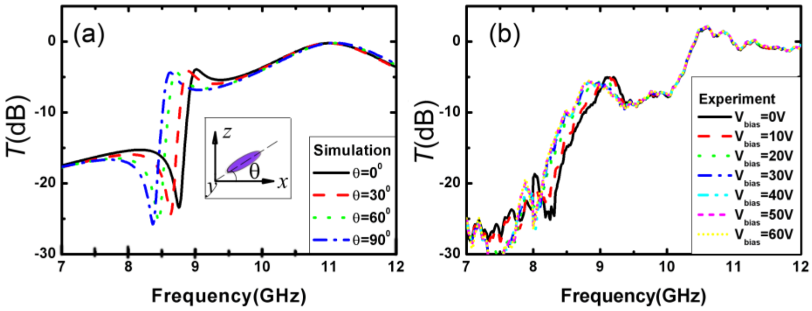

Fig. 4: (a) Simulated transmission of tunable fishnet metamaterial when LC director was reorientated. The inset is the schematic view of LC molecular reorientation in the *xz* plane. (b) Experimental transmission magnitude of fishnet metamaterial as a function of external dc bias voltage.

4. Conclusion

In summary, we reported tunability behaviour of single and double negative metamaterials incorporated nematic LC. Polyamide was used for the surface treatment so as to affiliate the full reorientation of nematic LC. As the bias voltage is applied, the resonance frequency shift of around 400 MHz, as a consequence of reorientation of LC molecular director was observed. The simulation agrees with the experimental results well.

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